IPR and Innovation Systems: An international comparison

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Introduction: What is an innovation system?

This chapter deals with IPRs in innovation systems. Even if both innovation systems and IPRs as such have been studied extensively, the specific problematic of this chapter has hardly been analysed before. This is even so much surprising as the form and extent of IPR regulations potentially have big impacts on the functioning of an innovation system. According to Granstrand (2005), 'IPRs, particularly patents, play several important roles in innovation systems – to encourage innovation and investment in innovation, and to encourage dissemination (diffusion) of information about the principles and sources of innovation throughout the economy' (Granstrand, 2005, p. 280). Thus, the extent, intensity and type of interactions between firms and universities, which represent the constituting relations of an innovation system, will obviously be effected by the way the IPR are constructed. This is especially the case in science driven activities, such as biotech, which is the focus of this book, being the object of the majority of implemented IPR regulations. This chapter will investigate this problematic through a comparative approach looking at how IPR are implemented and their conseqences for industry-university collaboration in the US and Europe with special focus on Germany, Switzerland and Denmark. This represents a contribution to the analysis of the importance of national variations in institutional frameworks, which in addition to sectoral differences (which in this chapter are handled by the differentiated knowledge base perspective), has been surprisingly little covered in the literature so far. The chapter starts with a short introduction of the innovation system concept as a national as well as a regional system.

The concept of innovation system (IS) - originally developed by Bengt-Åke Lundvall - is a relatively new one, and was first used by Chris Freeman in his analysis of Japan's blooming economy (Freeman, 1987). The concept of regional innovation system (RIS) appeared in the early 1990s (Cooke, 2001), approximately at the same time as the idea of the national innovation system was becoming more widespread, thanks to the books by Lundvall (1992) and Nelson (1993). Characteristic for a systems approach to innovation is the acknowledgement that innovations are carried out through a network of various actors underpinned by an institutional framework. This dynamic and complex interaction constitutes what is commonly labelled systems of innovation

(Edquist, 1997), i.e. systems understood as interaction networks (Kaufmann and Tödtling, 2001). A set of variations on this approach have been developed over time, either taking territories as their point of departure (national and regional) or specific sectors or technologies (Fagerberg et al., 2004).

The National Innovation Systems approach highlights the importance of interactive learning and the role of nation-based institutions in explaining the difference in innovation performance and hence, economic growth, across various countries. The rationale of having territorially based innovation systems (national and regional) is either the existence of historical technological trajectories based on 'sticky' knowledge and localised learning that can become more innovative and competitive by promoting systemic relationships between the production structure and knowledge infrastructure in the form of national or regional innovation systems (a policy of 'localised change' (Boschma, 2004)), or the presence of knowledge creation organisations whose knowledge could be exploited for economic useful purposes through supporting new emerging economic activity (a policy of 'structural change' (Boschma, 2004)). The 'innovation system' concept can be understood in both a narrow as well as a broad sense. A narrow definition of the innovation system primarily incorporates the R&D functions of universities, public and private research institutes and corporations, reflecting a top-down model of innovation. A broader conception of the innovation systems includes 'all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring' (Lundvall, 1992, p. 12), and, thus, has a weaker system character. The formation of innovation systems must be understood in this context of creating a policy framework aiming at a systemic promotion of knowledge creation and learning, in which universities play a strategic role, as well as an efficient transfer to industry in order to secure the innovativeness and competitive advantage of nations, regions and firms (Freeman, 1995; Cooke et al., 2000). According to Mowery and Sampat (2005) 'governments have sought to increase the rate of transfer of academic research advances to industry and to facilitate the application of these research advances by domestic firms since the 1970s as part of broader efforts to improve national economic performance. In this 'knowledge-based economy', according to this view, national system of higher education can be a strategic asset, if links with industry are strengthened and the transfer of technology enhanced and accelerated' (Mowery and Sampat, 2005, 214).

IPR in regional innovation systems

When discussing the role of IPRs in Innovation Systems it is specifically the second rationale for innovation systems which is of relevance, i.e. securing the exploitation of new knowledge creation at universities for economic useful purposes, applying a narrow definition of an innovation system. According to Mowery and Sampat (2005) this can be achieved by two types of policies: '(1) policies encouraging the formation of regional economic 'clusters' and spin-offs based on university research, and (2) policies attempting to stimulate university patenting and licensing activities' (Mowery and Sampat, 2005, 225).

Mowery and Sampat (2005) emphasize that especially the first type of policy typically takes place at the regional level, in the context of RIS, seeking 'to spur local economic development based on university research, e.g. by creating 'science parks' located nearby universities campuses, support for 'business incubators' and public 'seed capital' funds, and the organization of other forms of 'bridging institutions' that are believed to link universities to industrial innovation' (Mowery and Sampat, 2005, 210).

A RIS is constituted by (1) The regional production structure or knowledge exploitation subsystem which consists mainly of firms, often displaying clustering tendencies, and (2) the regional supportive infrastructure or knowledge generation subsystem which consists of public and private research laboratories, universities and colleges, technology transfer agencies, vocational training organisations, etc. Thus, in case the following two subsystems of actors are systematically engaged in interactive learning it can be argued that a regional innovation system is in place (Cooke, 1998). From this follows that clusters and RIS can (and often do) co-exist in the same territory. But whereas the regional innovation system by definition hosts several clusters, a cluster is not part and parcel of a RIS (Asheim and Gertler, 2005).

According to Mowery and Sampat (2005) also 'the increased interests in 'Bayh-Dole type' policies is rooted in the motives similar to those underpinning policy initiatives that seek to create 'high-technology' regional clusters' (Mowery and Sampat (2005), 228). As with the Bayh-Dole Act, the majority of these initiatives to support university-based research for the promotion of innovation and economic performance emphasize the importance of codification of knowledge as a precondition to impose property rights to individual inventions, based on the premise that the impact of university research primarily happens through the production by new knowledge for commercialization (e.g.

patented discoveries). (Mowery and Sampat, 2005). According to Mowery and Sampat (2005), ‘in many respects, the Bayh-Dole act is the ultimate expression of faith in the ‘linear model’ of innovation – if basic research results can be purchased by would-be developers, commercial innovation will be accelerated’ (Mowery and Sampat, 2005, 229).

The central role university research plays in contemporary economies with respect to the creation and diffusion of new knowledge, has resulted in additional analytical frameworks – complementing the innovation system approach – pointing to the importance of strong links between universities, industry and government in knowledge-based economies. Two such concepts, the new interdisciplinary ‘Mode 2’ (Gibbons et al. 1994) and the ‘Triple Helix’ (Etzkowitz and Leydesdorff, 2000), both argue that such interactions have increased (Mowery and Sampat, 2005).

Specifities and contradictions of knowledge generation

With the increasing socialization of knowledge production also the knowledge produced by the enterprises themselves increases. For this reason they depend more on “intellectual common goods” in the form of generally available qualifications, information and knowledge . The contradiction between increasing socialization of production and private appropriation inherent to capitalism appears even more obvious with knowledge production. The production of knowledge and new technologies is a process based on division of labor in complex systems and networks. Often innumerable people take part in this process. The classic contradiction between economic and business rationality, thus between privatization of the benefit and externalization of the expenses, becomes a particular guise. The enterprises aspire to free access to knowledge and information, and at the same time they want to reserve as much private property thereofas possible.

Knowledge production and its valorization exhibit some characteristics which are crucial for the transformation of the regime of property rights . In mainstream economics these traits are often described as market failure: First, intellectual activity enables considerable cumulative effects which bear much larger consequences than the productivity gains realized in material production. The benefits of science and information increase according to the number of people who use it. Knowledge develops and increases due to broad and free diffusion. These cumulative effects arise because codified information and knowledge can circulate extremely easily. They result from the collective and open character of intellectual activity (‘public good’ aspect and non-excludability of technological knowledge). Second, the production of scientific knowledge and of numerous new technologies requires very extensive, concentrated investments, similar to investments in fixed capital. Additionally, technological uncertainty investment leads to a general investment risk. The valorization, however, can often be organized with only marginal additional costs. Knowledge-relevant information can be multiplied and used without large costs.

For these reasons, using intellectual property titles (patents, copyrights) and technical safety devices (e.g. copy protection of computer programs) firms seek to limit the uncontrolled diffusion of their products and to artificially create scarcity. Intellectual property titles are designed to render this artificial scarcity legitimate in the area of knowledge and to exclude others from its use or force them to pay royalties. Intellectual property is a power instrument and contributes to a further accumulation of power. But in contrast to the power which arises for owners of scarce material goods, scarceness of intellectual property must be produced artificially by legal regulations.

Sectoral differences in IPR

As mentioned in the introduction, IPRs have potentially big impacts on the functioning of innovation systems. However, 'the importance of these roles varies across sectors (industries) and countries, and over time' (Granstrand, 2005, p. 280). Granstrand underlines that especially with respect to patents, the 'differences across industries or sectors are strikingly large' (Granstrand, 2005, p. 282). Regions and nations display a large diversity when it comes to industrial structure, innovative capacity, competitiveness and economic growth. One way of analyzing regional diversity within industrial sectors is to apply a differentiated knowledge base approach (Asheim and Gertler, 2005; Asheim and Coenen, 2005; Asheim et al., 2007). Despite the general trend towards increased diversity and interdependence in the knowledge process, Pavitt (1984) and others have argued that the innovation process of firms is also strongly shaped by their *specific* knowledge base, which tends to vary systematically by industrial sectors. The typology of Pavitt has been further elaborated into a Synthetic-Analytical-Symbolic knowledge base typology, instead of the more narrowly defined traditional categories such as 'scientific', 'engineering' and 'artistic' knowledge base, in order to capture the character of knowledge as output (Asheim and Gertler, 2005; Asheim et al., forthcoming). More critically, this broader conceptual typology is intended to encompass the diversity of professional and occupational groups and competences involved in the production of various types of knowledge. As an ideal-type, synthetic knowledge can be defined as knowledge to design something that work as a solution to a practical problem. Analytical knowledge can be defined as knowledge to understand and explain features of the universe. Symbolic knowledge is knowledge to create cultural meaning through transmission in an affecting senseous medium. As only the analytical (e.g. dominating pharmaceutical biotech) and synthetic knowledge (more important in agroindustrial and industrial biotech) bases are relevant with respect to biotech industry, the symbolic knowledge base will not be presented in more detail below.

Analytical knowledge base

This refers to industrial settings where scientific knowledge is highly important, and where knowledge creation is often based on cognitive and rational processes, or on formal models. Examples are biotechnology and nanotechnology. Both basic and applied research as well as systematic development of products and processes is relevant activities. Companies typically have their own R&D departments but they also rely on the research results of universities and other research organisations in their innovation process. University-industry links and respective networks, thus, are important and more frequent than in the other types ofknowledge base.

Knowledge inputs and outputs are in this type of knowledge base more often codified than in the other types. This does not imply that tacit knowledge is irrelevant, since there are always both kinds of knowledge involved and needed in the process of knowledge creation and innovation (Nonaka et al., 2000, Johnson et al., 2002). The fact that codification is more frequent is due to several reasons: knowledge inputs are often based on reviews of existing studies, knowledge generation is based on the application of scientific principles and methods, knowledge processes are more formally organised (e.g. in R&D departments) and outcomes tend to be documented in reports, electronic files or patent descriptions. These activities require specific qualifications and capabilities of the people involved. In particular analytical skills, abstraction, theory building and testing are more often needed than in the other knowledge types. The work-force, as a consequence, needs more often some research experience or university training. Knowledge creation in the form of scientific discoveries and technological inventions is more important than in the other knowledge types. Partly these inventions, under specific social and economic conditions, are susceptible to patents and licensing activities. Knowledge application is in the form of new products or processes, and there are more radical innovations than in the other knowledge types. Important routes of knowledge application are out-licensing activities of universities and publicly funded research organizations, and the creation of new firms and spin-off companies.

According to Granstrand (2005), ‘patents are most likely to support the growth of knowledge-intensive industries in fields characterized by low ratios of imitation to innovation costs. Such low ratios are likely in areas with large-scale R&D projects, especially if the R&D results in highly codified knowledge, as in chemicals’ (Granstrand, 2005, p. 283). This will typically be sectors or industries based on an analytical knowledge base, e.g. the biotech industry (and red bio in particular).

Synthetic knowledge base

This refers to industrial settings, where the innovation takes place mainly through the application of existing knowledge or through the new combination of knowledge. Often this occurs in response to the need to solve specific problems coming up in the interaction with clients and suppliers. Industry examples include plant engineering, specialized advanced industrial machinery and production systems, and shipbuilding. Products are often ‘one-off’ or produced in small series. R&D is in general less important than in the first type. If so, it takes the form of applied research, but more often it is in the form of product or process development. University-industry links are relevant, but they are clearly more in the field of applied research and development than in basic research. Knowledge is created less in a deductive process or through abstraction, but more often in an inductive process of testing, experimentation, computer-based simulation or through practical work. Knowledge embodied in the respective technical solution or engineering work is at least partially codified. However, tacit knowledge seems to be more important than in the first type, in particular due to the fact that knowledge often results from experience gained at the workplace, and through learning by doing, using and interacting. Compared to the first knowledge type, there is more concrete know-how, craft and practical skill required in the knowledge production and circulation process. These are often provided by professional and polytechnic schools, or by on-the-job training.

The innovation process is often oriented towards the efficiency and reliability of new solutions, or the practical utility and user-friendliness of products from the perspective of the customers. Overall, this leads to a rather incremental way of innovation, dominated by the modification of existing products and processes. Since these types of innovation are less disruptive to existing routines and organisations, most of them take place in existing firms, whereas spin-offs are relatively less frequent.

However, this distinction refers to ideal-types, and most industries are in practice comprised of all three or two types of knowledge creating activities. For instance, biotech based technology platforms or discovery tools also rely to large extend on continuously improved engineering knowledge. The degree to which certain activities dominate, is however different and contingent on the characteristics of the industry or phases of innovation processes within an industry (Moodysson et al. (forthcoming)).

‘Varieties of capitalism’ and national differences in IPRs

Granstrand maintains that ‘these intersectoral differences in the importance of IPRs have led several scholars to criticize the ‘one-size-fits-all’ design of patent system’ (Granstrand, 2005, 283). This criticism becomes even more valid when national differences in institutional contexts, constituted by history, path dependence, and institutional embeddedness, are taken into account. According to Mowery and Sampat (2005), the global diffusion of these policy proposals and initiatives - promoted among others by the OECD - display the classic problems of ‘selective ‘borrowing’ from another nation’s policies from implementation in an institutional context that differs significantly from that of the nation being emulated. … Indeed, emulation of Bayh-Dole could be counterproductive in other industrial economies, precisely because of the importance of other channels for technology transfer and exploitation by industry’ (Mowery and Sampat, 2005, 232-33).

Lam (2000) underlines that learning and innovation cannot be separated from broader societal contexts when analysing the links between knowledge types, organisational forms and societal institutions in order to meet the needs of specific industries in particular with respect to learning and the creation of knowledge in support of innovations. Soskice (1999) argues that different national institutional frameworks support different forms of economic activity, i.e. that coordinated market economies (e.g. the Nordic and (continental) West-European welfare states) have their competitive advantage in ´diversified quality production´ (Streeck, 1992), based on problem solving, engineering based knowledge developed through interactive learning and accumulated collectively in the workforce (e.g. the machine tool industry based on a synthetic knowledge base), while liberal market economies (e.g. the US and UK) are most competitive in production relying on scientific based, analytical knowledge, i.e. industries characterised by a high rate of change through radical innovations (e.g. IT, defence technology and advanced producer services). Following Soskice, the main determinants of coordinated market economies are the degree of non-market coordination and cooperation which exists inside the business sphere and between private and public actors, the degree to which labour remains 'incorporated' as well as the ability of the financial system to supply long term finance (Soskice, 1999). While coordinated market economies on the macro level support co-operative, long-term and consensus-based relations between private as well as public actors, liberal market economies inhibit the development of these relations but instead offer the opportunity to quickly adjust the formal structure to new requirements using temporary organisations frequently.

These differences - due to the impact of the specific modes of organisation of important societal institutions such as the market, the education system, the labour market, the financial system, and the role of the state - both contribute to the formation of divergent 'business systems' (Whitley, 1999), and constitute the institutional context within which different organisational forms with different mechanisms for learning, knowledge creation and knowledge appropriation have evolved (Casper and Whitley, 2004).

Varieties of capitalism differences between the liberal and the coordinated market economies can be observed when it comes to the ownership of IPR for inventions (either the academic institution or the researcher), the level of inter-university competition as well as the relative importance of private research universities. In Germany and Sweden, both typical examples of coordinated market economies 'researchers have long had ownership rights for the intellectual property resulting from their work, and debate has centered on the feasibility and advisability of shifting these ownership rights from the individual to the institution.' (Mowery and Sampat, 2005, 232). This was changed in Denmark – another coordinated market economy, though with more liberalist traditions than Sweden and Germany - in 2000, when the Danish Law on University Patenting (LUP) become effective (see later section for a discussion of its effects on university – industry cooperation within the pharmaceutical biotech industry).

With the exceptions of the university systems of the US and Britain, typical representatives of liberal market economies, inter-university 'competition' has been limited in most national systems of higher education. Inter-university competition played an important historical role in the evolution of US universities and their collaboration with industry; especially when university patenting began to change after 1970s, as private universities expanded their share of US university patenting in the same period as the share of biomedical patents within overall university patenting grew (Mowery and Sampat, 2005). A good illustration of the key role of a well-funded, high-quality research university for establishing a successful industry–university collaboration is MIT, and, thus, not surprisingly, research has found that a model design of Triple Helix based on MIT works less efficiently in different contexts with more average universities and regions (e.g. Australia and Sweden) (Cooke, 2005).

While the US model of implementing IPR might function reasonable efficient in the context of liberal market economies, these differences – based within a varieties of capitalism context – could lead to anomalies as well as dysfunctional situations and suboptimal allocation of resources in coordinated market economies. Mowery and Sampat, 2005, mention several potential criticism of, in particular the Bayh-Dole Act (Mowery and Sampat, 2005, 230-32)[1]:
- Firstly, that the commercialization incentive resulting from the Bayh-Dole could shift the focus on university research away from 'basic' and towards 'applied' research.
- Secondly, another potentially negative effect of a higher level of university patenting and licensing is a 'weakening of academic researchers' commitments to 'open science', leading to publication delays, secrecy, and withholding of data and materials' (Mowery and Sampat, 2005 2005, 230-31).
- Thirdly, in view of the importance of the 'nonpatent/licensing' channels of interaction with universities in many industrial sectors, it is important that these channels are not restricted or impeded by the strong focus on patenting and licensing in many universities. Thus, the 'emulation of the Bayh-Dole Act is insufficient and perhaps even unnecessary to stimulate higher levels of university-industry interaction and technology transfer' (Mowery and Sampat, 2005, 231-32).

From closed to open innovation – or from open science to patent-enclosed innovation?

The question of the role of intellectual property rights in innovation processes is controversial. On the one hand, intellectual property rights are justified as an answer to the market failure of technological knowledge which is an outcome of the specific characteristics of knowledge generation such as the inseparability of research expenditures and the burden of huge fixed costs for investors, the general investment risk that goes along with technological uncertainty, the 'public good' aspect and the non-excludability of technological knowledge . Thumm states that strengthening the patent system is likely to permit more trade in disembodied knowledge. Therefore, it is likely to facilitate the vertical disintegration of knowledge-based industries and to enable the entry of new firms that possess mainly intangible assets. Similarly Arora and Merges argue that a strong intellectual property regime supports vertical disintegration and the innovation activities of small firms. Chesbrough describes the

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[1] The Bayh Dole Act policy can, however, have disadvantageous effects even in the US. However, the US system is a global system and only works 'reasonable' because it can attract values from other parts of the globe.

new configuration characterized by an increased vertical disintegration and a bigger share of extramural research activities, in a quite uncritical way as *open innovation.* On the other hand, David or Orsi and Coriat emphasize the questionable effects of the extension of intellectual property rights. This controversy recalls the crucial issue already raised by Dasgupta and David , who argued that knowledge produced by academic institutions should retain the status of a ‘public good’. Coriat, Orsi and Weinstein emphasize a finance-driven model of innovation linked to institutional changes and the move from ‘open science’ to ‘patent intensive’ science . They emphasize that the rules of the game shaped by institutions such as financial markets, labor markets, the intellectual property regime, public research funding, the division of labor between academic and industrial research and the underlying accumulation regime must be considered.

New industry organization and stronger intellectual property rights

The discussion on these issues has to be put into the context of a far-reaching reorganization of the industry organization in the pharmaceutical and biotech industries. Due to the enormous differentiation of drug discovery technologies and in order to minimize their own risk, large pharmaceuticals outsource numerous research activities to biotech firms and academic research centers. They systematically observe technological development on a global scale and acquire promising substances and technologies. Thus, 'big pharma’ heavily relies on appropriating externally produced knowledge. This analytical knowledge is generated in a few regional innovation arenas . Publicly financed institutions play a central role in this generation. Out-licensing of drug candidates and technologies has become an important source of income for biotech firms and even universities. Biotech companies often have a mediating role. They transform and develop basic analytical knowledge generated in publicly financed institutes. They then can further develop promising projects together with pharmaceuticals or out-license.

The notion of open innovation and the problematic of knowledge transfer through channels and pipelines need to be clarified. In the sense of Chesbrough open innovation means that “firms commercialize external (as well as internal) ideas by deploying outside (as well as in-house) pathways to the market.” The boundary between a firm and its surrounding actors has become more porous, enabling innovation to move easily between the interested players . However, the notion ‘open innovation’ is misleading. Increased division of innovative activities, network membership and sharing of knowledge do not automatically mean augmented openness. On the contrary, exactly because the boundaries between a firm and its surrounding environment are more porous, intellectual property rights must be enforced as a consequence. In- and out-licensing are only possible when based on property rights. They have become bargaining chip for the exchange of technology between companies and for venture capital .

An increased, but highly selective openness can be observed in the sense of intensified knowledge transfer from universities to firms and between firms. However, science and knowledge generation have not become more open in the sense of a free dissemination of knowledge and information. On the contrary, the stronger IPR regime encloses knowledge more than before. There is even the danger that knowledge produced by academic institutions loses the status of a ‘public good’ .

Open channels and closed pipelines of knowledge transfer closely interfere with one another . Transactions are ‘pipelines’ when legally binding, confidential, contractual business is being transacted. But they rely on free contacts to ‘open science’. Publicly funded research institutes are major magnets for profit-seeking biotech firms and for large pharmaceuticals exactly because they operate with relatively open science conventions. However, in doing so, ‘big pharma’ tries to absorb a good portion of that knowledge exclusively . This shows that closed and open science, respectively innovation are inseparably related. Closed corporate innovation enclosed by property monopolies profits from open science in universities. How the processes of knowledge generation, acquisition and subsequent valorization interfere and interact depends on financial constraints, regulatory conditions and power relations within an industry, between firms, and even within firms.

Only codified knowledge can really be commercialized, either materialized in products or in the form of licenses. The acquisition of knowledge through open channels is necessary in order to convert this knowledge into commerciable information. In contrast to the idealistic picture of open science and open innovation, in the regime of monopolized intellectual property rights, the economy is increasingly shaped by secretiveness and patent disputes. Thus, technological progress adopts a quite specific face .

Enforcing intellectual property rights and the Anti-Commons Regime?

The effects of the strengthened and extended intellectual property rights are increasingly the subject of critical discussions. Various studies show that an extensive granting of patents can block the free usage and accumulation of knowledge and hence hinder innovation processes .

First, this can happen if patents are granted too broadly and therefore gate off subsequent research in the same area. Second, there is the frequent, so-called Anti-Commons Regime in biotechnology. If companies obtain private rights on DNA sequences, including fragments of a gene, before the corresponding gene, protein or the corresponding active substance has been identified, no one will be able to unify the rights or buy all licenses, respectively. In such a case, various owners of a good's fragments are given the right to exclude all others, with the ultimate effect that the product will not be produced . By creating the possibility of patenting gene fragments, regulatory authorities encouraged the race for private appropriation. However, the production of a recombinant protein drug and new genetic diagnostic test requires the combination of gene sequences. Third, innovation can be blocked if research tools, preliminary products for broad areas of research, or key approaches are patented, and if the patent holder aggressively prosecutes unlicensed users or only appoints one exclusive license . Those who are willing to pay a large sum, generally speaking large companies, may be best capable of tackling those obstacles and creating monopoly-like situations with exclusive rights.

In biotechnology, primarily in the area of genomics, different firms have practiced a systematic accumulation of patents. This has permitted them to enclose whole areas of drug targets, substances or technologies and, accordingly, to impose an 'immaterial toll' to block other interested parties if they are not willing to pay licensing fees. Entire cascades of products, such as the sequence of a protein encoded by a gene, the antibodies of a protein, gene vectors, host cells and genetically manipulated animals used in the preclinical trials, are often based on patents on gene sequences. Patent holders can thus block future, still unknown usages and respectively obtain rents from royalties .

Patents not only became a central valuation criterion for firms but also for academic research institutes. The US universities increased their license-based income from 186 million USD in 1991 to 1,3 billion USD in 2001. Many universities depend to large extent on such income to finance their research expenditures . The tendency to patent extensively and on an increasingly broad scale can hinder innovation processes. Companies which finance academic research require reliable and confidential results. This again discourages open interaction between researchers. But it is exactly in this way that academic research in the biosciences can distinguish itself from the business-oriented .

Changes of IPR regimes and national innovation systems in the USA and Europe

All industrial sectors have experienced a drastic increase in granting of patent during the last two decades. The United States Patent and Trademark Office (USPTO) granted 76,748 patents in 1985, already 107,124 in 1991 and even 221,437 in 2002. A similar development happened in Europe. There were 42,957 applications for patents in 1985, 60,148 in 1991 and 110,640 in 2002 at the European Patent Office (EPO) . From 1990 to 2000, the number of patents granted in biotechnology rose 15% a year at the USPTO and 10.5% at the EPO, against a 5% a year increase in overall patents. The number of gene patents granted has risen dramatically since the second half of the 1990s. In 2001, over 5,000 DNA patents were granted by the USPTO, more than the total for 1991-95 combined. Similarly, the EPO estimates it has approved several thousand patents for genetic inventions . Applications to the EPO for biotechnology patents rose from 2,453 in 1991 to about 6,200 in 2000, and slightly declined to 5,876 in 2002 . The European Commission described this trend towards increased patenting activity as the ‘pro-patenting era’ . This trend is expected to continue in the future, as different surveys have confirmed.

This inflation of patenting does not necessarily reflect an increase in inventive activity. It also expresses that patents are used for other reasons than the traditional appropriation function. This is generally known as ‘strategic patenting’ . This is not surprising in a context where knowledge and know how in form of patents have become a strategic commodity of firms. Kortum and Lerner explained this pro-patenting era with the change in the management of innovation, involving a shift towards more applied activities. Moreover, firms are more conscious of the importance of intellectual property rights. An increase in the bargaining power of companies and higher product market competition are the most important factors underlying this trend in patenting .

These explanations need to be complemented with a broader societal and economic perspective. The explosive expansion of intellectual property monopolies is less a result of technological breakthroughs than of far-reaching economic and institutional changes. A new regime of intellectual property rights consisting of far-reaching institutional changes emerged. It was accompanied by a changed role for universities and publicly funded research, and cannot be separated from the ascent of concentrated financial capital, changes in financial markets and the entry of pension funds into venture capital. These complementing and reinforcing *institutional complementarities* strongly influence national and regional innovation systems .

The patent system is an important element of national innovation systems and of innovation policies in national states. However, OECD countries are currently converging with respect to their policy designs in science and technology policies, which reflect similar constraints imposed by liberal policies. The US is the main model of reference for most changes and reforms . This convergence happens also in the field of intellectual property rights. In the context of globalization of markets and the increasing importance of patents as means to secure investments the international patent system increases continuously its importance at the expense of national patenting procedures. The changes in the intellectual property regime in the USA in the past three decades are crucial: first because of the relevance of the US economy to global dynamics and second because of the pioneer role of US policy. In the course of the implementation of the TRIPs (*Trade Related Aspects of Intellectual Property*) agreement, the US were able to enforce their "philosophy" of intellectual property rights almost on a global scale .

Below, first the major changes of the IPR regime in the US are presented. Then the measures towards homogenization intellectual property rights in Europe and creation of a European IPR regime is described. Finally is showed how Germany, Switzerland and Denmark adapted their intellectual property rights regime to this changing framework.

Bayh Dole Act and changing legal practice in the USA

Technologies developed over the course of the 1970s permit the modification of genetic substance. In 1980, the US Supreme Court for the first time granted a patent for a genetically engineered micro-organism to General Electric (*Diamond vs. Chakrabarty*). This decision marked a decisive turning point in U.S patent policy. Henceforth, they could enforce a monopoly claim on life-forms and gene sequences. Such patents unleash a considerably larger monopoly effect than one which monopolizes only a production process .

A comprehensive change in the property rights regime then occurred: First, the judges decided that discoveries and not only inventions could be patented. Second, the directives of the USPTO in 1995 and the US courts also authorized patents which could be a basis for different further developments, even if their use could not be proven at the time of the patent application. The renunciation of industrial "utility" as a criterion by the courts enabled the granting of patents on inventions whose uses were in the very early stages of research . Thus scientific insights became objects of systematic privatization. Since research results also can be patented now at an early stage of the innovation process, it has become possible to block research activities which rely on these insights. Generally, the scope and reach of patents has been greatly extended.

These institutional changes were conducted in light of a change in the universities' role. In the 1970s and 1980s, universities were increasingly assigned the task of contributing to the re-establishment of the US economy's international competitive position and technologic leadership in certain areas. A cornerstone of this development was the *Patent and Trademark Amendments Act*, known as the Bayh-Dole Act, in 1980. It gave universities and public research institutes the chance to own property rights on results from research financed by federal money. The passage of the Bayh-Dole Act, which could thus be viewed as 'one part of a broader shift in US policy toward stronger intellectual property rights' (Mowery and Sampat, 2005, 228), was strongly promoted by US research universities active in patenting. Previously, universities once understood their mission to be the practice of open sciences and the elaboration of publicly accessible knowledge. Thus since 1980, universities have been able to patent their findings and subsequently commercialize them, be it by new start-up firms or through licensing of patents to other firms .

Homogenization of regulatory framework in Europe

Although later, Europe is experiencing the same development towards stronger intellectual property rights. Two changes in the institutional landscape are to be mentioned: First, in the context of the creation of a single European market, the harmonization of intellectual property rights systems became more important. Second, the implementation of the TRIPS reinforced intellectual property right protection. Different national systems of intellectual property rights are in this political and economic context considered as non-tariff trade barriers.

Intellectual property laws are usually nationally based, whereas competition is transnational. The national, European (European Patent Convention, EPC) and international (Patent Convention Treaty, PCT) patent rights exist in parallel within Europe. The use of the European patent system has risen tremendously during the last decade and has largely eclipsed the number of national patent applications in Europe .

The existing European patent system is based on the 1973 Munich Convention on the European Patent, according to which the European Patent Organization was established. The European Patent permits a patent application in an official language (English, French, German) of the European Patent Office (EPO) to receive in unified procedure patent protection in all designated member states of the European Patent Convention of 1973. The European Patent Convention promoted administrative ease but did not introduce a single patent in the sense of enforcement with a material Europe wide patent law .

A European Community patent, covering with one right the entire territory of the European Union, has not yet been implemented. The proposal for a community patent, made in 1975 (Convention for the European Patent for the common market) and again in 1989 (Agreement relating to Community patents), has still not been adopted. The member states were reluctant to a European Community patent because of the high translation costs into all the official EU languages and because member states still consider the granting of patents as a matter for national sovereignty . Currently, the Community Patent is still object of controversial debates. However, the European Commission launched a new initiative to move towards the implementation of a Community Patent on January 16, 2006 . This renewed effort is in line with the life sciences and biotechnology strategy demanding explicitly a European Community patent adopted in January 2002 which is an element of the competitive agenda of the EU decided at its Lissabon summit in 2000.

There is still a possibility of different interpretations by national laws and national courts in the European patent system. But during the 1980s, European industry amplified its pressure to unify the European regulation for biotechnological inventions and to obtain patents on life forms. The Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions, adopted after 10-year lasting debate was a further step toward harmonization . The EU countries should have integrated it in their national law until July 2000. But the directive still continues to be debated in some countries. The directive does not create any specific patent law for biotechnological inventions. It is rather making adaptions and amendments which the national legislators must implement. National patent laws remain the essential basis for the legal appropriation of biotechnological inventions .

Heavily discussed was the patentability of DNA sequences. The directive excludes the human body and the discovery of one of its parts (e.g. a gene) or parts of it from patentability. However, a part of the human body (e.g. a human hormone, a human gene or nucleotide sequences) that is derived from genetic research and isolated from the human body by means of technical procedure is patentable, even if the isolated part is completely identical to the natural part in the human body. In this respect, there is a convergence of patent policy in Europe and in the US. Both patent offices provided a large number of patents for gene sequences .

A major difference between the patent system in the European countries and the U.S. concerns the point of time of the patent application. The first to invent system in the US requires for novelty that an invention must not have been in public use or on sale or patented or described in a printed publication until 1 year before the US filing. The European system is a first to file patent system. The researcher applying first a patent has priority before those having made the same invention but going later to the patent office. In the US the researcher can profit from a so-called grace period of twelve months during which she/he can publish her/his results without making impossible a later patent application. The grace period is criticized in particular by industry representatives because it creates a period of uncertainty mainly in complex and competitive fields such as biotechnology. However, universities, research institutes and firms collaborating with public institutes favor such a grace period also in Europe .

Bayh-Dole inspired legislation steps up the role of universities in taking out patents on the inventions of their employee scientists. Preparations for this legislation have not included systematic studies of the ways and the extent to which university scientists, prior to the legislation, were involved in commercial patenting, nor was it examined how this involvement could be affected by such legislation.

In the wake of this wave of legislation across Europe several recent studies demonstrate that university invented patents are far more prevalent than university owned patents, e.g. Italy , Finland , Germany . The same pattern is identified for single large universities e.g. University Louis Pasteur . A recent study offers a useful overview of these findings and presents results from a large analysis of

9000 EPO patents across 6 European countries, identifying one inventor in each. The sample also includes a small segment of 294 inventor contributions from university scientists, which gave rise to only 85 university assignments.

University-invented, company-owned patenting turns up as a far more prevalent mode of academic contribution to technological invention than is the mode in which universities are assigned patent rights. For the overall contribution of academia to the technological performance of European companies it emerges as an important issue if that contribution is negatively affected by Bayh-Dole inspired legislation, and if, in that case, adequate new mechanisms appear as substitutes. These issues are addressed below based on anempirical study on effects of the Danish version of Bayh-Dole.

Strong federalist support policy and regulatory adaptation to the international context in Germany

During a long period Bayer and Hoechst were among the leading chemical and pharmaceutical companies in the world. This traditionally strong position got lost in the 1990s. There is not any more one German pharmaceutical company among the top ten. Only focused pharmaceutical firms such as Schering (acquired recently by Bayer) and large firms still owned by families such as Boehringer Ingelheim and Merck KGaA were able to defend their strong position. Also in the early 1990s, more than ten years later than in the US, emerged the biotech industry in Germany. The rise of the biotech industry in Germany has been characterized by the economic and political ambition to catch up compared to the US and Britain.

On the federal level, three political measures substantially influenced the evolution of biotechnology in Germany: first, the establishment of the gencenters in Berlin, Heidelberg, Cologne and Munich between 1984 and 1989, second the adoption of gene technology law in 1990 and its amendment in 1993, and third, the BioRgio contest organized by the BMBF (Federal Ministry for Education and Research) in 1995. This BioRegio contest of 1995 played a crucial role. Actors in regions were invited to submit proposals and to describe how commercialization of biotechnology in their region could be promoted. The winners, the three most organized regional organizations, Initiativkreis Biotechnologie München, BioRegio Rheinland and BioRegio Rhein-Neckar-Dreieck, each received 25 million Euro over five years to invest in biotech. BioRegio Jena in East Germany was awarded a further grant of 15 million Euro. This contest activated a start-up dynamics in these winner regions and also in other regions. The BioRegio contest was an expression of a deliberate policy to promote

the commercialization process of the technological potential in order to improve national competitiveness. Due to the federalist structure of Germany this policy was implemented on a regional level, institutionally using the rivalry between regions in Germany .
The BioRegio contest was followed by a series of further promotion programs of the BMBF. BioProfile supported the specialization of established bioregions. BioChance launched in 1999 funded certain highly-risky R&D projects conducted by small and medium-sized biotech companies. It supported until 2005 young firms translating their biotechnology knowledge into new products with totally 50 Mio. Euro. In 2003 succeed BioChancePlus offering 100 million Euro to small and medium biotech which apply for funding with project submissions. With the BioFuture contest the BMBF finances young scientists in biotechnology and related fields with totally 75 million Euro until 2010 .

In the context of a so-called innovation offensive the BMBF started a High-tech Masterplan in 2003 which aimed a better access to venture capital, the creation of a competitive tax environment and new collaboration models between public research and small enterprise. This plan was less specifically directed to biotechnology than to technology-based companies in general. Additionally, on the level of the Bundesländer, especially in Bavaria, the biotechnology industry was promoted by different cluster initiatives implemented by Bundesländer .

In parallel the German government began to adapt its regulatory framework, especially in the field of intellectual property rights, to the general trend in Europe and initiated already before in the US In June 2003 the German government decided to transpose the European Community directive 98/44 into national law and in March 2004 the German parliament started consultations of the directive. The biotech sector strongly supported a fast implementation of the European biopatent directive .

In Germany university patents were traditionally regulated by the "Inventions made by employees Act" (ArbNErfG). In order to promote freedom of research it included a so-called "professor privilege", according to which the university inventor and not the university was the owner of the patent. This regulation was criticized by some practitioners and industry representatives. They argued that the research institutions had no incentives to support patent applications . In 2002 the ArbNErfG was amended transferring responsibility for patent application from the inventor working at a university to the institution. The aim of this amendment consisted at encouraging patenting activities in universities. Accordingly, since February 2002 an inventor, if he wants to publish his results, has to present the invention to the employing research institution which has to proof the convenience of applying for a patent. The institution can decide whether it wants to file a patent application or leave the invention to the inventor for application. Inventors receive 30% of the compensation profits . The abolishment of the “professor privilege” encouraged the universities to create their own structures for commercialization of inventions and patents. However, an inventor can abstain from a publication and therefore impede or prevent a patent application. This possibility creates uncertainty for firms being interested in collaborating with universities. This shows that, depending on the specific societal context a regulatory adaptation can provoke results which were not aimed originally.

However, the German biotech industry remained relatively weak compared to Britain and Switzerland, despite of the strong government support and the considerable public financing of the biotech sector. This raises the question to which extent such a promotion policy, applied in specific historical, economic and societal contexts and trajectories, can be an adequate means to improve so-called national competitiveness.

Federalist liberal science policy and adaptation of favorable regulatory conditions in Switzerland

Switzerland has traditionally applied a very liberal policy style in determining technology policy. Although Swiss governments, both at the federal and cantonal level have always fostered the promotion of academic research; undertaking technological research was, for ideological reasons, mainly left to business sector. Federal administration has traditionally been weak .

Swiss government strategy consists in developing excellent research in some selected priority areas. Applied technological research is mainly concentrated in a few multinational enterprises. Particularly, in the field of the pharmaceutical and biomedical industries large transnational companies are responsible for the main part of research expenditures. The Swiss federal government has not conceived a more active technology policy. It focuses on providing a good infrastructure and favorable legal conditions. The innovation system worked almost without extra-university governmental-financed research institutes that could have been used for technology policy purposes. Switzerland has a long tradition of niche specialization and development of high-value added products. This strategy has been highly successful including remarkable results in basic research .

The universities (Basel, Zürich, Lausanne and Geneva) as well as the Federal Institutes of Technology (ETH Zürich and EPF Lausanne) have been crucial for the creation of new ventures and technology transfer. Novartis and Roche, two major pharmaceutical companies, both located in Basel, played another central role in the formation process of the Swiss biotechnology industry. Therefore, the large majority of biotech firms in Switzerland are concentrated in the same regions.

In line with the policy mentioned above which consisted in strengthening selected technological fields the Swiss National Science Foundation (SNF) launched the Swiss Priority Program Biotechnology (SPP Biotechnology) in 1992 with public funds. A total of six research modules in biotechnology and complementary activities in continuing education, information, communication, technology assessment, and technology transfer were designated to receive state support over a period of 10 years, ending December 2001. The SPP Biotechnology had the objective to promote strategic, applied biotechnology research in Switzerland. This program contributed to the creation of eighteen new companies. The program budget contained CHF 100 million allocated by the Swiss Federation. Additionally, some CHF 40 million have been attracted from industry, as well as more than CHF 60 million of venture capital throughout the duration of the program . One outcome of the SPP was the creation of the technology transfer office Biotectra in 1996. Unitectra, the technology transfer organization of the universities of Berne and Zurich and the SNF's SPP Biotechnology was founded in 1999 and is the successor institution of Biotectra . The other universities installed their respective technology transfer organizations. In 2001, the SNF launched the first fourteen National Centers of Competence in Research (NCCR) which represented a new instrument of research and technology policy after completion of the SPP. In the field of life sciences, four NCCR have been started. They have focused on research in genetics, neurosciences, structural biology and molecular oncology .

The CTI (Commission for Technology and Innovation) assumes an important role in the biotech promotion policy. The CTI has been a traditional key instrument of the Swiss federal government's technology policy. In 2000, it became the "federal agency for applied research and development". The CTI promotes applied research and development projects through public-private partnerships and supports start-ups. The CTI Start-up initiative initiated in 1995 boosts the entrepreneurship at the junction between universities and industry. It supports the commercialization process of products and especially companies in their start-up phase. It selects new firms for venture capital financing and grants them the "CTI Start-up label" which qualifies them to access to CTI support and venture capital. This label also helps to convince potential investors investing in a project. Through its Life

Sciences section, the CTI backs applied R&D projects based on a public-private partnership model (50/50 funding as a basic rule) and facilitates a transfer from SNF to CTI funding. For example, it supports follow-up projects stemming from the National Centers of Competence in Research (NCCR) .

In contrast to Germany in Switzerland does not know a so-called "professor-privilege". According to Swiss Law of Obligation (Obligationenrecht / OR), inventions made by employees in the course of their employment belong to the employer. Consequently, the universities and research organizations are applicant and owner of the patents claiming such inventions.

The government combined the liberal attitude with a careful adaptation of legal conditions. Although Switzerland is not member of the European Union government has very consciously harmonized its regulatory framework in strategically important fields with the framework of the EU. In line with this orientation, in 1999 the parliament engaged the Federal Council to adapt the patent law to the European biotech directive, passed by the European Parliament and Council in 1998. This law revision aims to conform the patent law with the EU directive on the legal protection of biotechnological inventions . Mainly, the pharmaceutical and biotech industries have lobbied for the law revision. This revision partially takes into account also the interests of academic research in biotechnology. The draft revision of patent law adopted by the Swiss Federal Council in November 2005 defines three major issues :

Patentability of genes: According to the EU directive 98/44, isolated genes as such are patentable. In Switzerland, however, naturally occurring genes would be excluded from patenting under the new law. This is a restriction of patentability that goes beyond the practice applied by the EPO. However, it would continue to be possible to patent "derived sequences" such as the cDNA produced by PCR (Polymerase Chain Reaction), under the condition that at least one function of these sequences is known. This means that the properties and applications of sequences that are derived from gene sequences must already be described in the patent application. Adding them later is no longer possible. This is intended to prevent speculative patent applications.

Patentability of human beings and their body parts: In agreement to European Directive 98/44, the human body as such and human physical components in their natural environment shall also be excluded from patenting. The subject of a patent is a technical teaching as to how human beings can utilize nature in a new way for commercial purposes. This technical beneficial effect makes the discovery an invention under patent law. However, isolated and perhaps technologically modified components of the human body outside their natural environment (such as isolated and possibly genetically modified blood cells) are patentable. Explicitly excluded in the new patent law and also corresponding to Directive 98/44/EC are cloning of human organisms, chimeras with human germ cells, modification of human germ line cells or unmodified human embryonic stem cells.

Role of patents in Swiss biotechnology

There is not much empirical data available on the impact of intellectual property rights in biotechnology. In the context of the revision process of the patent law the Swiss government requested the Swiss Federal Institute of Intellectual Property to analyze the impact of patents on biotechnological innovations and the economic implications of patents .

The number of patent applications rises with firm size. Therefore most patent applications belong to large companies. However some very active, small, companies are strongly dependent on patenting and its commercialization. Small companies consider patents to be highly important in order to use them for the acquisition of venture capital. They are also more innovative in terms of patent applications per employee in research and development. Similarly, research institutes consider their patents to be important to get financing research and development. For most companies having participated on this survey, patents are very important for collaborations with other companies and for timing their scientific publications. Particularly, large companies pay attention to patents when they examine possibilities for collaborations or mergers . Not surprisingly and in line with the economic structure of the country the patent applications of Swiss firms are internationalized. This is expressed in a high number of tradic patents (patents applications filed with European Patent Office, US Patent and Trademark Office and the Japanese Patent Office). Switzerland takes the eighth place in triadic patent families, and measured in patent families per million inhabitants Switzerland, is the leading country, together with Sweden . Swiss biotech firms normally apply also for European and US patents .

Effects of Bayh-Dole inspired legislation on the biotech innovation system in Denmark

This section takes a closer look at some of the implications, which Bayh-Dole inspired legislation (discussed in previous sections) has had for the coherence of innovation systems (discussed in the first section of this chapter) in Denmark, focusing on the effects on industry-university (I-U) collaboration in biotech research .

In the 1950s both Denmark and Sweden enacted legislation giving explicit exception to academic scientists from the general principle whereby employers hold the right to inventions produced by their employees. Referred to as the "teacher's exception" (similar to what in Germany was referred to above as the "professor's privilege", this principle has been maintained in Sweden until now, but was changed in Denmark as per Jan. 1st 2000 in the Law on University Patenting (LUP) [2]. The act transfers to universities ownership inventions made as part of the work of employees. That also pertains to inventions resulting from collaborative work with third parties (e.g. firms), but in these cases the university may renounce the right to the inventions made by the project.

Sweden so far has maintained its teachers exception, but is currently considering reforms in this area. Hence comparing post-LUP patterns in I-U collaboration in Denmark with that of Sweden offers possibilities of a quasi-controlled experiment. Such a comparison benefits from the broad similarities between and two countries, and from the fact that regulations of university IPR uniformly affect all its academic research, unmodified by country-internal variations between e.g. private vs. public universities, or by variations at lower levels of government(länder or states).

This comparison is particularly informative if referring to a field in which I-U collaboration plays a significant role. That is the case in biotechnology where a number of studies have documented the strong reliance of firms of knowledge transfer from academic science . Biotech also is a field in which the two countries are strikingly similar, particularly when we focus on the segment of Dedicated Biotechnology Firms (DBFs) specialised in drug discovery. This segment emerged in the two countries at the same time through the 1990s, and has grown to the same number of firms, with quite similar patenting profiles. Denmark has 51 DBFs, of which 48 have filed patents. In Sweden 41of the total of 44 DBFs have filed patents.

The data by which the study compares Denmark and Sweden is extracted from all the 1087 patents filed by these firms. Inventors listed (by name and area only) on each patent front page were identified and their organisational affiliation was established[3] as per the date of patent application.

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[2] The "Act on inventions at public research institutions" of June 2nd 1999 may be accessed at http://www.videnskabsministeriet.dk/cgi-bin/doc-show.cgi?doc_id=14206&leftmenu=LOVSTOF. An English translation is available at http://www.videnskabsministeriet.dk/cgi-bin/doc-show.cgi?doc_id=20047&doc_type=22&leftmenu=1 .

[3] The methodology for inventor tracking is described in Valentin and Jensen (2006)

These 3640 inventor identifications permit calculation of the share of university scientists for each patent, and of aggregated shares for each country, for specific periods.

Effects of LUP on the share of university scientists in these patents are examined, defining the "event date" with a lag of one year (i.e. Jan 2001), since the law respects collaborative arrangements established prior to its enactment.

Tests are made for LUP-related shifts 1) in the share of *domestic* scientists (i.e. Danish university scientists contributing to patented inventions assigned to Danish DBF, and 2) in the share of *non-domestic* university scientists. For both shares differences between pre- and post LUP levels, comparing Denmark and Sweden, are tested by Difference-in-Difference (DD) regressions.

Furthermore, to enhance interpretation of DD findings, tests are made for LUP-related shifts in *trends*, of shares of university scientists, aggregated separately forthe two countries by quarters.

These tests bring out the following:

- Since the mid 1990s the number of DBF patents in Sweden and Denmark as a whole has increased steeply, as has the number of academic scientists contributing to inventions not only in absolute number. An increase also is observed in academic inventors as a share of all inventors.
- Throughout the 1994-2004 period, the academic involvement in Swedish patents is notably above what is seen in Danish patents. However, the Danish pattern, until the introduction of LUP quite systematically *converges* towards the higher Swedish level.
- Compared to the Swedish control group, the DD regression identifies a drop of 12.6% in the share of domestic academic inventors behind the Danish patents, specifically attributable to the event. In the trend analyses this appears as a *reversal* of the previous convergence towards the higher Swedish level into a sharp *downward* trend.
- Non-domestic inventors on the whole are involved with notably lower shares as compared to domestic inventors, and also in this respect the Danish level is below Sweden. However DD regressions identify a significant increase in Danish non-domestic shares of 13.7%, as compared to the Swedish control group, specifically for the post-LUP period. The trend analysis in this case offers only tenuous results, but they suggest a steep increase in the Danish

post-event involvement of non-domestic inventors. Consistent yearly increases are observed over the four post-event years, bringing the level from 4.9% to 11% of all Danish inventor contributions.

Taken together these findings strongly indicate a Danish pattern, significantly distinct from the Swedish counterpart, of a post-LUP decrease in the involvement of domestic academic scientists. At the same time, non-domestic university scientists to a notable extent substitute for their domestic counterpart in Danish inventor teams.

To see this decline in university involvement in context the study examines if Danish academics in the life sciences in stead *redirect* their inventiveness into *university-owned* patents, as indeed was one of LUP's key objectives.

The number of domestic academic inventor contributions to university-owned patents, in relevant IPC categories, filed subsequent to LUP is identified. This number may be subtracted from the number of inventor contributions equivalent to the 12% post-LUP decline detected in the DD-regression. On this basis the study estimates the extent to which university owns patents provides a substitutive outlet. The two variations of this estimate presented in the study indicate substitutions at rates of 19% and 26%.

University-owned patents, in other words, are very far from providing a substituting outlet for the inventive potential of university scientists previously mobilised for company-owned drug discovery patents. By far the largest part of this academic inventive potential simply seems to have been rendered inactive as an effect of LUP.

To examine the causes behind observed LUP effects the study is underpinned by interviews with academics and DBFs selected from the patent data on which the study is based, identifying explanations consistent with quantitative results from other studies . The interviews bring out that collaborations typically are concerned with *exploratory* research, by some firms referred to as "pre-project research". DBFs enter such collaborations well aware that it is highly uncertain if and how results will be commercially relevant, and that they become so only based on an unknown body of subsequent in-house R&D. Firms tend to find this set-up inconsistent with the LUP- principle that universities ex ante own the rights to resultant inventions, and reduce involvement of *Danish* academic scientists accordingly. For their part, academic scientists typically collaborate in exploratory research to deploy some specialised research experience, which the collaboration may further enhance by offering better research funding, access to an interdisciplinary environment or to the specialised research facilities of the industrial partner. The academic scientist collaborates on such explorative research, in other words, based on skills and motivations, which would not allow her to pursue equivalent patenting on her own.

This explanation clarifies not only why LUP has brought about a decline in collaboration within exploratory research. It also explains why LUP would *not* necessarily have similar effects in university research operating in “down-stream” fields closer to technology. Down-stream fields are less demanding in terms of complex, post-discovery development, so here academics are better positioned to invent on their own, without relying on clues and information from industrial partners. Furthermore, in cases when such downstream issues are addressed in collaborative projects, they also lend themselves more easily to ex ante allocation of IPR.

Implications for the Danish innovation system in biotechnology

Several studies document that research collaborations in biotechnology are established with a strong preference for partners from the same country, even the same region . The advantage of proximate research relationships is not derived from superior qualities of partners, who just happen to be local. Rather it comes from the fact that proximate relations tend to be embedded in networks in which actors have repeated interactions and learn about each other over time via multiple channels . In this way networks become architectures capable of retaining and transmitting vastly richer information about each actor, as compared to arms-length relationships to partners who are distant (in the sense of not being part of the network) . That is why networks offer superior search, allowing actors with complex agendas to access the types of complementarity which gives rise to effective research partnering . However, depending on which activities are carried out and their respective knowledge bases, such networks can also have a global reach as is the case with epesthemic communities (Moodysson et al. forthcoming).

For the issues in the present paper the implication of this argument is that an important part of the value emerging from industry-academia collaborations lies in *the quality of the network* through which either side may undertake effective search so as to identify “the right complementarity at the right time”. Danish DBFs have no advantage above that of DBFs from other countries when it comes to search into the global “market” for academic collaboration. But they do have an advantage in search into the Danish academic setting, since there are strong indications that they are particularly well connected into Danish universities. The authors behind the LUP analysis summarized above in another study identify all founders and board members affiliated with all Danish and Swedish DBFs through their first year of existence . This study shows that the vast majority of founders and board members are recruited from Danish organizations.

Founder teams involving Danish university scientists established more than half of Danish DBFs. Similarly academics were present on more than half of the boards that took firms through their first year of business. These compositions of founder teams and boards make them highly effective in subsequent search into the academic potential for research collaboration.

These figures bring out the particular connectivity, which Danish DBFs have into Danish academia. In turn this connectivity is a key asset for scientists from both the academic and from the industrial side when they look for the complementarity of skills and agendas which are so important for making university- industry research collaboration effective and useful for both commercial and scientific objectives. The paper demonstrates, consistent with this argument, that this composition of founders and boards matters for the ability of Danish DBFs to establish the diversity of inventor collaborations which in turn affects their commercial performance . These observations substantiate that research networks are an important part of the Danish innovation system in biotechnology, and that it matters significantly for the inventiveness and competitiveness of firms. It is therefore cause for concern that LUP, as an unforeseen consequence, induce Danish biotech firms to disengage themselves form the national research network, substituting in stead with search in the global market for academic research partners. It signifies that LUP, as an unintended side effect, seems to have induced an erosion of parts of the national innovation system of considerable value for Danish science-based competitiveness.

6. Conclusions

IPR as a regulatory institution in innovation systems can play a decisive role with potentially big impacts on the governance of the systems. In the chapter we have shown that there across industrial sectors has been a big increase in patent granting during the last two decades both in the US and in Europe. In Europe Switzerland is the leading country measured in patent families per million inhabitants followed by Sweden. This reflects the strength of the pharmaceutical biotech industry in these two countries in contrast to Germany whose biotech industry has remained weak compared to Britain and Switzerland.

However, this big increase in the use of IPRs is more a result of economic and institutional changes than of technological breakthroughs. A new regime of IPRs emerged accompanied by a changed role of universities and publicly funded research, and, thus, had major impacts on the functioning of regional and national innovation systems. The US has been the model of reference for most of these changes and reforms lead by the introduction of the Bayh-Dole Act in 1980. Also in Europe Bayh-Dole legislation has been influential, e.g. in stepping up the role of universities taking out patents on the inventions carried out by their employed scientists. However, company-owned, university-initiated patenting represents a more important academic contribtution to technological invention than university owned patent rights. Morever, the Danish example showed that the introduction of a Bayh-Dole inspired law has had negative impacts on university-industry collaboration in contrast to the situation in Sweden, which still practice the principle of 'teachers exception'.

As shown in the chapter the consequences of introducing IPR differ according to sectors, knowledge bases, phases in the innovation process, and political-institutional frameworks. A patent based IPR makes a 'better fit' in certain sectors and knowledge bases than in others, and works better in specific political environments than in others depending on the types of institutional complementarities present. There may, for example, be a real problem with the current IPR system favouring radical innovations when biotechnology develops from early-phase, hi-tech to more generally diffused multi-tech. All this provides strong arguments against a global generic patent system.

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ARE FIRMS EQUALS IN TERMS OF LEGAL PROTECTION ?

AN ECONOMETRIC INQUIRY INTO THE OUTCOME AND DURATION OF TRADEMARK LITIGATION

Marc Baudry[1] & Béatrice Dumont[2]

ABSTRACT

The economic value of IP rights and the strategic use of IP litigation by competing firms strongly depend on the way IP rights are granted but also enforced by the courts. To illustrate the importance of court decisions in infringement suits, we try to assess whether firms are equals in terms of legal protection and whether some characteristics are more or less influential on the outcome of the trial. To do so, we develop a duration model with two incompatible events (the trademark's holder wins/looses the trial) as outcomes rather than one unique event. Indeed, our purpose is to examine in which context and/or for what type of firm, the legal protection offered by a trademark is the most valuable one. Our findings show that contrary to standard theory, the outcome and duration of the litigation process may be influenced by the characteristics of the parties. We also show that the legal value of a trademark for a plaintiff is strengthened by the importance of its trademark portfolio.

JEL Classification: D73, K41, O34

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I. INTRODUCTION

To have any value or meaning, intellectual property requires a mechanism to force others to do (or stop doing) something and to recover monetary damages for unauthorized use. IP litigation is that mechanism and in today's knowledge economy, it has become one of the primary legal tools available to promote or defend a business[3]. However, little information is available in sufficiently complete form to provide a true picture of litigation. While judicial cases of all types have stimulated a wide array of research aimed at assessing the empirical relevance of the complete and incomplete information models of litigation, IP rights remain somewhat isolated, so that our knowledge of how they are enforced remains tenuous. Such a lack of knowledge is however less and less acceptable. Indeed, from a theoretical standpoint, the costs and uncertainties associated to the solving of a legal conflict could reduce the incentives to innovate (Aoki and Hu, 1999). Moreover, recent studies stress that due to their lack of financial resources and legal experience, small businesses resent with a greater acuity the burden of costs associated to judicial disputes and are therefore reluctant to use the IP system (Cohen and alii, 1997).

Our paper attempts to address this gap in the literature by providing an empirical study of IP enforcement in French courts during the period 1999 to 2004. The main idea is to examine what lies behind IP litigation and more specifically to determine whether the value of legal protection of IP is more beneficial for some firms than others. Indeed, whereas standard economic theory tells us that there is a tendency for plaintiffs to prevail at trial with a probability of 50% (Klein & Priest, 1984), we reconsider this result and test whether the characteristics of the parties have an effect on the outcome and duration of the trial. If it is the case, this would mean that firms are not equal in terms of the legal protection of their IP rights.

Our analysis is directed at a particular type of IP rights, namely the much neglected trademarks[4] disputes. Indeed, despite the importance of court-based enforcement of IP, little is known about how trademark owners actually go about enforcing their registered trademarks in the courts. While there is a growing recognition that companies with a strong brand

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[3] According to trademark laws, the issuance of a trademark does no more than confer a trademark right that is presumed valid in that the final responsability for validity or invalidity of the trademark resides with the courts. This residual uncertainty as to the validity and coverage of trademarks makes disputes inevitable.

[4] A trademark is a word, phrase, slogan, symbol or design which may be used to identify the source of goods or services. It acts like a badge and provides the holder with the exclusive right to use the mark for the holder's goods and services and prevent other persons or businesses from using the same mark for their own goods and services as a means of benefiting from the holder's existing business or goodwill. Trademarks facilitate innovation of new products and quality improvement, and are particularly important for firms when entering new markets.

reputation outperform the market with respect to shareholder return and risk (Madden, Fehle & Fournier, 2002), such enforcement has rarely been the subject of empirical studies. By contrast, there is a burgeoning empirical literature concerning patent litigation and enforcement (Crampes & Langinier, 2002; Ziedonis, 2004; Bessen & Meurer, 2005). This lack of analysis can be explained by the fact that trademark litigation cannot be empirically apprehended in the same fashion as patent disputes. Indeed, trademark data are seldom as available as their patent counterparts. While several proxies can be devised from patent data to assess the value of the patent, trademarks only provide the distinctive sign and the associated industry classes which are far more aggregated than patent technology classes. One of the originality of our paper is to fill this gap. By reading the judgements and thus obtaining detailed information about the nature of the case before the courts, we are able to present a more complex picture of this litigation than existing statistical reports on trademark enforcement.

Another originality of our paper is that we develop a duration model with two incompatible events (the trademark's holder wins/looses) as outcomes rather than one unique event to analyse the outcome and duration of a trial. Indeed, our purpose is to examine in which context and/or for what type of firm the legal protection offered by a trademark is the most valuable one. The idea is to examine the result of the litigation process to see whether some characteristics have more or less influence. At this stage, it is worth recalling that usually two problems emerge from conducting such an analysis. First, univariate analysis usually encompasses many drawbacks: what happens for instance if two variables are of opposite influence[5]? Second, such an analysis usually focuses on the probability to win but not on the benefits or costs of the trial which may be different according to the characteristics of the parties. To better address these two problems, we try to develop a model which deals with the influence of multi-variables on the probability of gains and on the duration of the trial. For this purpose, we build on the analysis of the rational decision to go to trial rather than to settle the case to infer information on the legal value of a trademark measured as the ration between the gain in case of victory and the opportunity cost of going to trial for a trademark owner. We then try to detect which variables influence positively or negatively this ratio.

This paper is organized as follows: Part II presents the dataset and some descriptive statistics. Part II also reviews the litigation course in France. Indeed, it is important to understand the specificities of the French litigation system (compared to common-law jurisdiction) as it may impact the set up of our model. Part III introduces the model. We first detail how to infer information on the value of the legal protection from the rational decision of a trademark

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[5] Let's say for instance the age of the trademark and the number of trademarks owned by one of the party.

owner to go to trial rather than to settle. The probabilities to win or loose after a given delay that are required to implement this inference procedure are then obtained as the result of a Bayesian learning process by the judge in charge of the case. In part IV, the estimation method is presented and the estimation results are discussed. We try to determine whether the outcome and duration of trials are influenced by the characteristics of the parties involved and/or the type of litigation at stake. We finally attempt to determine which trademark owners benefit most from the legal protection. Concluding remarks are given in Part V.

II. METHODOLOGY OF THE STUDY

II.1. The data

In order to test the issues at stake and establish the pattern of trademark enforcement actions brought before French courts and their outcome, we constructed a dataset comprising civil trademark enforcement decisions rendered by French courts in relation to registered trademarks for the period 1999 to 2004. This type of information is time-consuming to collect in a rigorous and reliable way in the absence of publicly available databases. Indeed, we had to read every decision reported in the *Annales de la Propriété Intellectuelle*[6] and in *Lexisnexis©* and to record information about those decisions in a custom-built database. This explains the limited number of cases analysed in this study (203 cases in total but a final sample of 43 cases due to a restriction to first instance proceedings). Information on trademark disputes includes basic information about the proceedings, including the type of cases, the people involved (parties, counsel and judges), the characteristics of the trademark (IPC classes assignments, date of registration, number of trademarks, etc), the case length (number of days elapsed between the issue date of the proceedings and the last decision date). These figures are of interest, in part, because the amount of time taken to resolve a case is a proxy for the cost of the proceedings.

While the number and length of cases is of interest to policy-makers, of even more practical interest is the outcome. The value of a registered trademark to its owner lies in its ability to stop rivals from using a substantially identical or deceptively similar trademark. To succeed in an action for trademark infringement, a trademark owner must establish that he does have a registered trademark (and if challenged, that the trademark registration is valid) and that the alleged infringer must have engaged in conduct amounting to infringement. For this reason, we collected data on the outcome of each decision ("outcome data") recording the outcome on

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[6] One of the drawback of the cases reported in a set of law reports is that the editors of law reports select the case on the grounds of their importance as precedent, a matter not relevant to our aims.

infringement and validity, unfair competition, opposition proceedings[7] and non-opposition proceedings of each trademark in dispute. This distinction is important as there are several kinds of trademark disputes here the stakes and the issues of which are different. For each trademark enforcement decision we have also recorded, where applicable, the grounds on which a trademark owner failed, such as the non infringement grounds (i.e. the trademark was not used as a trademark or was not substantially identical or deceptively similar to the registered mark). Data in terms of awarded damages, number and cost of publication and ancillary sanctions were also collected. Finally, to complete our dataset, we have extracted from the *Datastream, Hoovers and Kompass* databases data on firms' characteristics (nationality, sector, date of creation, number of employees, turnover). While the dataset explored in this article presents several limitations[8], it allows us nevertheless to cast a look at trademark disputes.

II.2. Some Descriptive Statistics

Tables 1 and 2 provide some descriptive statistics on the trademark litigation course in France.

Insert Table 1

As stressed in Table 1, out of a total of 43 cases, the trademark's holder A is only successful in 44,19% of the cases (thus below the probability of 50% found by Klein & Priest, 1994). The average length of the first instance proceeding is of 424.05 days in case of victory for A and of 374.05 days when A is unsuccessful in proving validity/infringement.

Insert Table 2

Table 2 gives us the average value of the different variables. It allows us to give some insights on which characteristics presumably make it easier or not for A to win the litigation process. Interestingly, our descriptive statistics show that the proportion of trademark's holder A that are individuals rather than firms is higher in the subset of cases where A is successful (11%) compared with the subset of cases where A is unsuccessful (8%). Accordingly, being an individual rather than a firm seems to act in favour of A. In the same way, being an individual rather than a firm seems to act in favour of B. Regarding the nationality of the parties, non

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[7] A registered trademark owner who becomes aware of an application for registration of a mark that will be, as they perceive it, too close to their own, may oppose registration of that mark, thus heading off at an early stage a dispute that might otherwise become a fully-fledged infringement suit. Such opposition proceedings are an important means by which trademark owners enforce their rights.

[8] There is no doubt that the cases that make it all the way to judgement are not a representative sample of all trademark disputes.

national and non European trademark's owners are clearly more often encountered in the subset of cases where A is unsuccessful. This result stresses the existence of a possible national bias. The cases where A has won are cases where the trademark(s) at stake are the oldest in average. However, cases where A lost are those where the trademark covers many classes. Finally, it turns out that the less favourable configuration for the trademark's holder is when both the turnover of A and B are large. In the same ways, cases where A looses are those where A has a larger size (as measured by the number of employees) than B.

As previously underlined, one of the main drawbacks with such an univariate analysis is that it disregards the joint effects of variables. Obviously, before inferring any conclusive remarks, it is necessary to get more robust statistical results and therefore to develop an econometric test. To do so, we need to model the duration and outcome of the litigation process. But first, it is important to understand the specificities of the litigation course in France which may impact the set up of our model.

II.3. The litigation course

It is perhaps commonplace to suggest that civil litigation in France is very different from litigation in common-law jurisdictions[9]. For example, to commence proceedings[10], the plaintiff must serve summons on the opposing party (the defendant). The plaintiff has to register the summons before the Court office. The claims have to be initiated within a short time (6 months) and should seem to be serious. The parties then exchange pleadings (there is no limitation in the number of written pleadings exchanged) and exhibits (including expert reports) under the control of a judge in charge of case management. An oral hearing takes place before the court issues its decision. However, it should be noted that the oral advocacy part of proceedings carries far less weight than in common-law jurisdictions and the matter is decided principally on the basis of the exchange(s) of written submissions prior to the trial. Compared say to the USA, there are no juries at Civil hearings. The judge managing the case controls the instruction of the procedure but the timetable is rather flexible. The pleadings are systematic. For all comparative intents and purposes, cross-examination of witnesses does not exist either. The time taken for a matter to come to trial, i.e. with effect from the service of the writ or claim form, often depends on the geographical location within France (it is observable that the delays in many matters are often longest in the southern part of the country). However, it would not be unusual in most of France for a period of between 16 and 22 months

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[9] *Cf.* Figure 1 for a summary.

[10] The imitated firm proceed to a full trial. We do not examine out of court agreements.

to elapse between the service of the writ and the trial at First Instance. Finally, large scale punitive damages are never awarded, and what is more, class-actions do not exist.

In infringement cases[11], the first instance judgment usually decides only the validity and the infringement issues. Infringement can be proven by any means. The search and seizure ("*saisie-contrefaçon*") is the usual preliminary of nearly all infringement cases in France and an efficient measure to prove infringement. A search and seizure may be performed upon authorization of the Presiding judge of the local court, obtained *ex parte*. With this Court order, the bailiff can enter into the premises of any person which detains evidence of the infringement and, to perform the authorized investigations, he can be accompanied by any person(s) skilled in the art chosen by the patentee.

The appeal suspends the enforcement of the first instance judgment except for provisional measures and unless otherwise decided. It consists in a full re-hearing of the case as to the facts and the points of law. There is a possibility of bringing additional exhibits. The Court of Appeal decides *de novo*. The Paris Court of appeal also rules on a very specific type of litigation: appeals brought against decisions of the director of the French Industrial Property Institute (INPI). The appeal before the Supreme Court ("*Cour de Cassation*") consists in a review of the judgement of the Court of Appeal and is limited to the points of law only.

Insert Figure 1

III. THE MODEL

III.1. Inferring information from the decision to go to trial

Following a well known strand of literature, we assume that the decision to go to trial rather than to settle is the outcome of a rational trade-off made by the plaintiff A between the associated expected gains and losses. More precisely, we assume that the current situation, or *status quo* situation, corresponds to a duopoly since the trademark of the plaintiff A is counterfeited by the defendant B. If A wins the trial, his benefit compared to the *status quo* situation amounts to the sum of two terms. The first term is the discounted sum of the

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[11] In legal terms, counterfeit trademark goods are defined in TRIPs as having two key features : the infringer uses an identical mark to the registered trade mark and the infringer uses the mark in relation to the same goods as those for which the trademark is registered. To win an infringement suit, a trademark owner must show there is a likelihood of mistake, confusion, or consumer deception by the defendant's use of the similar mark. The basic questions in a trademark infringement action tend to turn largely on issues of facts. The key factors are whether the marks are confusingly similar, and whether they are used on the same or "related" goods. This includes goods or services into which the trademark holder's business is reasonably likely to expand.

difference between monopoly and duopoly profit flows from the end of the trial onwards. If the current date is the date of end of the trial, this term is given by

$$B_A = \sum_{t=0}^{\infty} \frac{\pi_M - \pi_D}{(1+r)^t} \quad \text{or} \quad (\pi_M - \pi_D)\frac{r}{1+r} \tag{1}$$

where π_M and π_D respectively denote the monopoly and duopoly profit flows. r is the interest rate[12]. The second term is associated with the reimbursement of the discounted sum of the same difference between monopoly and duopoly profits flows from the date T where B started to counterfeit A's trademark to the date where the trial ends. It is given by the following damage expression:

$$D = \sum_{t=-T}^{0} \frac{\pi_M - \pi_D}{(1+r)^t} \quad \text{or} \quad B_A \frac{(1+r)^{T+1} - 1}{1+r} \tag{2}$$

If the trademark's holder A decides to go to trial, A's objective is to maximise his expected gain with respect to an initial investment I_A that influences the duration and outcome of the trial due for instance to the more or less good reputation of the attorney he chooses. To keep things simple, we assume that this investment is only incurred at the beginning of the trial. The objective of A may then be described by the following maximisation program

$$\underset{I_A}{Max}\left\{ \sum_{\tau=0}^{\infty} \Pr_A^{\tau}(I_A, I_B) \frac{B_A(1+\delta)}{(1+r)^{\tau}} - I_A \right\} \tag{3}$$

where δ denotes the coefficient of B_A in (2). τ stands for the date at which the lawsuit is resolved in favour of A. The probability that A wins at date τ is denoted by $\Pr_A^{\tau}(I_A, I_B)$ and is influenced not only by the investment I_A made by A but also by the investment I_B made by the defendant B.

If the verdict goes against the defendant, the cost of a trial for B compared to the *status quo* is the sum of two terms. The first term is associated with the reimbursement of the difference between monopoly and duopoly profit flows to the plaintiff. This term is given by the damage expression (2). The second term is associated with the loss of the duopoly profit flow from the end of the trial onwards compared to the *status quo*. This second term reads as

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[12] Note that we assume that A's trademark will not be counterfeited again. Actually, introducing the possibility of new counterfeits as the outcome of an exogenous random Poisson process would just result in an increase of the relevant discount factor.

$$C_B = \sum_{t=0}^{\infty} \frac{\pi_D}{\left(1+r\right)^t} \quad \text{or} \quad \pi_D \frac{r}{1+r} \tag{4}$$

The objective of the defendant B is to minimise his expected total cost of the trial with respect to his own investment I_B that influences the duration and outcome of the trial. The corresponding minimisation programme is

$$\underset{I_B}{Min} \left\{ \sum_{\tau=0}^{\infty} \Pr_A^{\tau}\left(I_A, I_B\right) \frac{B_A \delta + \pi_D r/(1+r)}{\left(1+r\right)^{\tau}} - I_B \right\} \tag{5}$$

The solutions $\hat{I}_A(I_B)$ and $\hat{I}_B(I_A)$ to (3) and (5) define the reaction functions characterising the strategic choice of investment amounts. Let I_A^* and I_B^* be the associated Nash equilibrium. The plaintiff A prefers to go to trial if his objective function in (3) evaluated at I_A^* and I_B^* exceeds his expected gain S_A from settlement. Rearranging this condition, we obtain that A goes to trial if

$$\frac{B_A(1+\delta)}{S_A + I_A^*} \geq \frac{1}{\sum_{\tau=0}^{\infty} \frac{\Pr_A^{\tau}\left(I_A^*, I_B^*\right)}{\left(1+r\right)^{\tau}}} \tag{6}$$

The left hand side of (6) may be thought of as an index of return from trial if the verdict goes in favour of the plaintiff. Indeed it yields the ratio between the gross gain from the trial if A wins and the cost of the trial which is given by the sum of the direct cost I_A^* and the opportunity cost that amounts to the expected gain S_A from settlement. The right hand side of (6) yields the multiplicative coefficient for the transition from the gain if A wins (the numerator in the left hand side) to the expected gain whatever the outcome of the trial. As already outlined by Choi (1998) for instance, some information is revealed by the condition (6). Indeed, whereas we are generally not able to obtain data on the elements of the left hand side of (6), we are able to estimate the elements of the right hand side from data on the duration and outcome of trials. Assuming an *ex ante* distribution function for the left hand side, we can derive the *ex post* distribution from an estimate of the right hand side. This is illustrated by Figure 2 where the grey area distinguishes the part of the *ex ante* distribution function that is no more relevant according to condition (6). Moreover, if the right hand side is estimated as both a function of the characteristics of the plaintiff and defendant and the characteristics of the case and/or of the trademark at stake, then we are able to determine for which trademark owners the value of the legal protection is the highest compared with its cost. Assume for instance that one of the characteristics positively influence the value of the threshold. Then the grey area in Figure 2 expands to the right so that the expected value of the left hand side (6) increases. This means that plaintiffs with a high value of this characteristic have a higher rate of return from legal suits.

Insert Figure 2

II.2. Trial as a duration model

In order to infer information from the decision to go to trial as described above, an estimate of the probability that the lawsuit is resolved in favour of the plaintiff at each given date τ is required. For this purpose, we analyse the length of a trial as a duration model, the main feature of which is that the end of the process depends on the realisation of one of two events rather than a sole event. Our point of departure for this duration model is a complete information framework. In such a context, the judge in charge of the case immediately knows whether the plaintiff A is in his right or, conversely, if the defendant B is in his right so that the duration of the trial is infinitely close to zero. Let W_A denotes the scenario where the verdict goes in favour of A and W_B denotes the scenario where the verdict goes against A and thus in favour of B. To deal with a more realistic approach where the trial lasts for a non infinitesimal period, we turn to an incomplete information framework. More precisely, we consider a discrete time framework and assume that between two consecutive dates the judge receives one information. Information consists on a message which may be of two types. It may be either a message of type M_A in favour of A or a message of type M_B in favour of B. Moreover, both types of messages are noisy. This means that between two consecutive dates a message M_A is received with probability $p_A > 1/2$ if the scenario W_A is the correct one in the complete information framework and with probability $1 - p_B < 1/2$ otherwise and, conversely, a message M_B is received with probability $p_B > 1/2$ if the scenario W_B is the correct one in the complete information framework and with probability $1 - p_A < 1/2$ otherwise. The conditional probabilities of the two types of messages are then as follows

$$\begin{pmatrix} \Pr[M_A/W_A] & \Pr[M_A/W_B] \\ \Pr[M_B/W_A] & \Pr[M_B/W_B] \end{pmatrix} = \begin{pmatrix} p_A & 1 - p_B \\ 1 - p_A & p_B \end{pmatrix} \tag{7}$$

We are not interested as such in the probabilities of the two types of messages but rather in the probabilities of the two scenarios. With this aim in view, we denote by X_t the subjective probability associated with scenario W_A for the judge at time t. This probability describes the beliefs of the judge on the true scenario. The judge puts an end to the suit as soon as X_t takes a value outside the interval $\left]1 - \overline{X}, \overline{X}\right[$ where $\overline{X}$ is an exogenously given threshold. The judge gives a verdict in favour of the plaintiff A if X_t exceeds the threshold $\overline{X}$ and, conversely, gives a verdict against A if X_t is lower than $1-\overline{X}$. The threshold value is exogenously determined and measures the degree of certainty required to end a trial. The higher $\overline{X}$, the higher the degree of certainty required. When starting a trial, the judge has no *a priori* on the true scenario so that $X_0 = 1/2$. The belief of the judge, and thus the value of X_t, changes from date to date due to the arrival of new noisy messages of type M_A or M_B. In order to obtain the new probability X_{t+1} given X_t we use Bayes' rule to compute the probabilities of the two scenarios conditionally on the type of message received between t and $t+1$ and the value of X_t:

$$\begin{pmatrix} \Pr\left[W_A/M_A\right] & \Pr\left[W_A/M_B\right] \\ \Pr\left[W_B/M_A\right] & \Pr\left[W_B/M_B\right] \end{pmatrix} = \begin{pmatrix} \dfrac{p_A X_t}{\Pr_A^t} & \dfrac{\left(1-p_A\right) X_t}{\Pr_B^t} \\ \dfrac{\left(1-p_B\right)\left(1-X_t\right)}{\Pr_A^t} & \dfrac{p_B \left(1-X_t\right)}{\Pr_B^t} \end{pmatrix} \tag{8.a}$$

with

$$\Pr_A^t = p_A X_t + \left(1-p_B\right)\left(1-X_t\right) \tag{8.b}$$
$$\Pr_B^t = \left(1-p_B\right) X_t + p_A \left(1-X_t\right) \tag{8.c}$$

as the unconditional probabilities of receiving respectively a message of type M_A or M_B. The first line in (8.a) yields the new subjective probability X_{t+1} associated with scenario W_A if a message M_A is received between t and $t+1$ (first column) or if a message M_B is received between t and $t+1$ (second column). The second line in (8.a) yields the corresponding values for $1-X_{t+1}$.

From a computational point of view, it is more convenient to use the process Z_t defined by

$$Z_t = \ln\left(\frac{X_t}{1-X_t}\right) \quad \Leftrightarrow \quad X_t = \frac{\exp\left(Z_t\right)}{1+\exp\left(Z_t\right)} \tag{9}$$

Indeed, the stochastic process Z_t corresponding to the natural logarithm of the likelihood ratio of the two scenarios evolves according to the relatively simple following rule:

$$Z_t = \begin{cases} \Delta^{+} Z & \text{with probability} \quad \Pr_A^t\left(Z_t\right) \\ \Delta^{-} Z & \text{with probability} \quad \Pr_B^t\left(Z_t\right) \end{cases} \tag{10.a}$$

with

$$\Delta^{+}Z = \ln\left(p_A/1 - p_B\right) > 0 \tag{10.b}$$

$$\Delta^{-}Z = -\ln\left(p_B/1 - p_A\right) < 0 \tag{10.c}$$

and where the probabilities $\mathrm{Pr}_A^t(Z_t)$ and $\mathrm{Pr}_A^t(Z_t)$ are obtained by substituting the expression of X_t as a function of Z_t given in (9) in (8.b) and (8.c). The magnitudes of the positive and negative shocks differ from each other and only depend on the two probabilities p_A and p_B. The probabilities of these shocks correspond to the unconditional probabilities of the receipt of a message M_A and a message M_B and depend on p_A and p_B but also on the current value of Z_t. The process Z_t starts at the initial value $Z_0 = 0$ and increases with X_t for $X_t \in [0,1]$. Therefore, the law suit ends in favour of the plaintiff A as soon as Z_t exceeds $\overline{Z} = \ln\left(\overline{X}/1 - \overline{X}\right) > 0$ or in favour of the defendant B as soon as Z_t lies behind $-\overline{Z} < 0$. The main interest of the process Z_t is that it may be illustrated by the tree form in Figure 3 where the horizontal axis is associated with time while the vertical axis is associated with the value of the process.

Insert Figure 3

Accordingly, the process Z_t has $t+1$ possible values at time t which are referred to as $Z_t^i = i\,\Delta^{+}Z + (t-i)\Delta^{-}Z$ with $i \in \{0,\cdots,t\}$. Thus Z_t^i exceeds $\overline{Z}$ if and only if $i > \left(\overline{Z} - t\,\Delta^{-}Z\right)/\left(\Delta^{+}Z - \Delta^{-}Z\right)$. Conversely, Z_t^i lies behind $-\overline{Z}$ if and only if $i < \left(-\overline{Z} - t\,\Delta^{-}Z\right)/\left(\Delta^{+}Z - \Delta^{-}Z\right)$. Let $\Theta(Z)$ be the dummy variable defined by

$$\Theta(Z) = \begin{cases} 1 & \text{if} \quad Z \in \left[-\overline{Z}, \overline{Z}\right] \\ 0 & \text{if} \quad Z \notin \left[-\overline{Z}, \overline{Z}\right] \end{cases} \tag{11}$$

The probability $\overline{\mathrm{Pr}}_\tau\left\lfloor Z_\tau^i \right\rfloor$ that the process Z_t takes the value Z_τ^i at time τ knowing that it has never taken values outside the range $\left\lfloor -\overline{Z}, \overline{Z} \right\rfloor$ before τ is given by

$$\overline{\mathrm{Pr}}_\tau\left[Z_\tau^i\right] = \begin{cases} P^{-}\left[Z_\tau^i + \Delta^{+}Z\right] & \text{if} \quad i = \tau \\ P^{-}\left[Z_\tau^i + \Delta^{+}Z\right] + P^{+}\left[Z_\tau^i + \Delta^{-}Z\right] & \text{if} \quad i \in \{1,\cdots,\tau-1\} \\ P^{+}\left[Z_\tau^i + \Delta^{-}Z\right] & \text{if} \quad i = 0 \end{cases} \tag{12.a}$$

with

$$P^{+}\left\lfloor Z_\tau^i + \Delta^{-}Z \right\rfloor = \quad \Theta\left(Z_\tau^i + \Delta^{+}Z\right)\overline{\mathrm{Pr}}_{\tau-1}\left\lfloor Z_\tau^i + \Delta^{+}Z \right\rfloor \mathrm{Pr}_B^{\tau-1}\left\lfloor Z_\tau^i + \Delta^{+}Z \right\rfloor \tag{12.b}$$

$$P^{-}\left\lfloor Z_\tau^i + \Delta^{+}Z \right\rfloor = \quad \Theta\left(Z_\tau^i + \Delta^{-}Z\right)\overline{\mathrm{Pr}}_{\tau-1}\left\lfloor Z_\tau^i + \Delta^{-}Z \right\rfloor \mathrm{Pr}_A^{\tau-1}\left\lfloor Z_\tau^i + \Delta^{-}Z \right\rfloor \tag{12.c}$$

Indeed, if $i\in\{1,\cdots,\tau-1\}$ the process Z_t may reach the value Z^i_τ at time τ following either a negative shock from the value $Z^i_\tau+\Delta^+ Z$ (with probability $P^+\lfloor Z^i_\tau+\Delta^- Z\rfloor$) at time $\tau-1$ or a positive shock from the value $Z^i_\tau+\Delta^- Z$ (with probability $P^-\lfloor Z^i_\tau+\Delta^+ Z\rfloor$) at time $\tau-1$. If $i=0$, the process Z_t may only reach the value Z^i_τ at time τ following a negative shock from the value $Z^i_\tau+\Delta^+ Z$ (with probability $P^+\lfloor Z^i_\tau+\Delta^- Z\rfloor$) at time $\tau-1$. Conversely, if $i=\tau$ the process Z_t may only reach the value Z^i_τ at time τ following a positive shock from the value $Z^i_\tau+\Delta^- Z$ (with probability $P^-\lfloor Z^i_\tau+\Delta^+ Z\rfloor$) at time $\tau-1$. Accordingly, the probability $\Pr^\tau_A\left(I^*_A, I^*_B\right)$ used in condition (6) for the plaintiff to prefer to go to trial rather than to settle is computed as

$$\Pr^\tau_A\left(I^*_A, I^*_B\right)=\begin{cases} 0 & \text{if} \quad \tau<\bar{Z}/\Delta^+ Z \\ \sum\limits_{i=I}^{\tau}\overline{\Pr}_\tau\left[Z^i_\tau\right] & \text{if} \quad \tau\geq\bar{Z}/\Delta^+ Z \end{cases} \tag{13.a}$$

with I the lower integer value above $\left(\bar{Z}-\tau\Delta^- Z\right)/\left(\Delta^+ Z-\Delta^- Z\right)$. Similarly, the probability $\Pr^\tau_B\left(I^*_A, I^*_B\right)$ that the defendant wins the trial at time τ is computed as

$$\Pr^\tau_B\left(I^*_A, I^*_B\right)=\begin{cases} 0 & \text{if} \quad \tau<-\bar{Z}/\Delta^- Z \\ \sum\limits_{i=0}^{J}\overline{\Pr}_\tau\left[Z^i_\tau\right] & \text{if} \quad \tau\geq\bar{Z}/\Delta^+ Z \end{cases} \tag{13.b}$$

with J the higher integer value behind $\left(-\bar{Z}-\tau\Delta^- Z\right)/\left(\Delta^+ Z-\Delta^- Z\right)$. These two last expressions serve as a basis for the estimation of the duration model.

IV. ESTIMATION METHOD AND RESULTS

IV.1. Estimation method

Prior to describing the estimation method, note that a key feature of the process Z_t is that it only depends on two parameters, namely p_A and p_B. However, it is assumed that the plaintiff and the defendant may at least partly influence the duration and outcome of the trial and, thus, the probabilities $\Pr^\tau_A\left(I^*_A, I^*_B\right)$ and $\Pr^\tau_B\left(I^*_A, I^*_B\right)$. In order to take into account this assumption, we thus have to assume that the two parameters p_A and p_B are themselves influenced by I^*_A and I^*_B. This means that each protagonist is able to make messages in his favour less noisy and messages in favour of the other protagonist more noisy. Finally, since we do not directly observe the investments made by the two protagonists, we suppose that they are functions on the one hand of both observed characteristics of the plaintiff and defendant and characteristics of the case and/or the trademark at stakes and, on the other hand, of some unobserved factors intrinsic to each case. Since p_A and p_B are probabilities, we use a logistic functional form to make sure that they take values inside the range $[0,1]$. Hence, for each case $n \in \{1,\cdots,N\}$ we have

$$p_A^n = \exp\left(\sum_{k=1}^{K} \alpha_k \, v_k^n + \varepsilon_n\right) \Big/ 1 + \exp\left(\sum_{k=1}^{K} \alpha_k \, v_k^n + \varepsilon_n\right) \tag{14.a}$$

$$p_B^n = \exp\left(\sum_{k=1}^{K} \beta_k \, v_k^n + \xi_n\right) \Big/ 1 + \exp\left(\sum_{k=1}^{K} \beta_k \, v_k^n + \xi_n\right) \tag{14.b}$$

where v_n^k ($k \in \{1,\cdots,K\}$) are variables measuring one of the K characteristics of protagonists or of the case, α_k and β_k ($k \in \{1,\cdots,K\}$) are real parameters to be estimated and ε_n and ξ_n are i.i.d random terms capturing the influence of unobserved factors. For estimation purposes, expression (14.a) and (14.b) are rearranged as

$$\ln\left(p_A^n / 1 - p_A^n\right) = \sum_{k=1}^{K} \alpha_k \, v_k^n + \varepsilon_n \tag{15.a}$$

$$\ln\left(p_B^n / 1 - p_B^n\right) = \sum_{k=1}^{K} \beta_k \, v_k^n + \xi_n \tag{15.b}$$

Equations (15.a) and (15.b) may be estimated by a standard least square or maximum likelihood method. A crucial step prior to this estimation is to obtain values for p_A^n and p_B^n and thus for the dependant variables. For this purpose, note that the likelihood of the outcome and duration of case n is

$$L_n = \prod_{\tau=0}^{\infty} \left(\Pr_A^\tau\left(p_A^n, p_B^n\right)^{w_A^n} \Pr_B^\tau\left(p_A^n, p_B^n\right)^{1-w_A^n} \right)^{w_\tau^n} \tag{16}$$

where w_A^n is a dummy variable taking value 1 if the verdict is in favour of A and value 0 if B wins the trial while w_τ^n is a dummy variable taking value 1 is the trial ends at date τ and value 0 otherwise. The two values used for p_A^n and p_B^n in (15.a) and (15.b) are those that maximise the likelihood (16). Since we do not have an analytical expression of the probabilities $\Pr_A^\tau(p_A, p_B)$ and $\Pr_B^\tau(p_A, p_B)$, this maximisation is based on numerical methods. More precisely, the probabilities $\Pr_A^\tau(p_A, p_B)$ and $\Pr_B^\tau(p_A, p_B)$ have first been computed for each element $\{p_A, p_B\}$ of a grid a values generated for p_A and p_B taking values from 0.5 to 1 with a step equal to 0.05. We then used the *ListInterpolation* instruction on *Mathematica® 5* to obtain $\Pr_A^\tau(p_A, p_B)$ and $\Pr_B^\tau(p_A, p_B)$ as functions of p_A and p_B. Note that in order to make these two expressions relatively smooth functions of p_A and p_B we have assumed that the basic time period separating two dates in the duration model was one month but we have divided this period on a daily basis so that 30 messages of type M_A or M_B are received on each time period. Figure 4 displays the resulting graphic of $\Pr_A^\tau(p_A, p_B)$ as a function of p_A and p_B for $\tau = 4$ months.

Insert Figure 4

IV.2. Estimation results

The estimation method described above has been implemented to the dataset introduced in part II. The values of p_A^n and p_B^n that maximise the likelihood of the outcome and duration of each case in the database are reported on Figure 5. The mean of p_A^n amounts to 0.648919 and its standard deviation is equal to 0.160028 while the corresponding values for p_B^n are respectively 0.752394 and 0.0896362. Thus, the trials considered on our database are generally characterised by messages in favour of the plaintiff that are noisier than those in favour of the defendant. Although Figure 5 exhibits a slightly upward linear relation between p_A^n and p_B^n their correlation coefficient only amounts to 0.0489139.

Insert Figure 5

The estimation results for equations (15.a) and (15.b) are reported in Table 3. A first striking result is that p_B is better explained by observed variables than p_A. This means that the strategic investments made by the two protagonist are intended to affect (increase for A and reduce for B) the noise on messages in favour of the defendant rather than to affect the noise on messages in favour of the plaintiff. Indeed, almost half of the variance of the dependent variable in equation (15.b) is explained by the model whereas this part is slightly inferior to one third for equation (15.a). This results also stresses the role of unobserved intrinsic characteristics of the cases to determine the value of p_A. Another striking result is that the variables that significantly affect the value of p_A differ from those that significantly affect the value of p_B. Indeed, p_B is significantly and negatively affected by the fact that the case is a case of counterfeit, of opposition proceedings or of non opposition proceedings rather than a case of unfair competition[13]. Accordingly messages in favour of the defendant are less noisy for the first three types of cases compared with the last type. p_B is also significantly and negatively affected by the fact that the defendant B is an individual rather than a firm. By contrast, the only two variables that have a significant and positive impact on p_A are the age of the trademark at stake and the number of trademarks owned by the plaintiff. The higher these two variables, the less noisy are the messages in favour of the plaintiff. Otherwise stated, it seems that it is *ceteris paribus* easier for a trademark owner to present his arguments to the judge if his trademark is an old one and if he possesses a large trademark portfolio. In this sense, we are able to conclude that the legal value of a trademark for a plaintiff is

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[13] The sum of the corresponding dummy variables does not yield 1 because a same case may be coded with 1 for several of the dummies (for instance for unfair competition and counterfeit)

strengthened by the importance of its trademark portfolio (number of trademarks and age of the trademark at stake). This conclusion is confirmed by Table 4 which displays the elasticity or quasi elasticity of the threshold on the right hand side of (6) with respect to the variables with an significant impact on the quality of messages[14]. Note that in Table 3 the coefficient of the dummy variable taking value 1 if the defendant is an individual and 0 otherwise is high but not significantly different from zero so that the quasi elasticity of p_A and the quasi elasticity of the threshold with respect to that variable in Table 4 are artificially high. An increase by one percent of the age of the trademark indices a rise of 0.012% of the threshold in the right hand of conditions (6). Similarly, an increase of one percent of the number of trademarks in the portfolio of the plaintiff results in an increase by 0.072% of the critical threshold. The age and wide of the trademark portfolio thus implies an increase of the rate of return expected from going to trial for an infringe trademark owner.

Insert Table 3

Insert Table 4

V. CONCLUDING REMARKS

It is now well known for firms that along with intellectual property reward comes IP risk. Indeed, if IP are an opportunity for firms to boost their bottom lines, they also constitute an exposure for firms that may face an IP litigation suit and have to pay high damage awards or worst may have their IP rights be declared invalid. This explains, in part, why many SMEs are willing to subscribe an insurance against loss due to infringement of their IP rights[15]. This also explain why both the European Commission and Member States have recently introduced measures intended to improve and step up the fight against counterfeiting but have also strengthen the means of enforcing IPRs rights[16]. However, our paper suggests that the judicial system may not be so neutral as supposed. Indeed, contrary to standard theory, we show that in France the outcome and duration of the litigation process may be influenced by the characteristics of the parties. We also show that the devise of a trademark portfolio strategy strengthens the legal value of each peculiar trademark. Indeed, the return on the legal

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[14] A quasi elasticity measures the variation of the threshold (in percent) that results *ceteris paribus* from setting a dummy variable at 1 rather than 0 .

[15] *Cf.* the study for the European Commission (January 2003), Patent litigation insurance : the possible insurance schemes against patent litigation risks.

[16] *Cf.* Directive 2004/48/EC of the European Parliament and of the Council of 29 April 2004 on the enforcement of intellectual property rights.

protection as defined by the ratio between the gain in case of trial victory and the opportunity cost of the trial increases with the importance of the trademark portfolio. In other words, if firms want to avoid the expense, inconvenience and confusion that occur from the fact that a trademark right is only “presumed” to be valid, they should recognize that a comprehensive, well-crafted and cost-effective trademark portfolio can be of substantial value and is likely to reward them with positive returns for years to come.

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Figure 1
The first instance proceedings

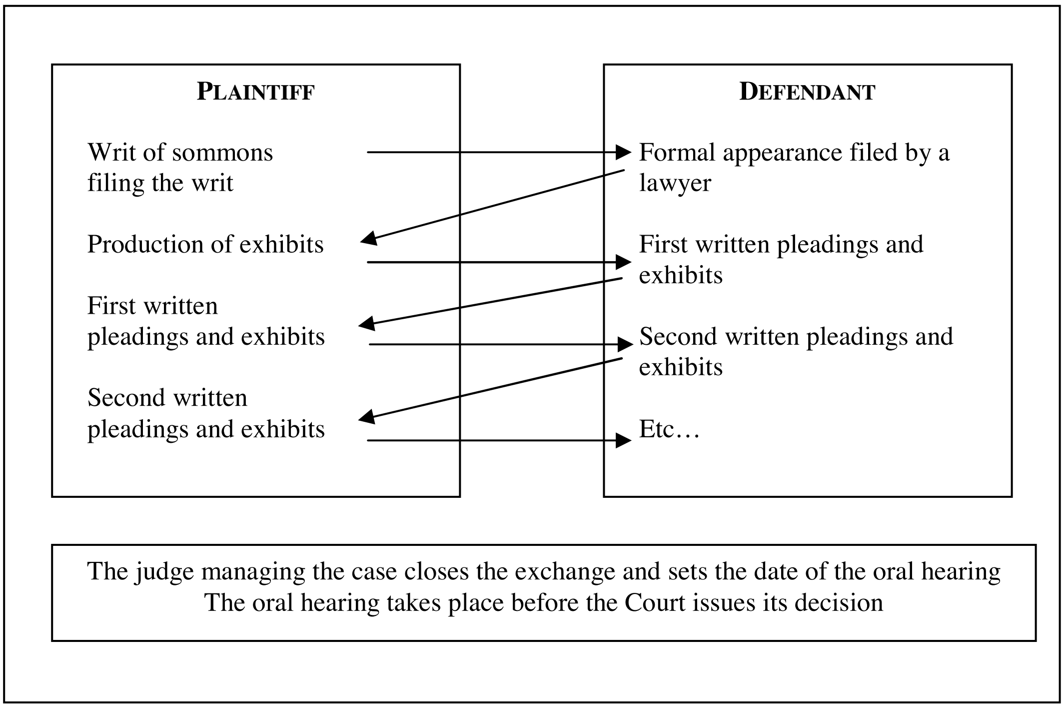

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Figure 2
Inferring information from the decision to go to trial

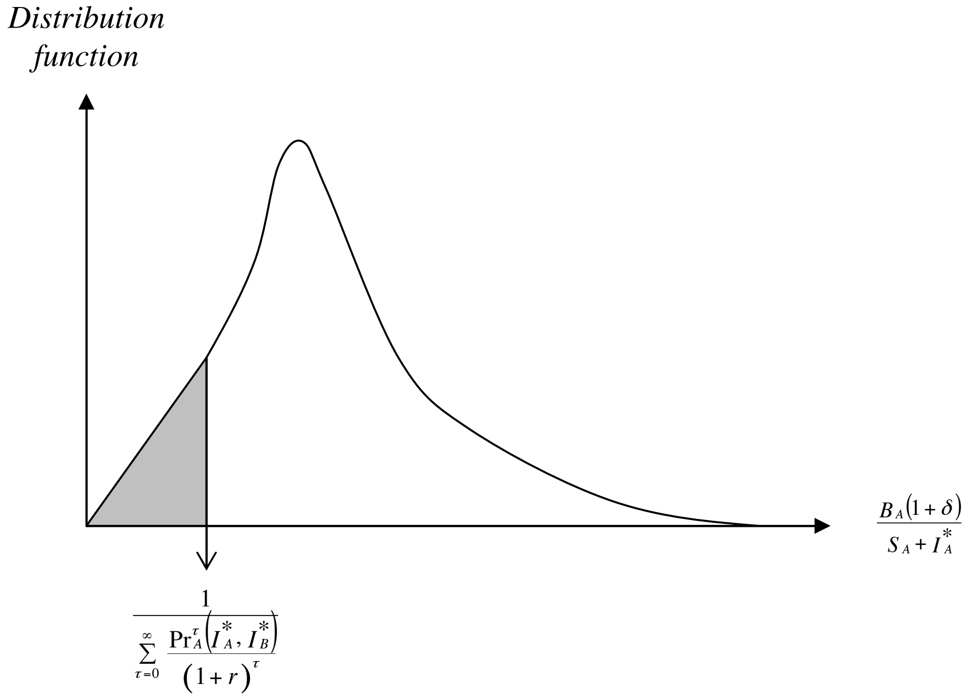


Figure 3

The tree form evolution of the process Z_t

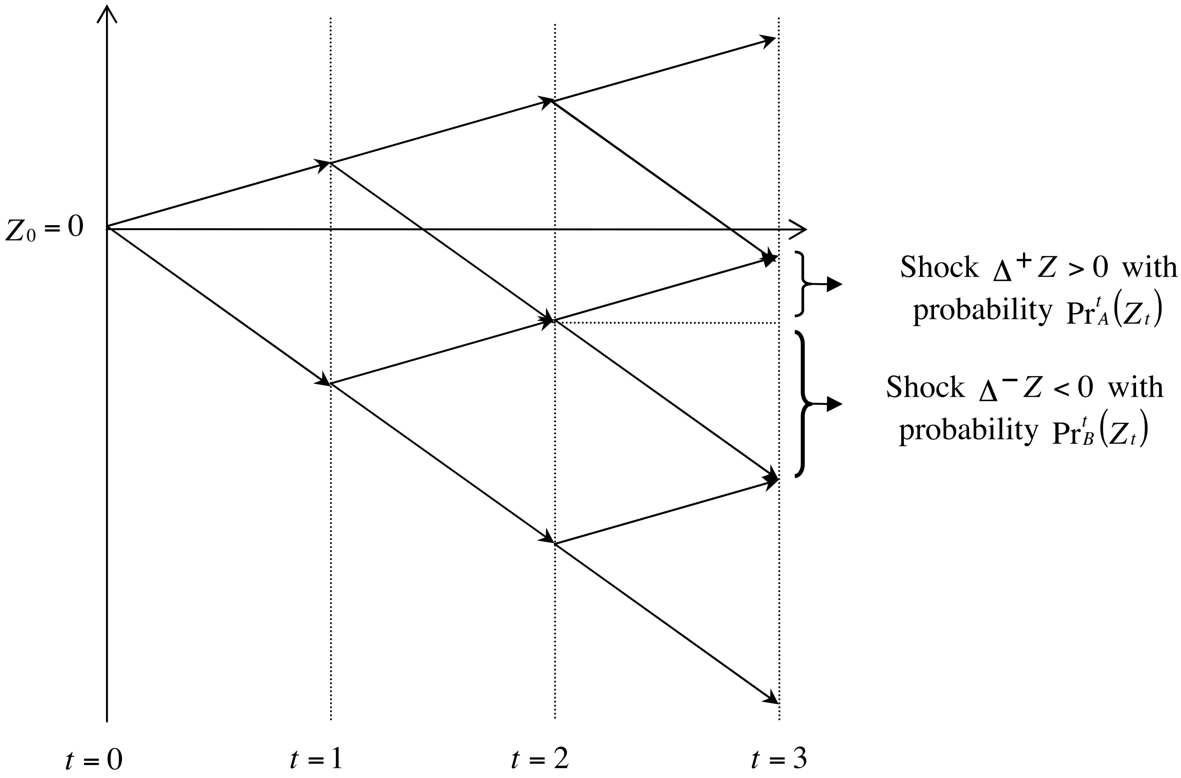


Figure 4

$\Pr_A^{\tau}\left(p_A, p_B\right)$ *as a function of* p_A *and* p_B *for* $\tau = 4$ *months*

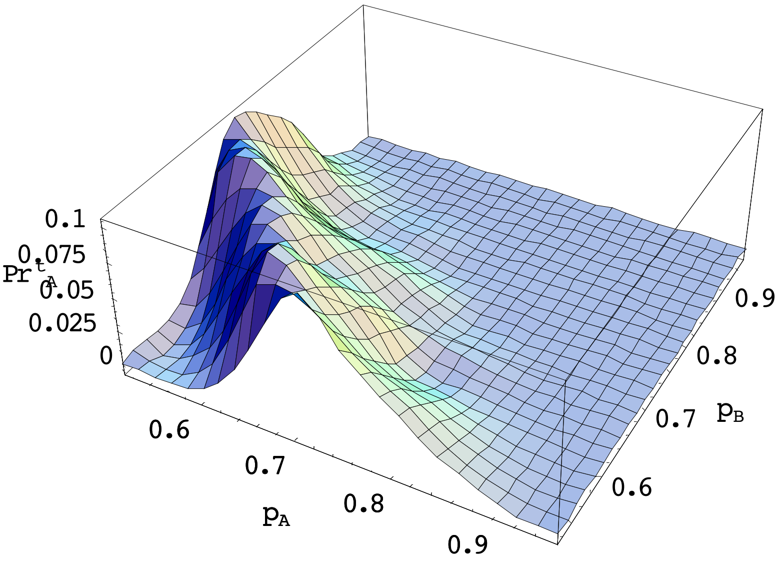
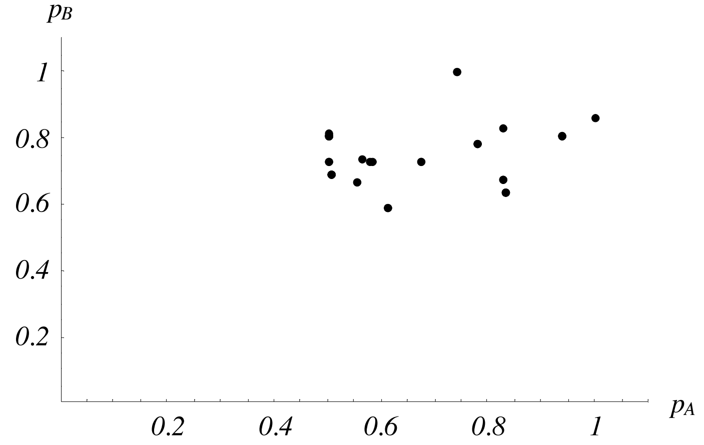


Figure 5

Values of p_A^n and p_B^n that maximise the likelihood of the outcome and duration of each case



nb: several points may overlap, causing the increase of the point size

<u>Table 1</u>: basic statistics

	Cases in which the trademark's holder A wins the trial	Cases in which the trademark's holder A looses the trial	Total
Number of cases	19	24	43
% of cases	44,19%	55,81%	100,00%
Average length (in days)	424,05	374,50	396,40

<u>Table 2</u>: average value (or % of occurrence) of variables

	Cases in which the trademark's holder A wins the trial	Cases in which the trademark's holder A looses the trial	Total
Duration (in days)	424.05	374.50	396.40
Dummy variable equal to 1 if A is an individual, 0 otherwise	11%	8%	9%
Dummy variable equal to 1 if B is an individual, 0 otherwise	11%	38%	26%
Dummy variable equal to 1 if A is a non national but European firm, 0 otherwise	16%	13%	14%
Dummy variable equal to 1 if A is a non national and non European firm, 0 otherwise	16%	33%	26%
Dummy variable equal to 1 if B is a non national but European firm, 0 otherwise	11%	8%	9%
Age of A (in years)	51.00	55.33	53.42
Age of the trademark at stake (in days)	4633.11	3810,08	4173.74
Number of trademarks owned by A	1.00	2.00	1.67
Number of IPC classes of the trademark at stake	1.31	4.00	2.83
Turnover of A (in €)	2310052393	5428370623	4069103702
Turnover of B (in €)	145590551	2519911557	1258553523
Ratio between the turnovers of A and B	140.33	844.26	533.22
Number of employees of A	19691	43468	31989
Number of employees of B	22910	8967	16374
Ratio between the number of employees of A and B	1047.29	2137.65	1655.86

Table 3: Estimation results

	Dependant variable: $\ln\left(p_A^n/1-p_A^n\right)$			Dependant variable: $\ln\left(p_B^n/1-p_B^n\right)$		
	Estimated coefficient	Standard deviation	t-stats	Estimated coefficient	Standard deviation	t-stats
Intercept	-36.1575	27.5855	-1.31074	66.5889	22.395	2.97339
Dummy variable equal to 1 in the case of counterfeit, 0 otherwise	-10.6763	25.541	-0.418007	-43.0756	20.7352	-2.07742
Dummy variable equal to 1 in the case of unfair competition, 0 otherwise	6.7673	28.0539	0.241225	-6.56399	22.7753	-0.288207
Dummy variable equal to 1 in the case of opposition proceedings, 0 otherwise	-5.95635	32.5679	-0.18289	-49.6389	26.4399	-1.87742
Dummy variable equal to 1 in the case of non opposition proceedings, 0 otherwise	-1.58415	24.8928	-0.063639	-47.7328	20.2089	-2.36197
Ratio between the turnovers of A and B	-0.0013032	0.0128355	-0.101531	0.0132844	0.0104203	1.27485
Ratio between the number of employees of A and B	-0.000227936	0.00485648	-0.0469344	-0.00663962	0.00394268	-1.68404
Turnover of A (in €)	$1.6865*10^{-9}$	$2.32818*10^{-9}$	0.724385	$2.26371*10^{-9}$	$1.8901*10^{-9}$	1.19766
Number of employees of A	0.00003499	0.000342695	0.102102	-0.00002921	0.000278213	-0.104994
Dummy variable equal to 1 if A is an individual, 0 otherwise	10.9448	30.8625	0.35463	-18.7929	25.0554	-0.750054
Dummy variable equal to 1 if B is an individual, 0 otherwise	8.42416	23.4283	0.359572	-39.5362	19.02	-2.07866
Age of A (in years)	-0.140833	0.203044	-0.693609	-0.185831	0.164839	-1.12735
Age of the trademark at stake (in days)	0.00248784	0.00131809	1.88745	0.000146655	0.00107008	0.137051
Number of trademarks owned by A	30.0152	16.4751	1.82186	-5.30417	13.3751	-0.39657
Number of IPC classes of the trademark at stake	-0.63943	0.871365	-0.733825	-0.0754425	0.707408	-0.106646
Dummy variable equal to 1 if A is a non national but European firm, 0 otherwise	-19.1528	29.011	-0.660192	33.3268	23.5522	1.41502
Dummy variable equal to 1 if A is a non national and non European firm, 0 otherwise	-13.7042	25.6147	-0.535012	11.7349	20.795	0.564312
Dummy variable equal to 1 if B is a non national but European firm, 0 otherwise	26.5993	35.0667	0.758535	-50.3951	28.4685	-1.77021
R^2		0.290461			0.454189	
Log likelihood		-216.039			-207.075	

Table 4: Elasticities and quasi elasticities

	Of p_A	*Of* p_B	*Of the critical threshold* $1 \Big/ \sum_{\tau=0}^{\infty} \frac{\Pr_A^{\tau}\left(I_A^*, I_B^*\right)}{\left(1+r\right)^{\tau}}$
Dummy variable equal to 1 in the case of counterfeit, 0 otherwise	-0.587404	-0.618774	-0.629246
Dummy variable equal to 1 in the case of opposition proceedings, 0 otherwise	-0.62342	-0.860628	-0.817829
Dummy variable equal to 1 in the case of non opposition proceedings, 0 otherwise	-0.405411	-0.780515	-0.171266
Dummy variable equal to 1 if B is an individual, 0 otherwise	936.403	-0.787143	146.52
Age of the trademark at stake (in days)	0.0278914	0.00173392	0.012258
Number of trademarks owned by A	0.153176	-0.0233048	0.0724923

ARE FIRMS EQUALS IN TERMS OF LEGAL PROTECTION ?

AN ECONOMETRIC INQUIRY INTO THE OUTCOME AND DURATION OF TRADEMARK LITIGATION

Marc Baudry[1] & Béatrice Dumont[2]

ABSTRACT

The economic value of IP rights and the strategic use of IP litigation by competing firms strongly depend on the way IP rights are granted but also enforced by the courts. To illustrate the importance of court decisions in infringement suits, we try to assess whether firms are equals in terms of legal protection and whether some characteristics are more or less influential on the outcome of the trial. To do so, we develop a duration model with two incompatible events (the trademark's holder wins/looses the trial) as outcomes rather than one unique event. Indeed, our purpose is to examine in which context and/or for what type of firm, the legal protection offered by a trademark is the most valuable one. Our findings show that contrary to standard theory, the outcome and duration of the litigation process may be influenced by the characteristics of the parties. We also show that the legal value of a trademark for a plaintiff is strengthened by the importance of its trademark portfolio.

JEL Classification: D73, K41, O34

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I. INTRODUCTION

To have any value or meaning, intellectual property requires a mechanism to force others to do (or stop doing) something and to recover monetary damages for unauthorized use. IP litigation is that mechanism and in today's knowledge economy, it has become one of the primary legal tools available to promote or defend a business[3]. However, little information is available in sufficiently complete form to provide a true picture of litigation. While judicial cases of all types have stimulated a wide array of research aimed at assessing the empirical relevance of the complete and incomplete information models of litigation, IP rights remain somewhat isolated, so that our knowledge of how they are enforced remains tenuous. Such a lack of knowledge is however less and less acceptable. Indeed, from a theoretical standpoint, the costs and uncertainties associated to the solving of a legal conflict could reduce the incentives to innovate (Aoki and Hu, 1999). Moreover, recent studies stress that due to their lack of financial resources and legal experience, small businesses resent with a greater acuity the burden of costs associated to judicial disputes and are therefore reluctant to use the IP system (Cohen and alii, 1997).

Our paper attempts to address this gap in the literature by providing an empirical study of IP enforcement in French courts during the period 1999 to 2004. The main idea is to examine what lies behind IP litigation and more specifically to determine whether the value of legal protection of IP is more beneficial for some firms than others. Indeed, whereas standard economic theory tells us that there is a tendency for plaintiffs to prevail at trial with a probability of 50% (Klein & Priest, 1984), we reconsider this result and test whether the characteristics of the parties have an effect on the outcome and duration of the trial. If it is the case, this would mean that firms are not equal in terms of the legal protection of their IP rights.

Our analysis is directed at a particular type of IP rights, namely the much neglected trademarks[4] disputes. Indeed, despite the importance of court-based enforcement of IP, little is known about how trademark owners actually go about enforcing their registered trademarks in the courts. While there is a growing recognition that companies with a strong brand

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[3] According to trademark laws, the issuance of a trademark does no more than confer a trademark right that is presumed valid in that the final responsability for validity or invalidity of the trademark resides with the courts. This residual uncertainty as to the validity and coverage of trademarks makes disputes inevitable.

[4] A trademark is a word, phrase, slogan, symbol or design which may be used to identify the source of goods or services. It acts like a badge and provides the holder with the exclusive right to use the mark for the holder's goods and services and prevent other persons or businesses from using the same mark for their own goods and services as a means of benefiting from the holder's existing business or goodwill. Trademarks facilitate innovation of new products and quality improvement, and are particularly important for firms when entering new markets.

reputation outperform the market with respect to shareholder return and risk (Madden, Fehle & Fournier, 2002), such enforcement has rarely been the subject of empirical studies. By contrast, there is a burgeoning empirical literature concerning patent litigation and enforcement[5]. This lack of analysis can be explained by the fact that trademark litigation cannot be empirically apprehended in the same fashion as patent disputes. Indeed, trademark data are seldom as available as their patent counterparts. While several proxies can be devised from patent data to assess the value of the patent, trademarks only provide the distinctive sign and the associated industry classes which are far more aggregated than patent technology classes. One of the originality of our paper is to fill this gap. By reading the judgements and thus obtaining detailed information about the nature of the case before the courts, we are able to present a more complex picture of this litigation than existing statistical reports on trademark enforcement.

Another originality of our paper is that we develop a duration model with two incompatible events (the trademark's holder wins/looses) as outcomes rather than one unique event to analyse the outcome and duration of a trial. Indeed, our purpose is to examine in which context and/or for what type of firm the legal protection offered by a trademark is the most valuable one. The idea is to examine the result of the litigation process to see whether some characteristics have more or less influence. At this stage, it is worth recalling that usually two problems emerge from conducting such an analysis. First, univariate analysis usually encompasses many drawbacks: what happens for instance if two variables are of opposite influence[6]? Second, such an analysis usually focuses on the probability to win but not on the benefits or costs of the trial which may be different according to the characteristics of the parties. To better address these two problems, we try to develop a model which deals with the influence of multi-variables on the probability of gains and on the duration of the trial. For this purpose, we build on the analysis of the rational decision to go to trial rather than to settle the case to infer information on the legal value of a trademark measured as the ration between the gain in case of victory and the opportunity cost of going to trial for a trademark owner. We then try to detect which variables influence positively or negatively this ratio.

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[5] Siegelman & Waldfogel (1999) look at the probabilities of victory for the patent holder, the informational context of the conflicts and the level of awarded damages. Lanjouw & Schankerman (2001) examine the characteristics of litigated patents and their owners. Their results underline the importance of firm's size and high-value patent. Crampes & Langinier, 2002 investigate how intensive the monitoring effort of a patentholder should be and how the reaction of the patentholder may influence the entry decision of an alleged infringer. Ziedonis, 2004 trace patterns of patent litigation for US semiconductor firms. Her results show that the high-propensity of small firms to be involved in patent-related lawsuits stems less from the bargaining disadvantages they face due to small patent portfolio and more from the fact that many small firms within the industry are technology specialists for whom exclusionary control over proprietary technology is important. Bessen & Meurer, 2005 address the origin of patent disputes.

[6] Let's say for instance the age of the trademark and the number of trademarks owned by one of the party.

This paper is organized as follows: Part II presents the dataset and some descriptive statistics. Part II also reviews the litigation course in France. Indeed, it is important to understand the specificities of the French litigation system (compared to common-law jurisdiction) as it may impact the set up of our model. Part III introduces the model. We first detail how to infer information on the value of the legal protection from the rational decision of a trademark owner to go to trial rather than to settle. The probabilities to win or loose after a given delay that are required to implement this inference procedure are then obtained as the result of a Bayesian learning process by the judge in charge of the case. In part IV, the estimation method is presented and the estimation results are discussed. We try to determine whether the outcome and duration of trials are influenced by the characteristics of the parties involved and/or the type of litigation at stake. We finally attempt to determine which trademark owners benefit most from the legal protection. Concluding remarks are given in Part V.

II. METHODOLOGY OF THE STUDY

II.1. The data

In order to test the issues at stake and establish the pattern of trademark enforcement actions brought before French courts and their outcome, we constructed a dataset comprising civil trademark enforcement decisions rendered by French courts in relation to registered trademarks for the period 1999 to 2004. This type of information is time-consuming to collect in a rigorous and reliable way in the absence of publicly available databases. Indeed, we had to read every decision reported in the *Annales de la Propriété Intellectuelle*[7] and in *Lexisnexis©* and to record information about those decisions in a custom-built database. This explains the limited number of cases analysed in this study (203 cases in total but a final sample of 43 cases due to a restriction to first instance proceedings). Information on trademark disputes includes basic information about the proceedings, including the type of cases, the people involved (parties, counsel and judges), the characteristics of the trademark (IPC classes assignments, date of registration, number of trademarks, etc), the case length (number of days elapsed between the issue date of the proceedings and the last decision date). These figures are of interest, in part, because the amount of time taken to resolve a case is a proxy for the cost of the proceedings.

While the number and length of cases is of interest to policy-makers, of even more practical interest is the outcome. The value of a registered trademark to its owner lies in its ability to

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[7] One of the drawback of the cases reported in a set of law reports is that the editors of law reports select the case on the grounds of their importance as precedent, a matter not relevant to our aims.

stop rivals from using a substantially identical or deceptively similar trademark. To succeed in an action for trademark infringement, a trademark owner must establish that he does have a registered trademark (and if challenged, that the trademark registration is valid) and that the alleged infringer must have engaged in conduct amounting to infringement. For this reason, we collected data on the outcome of each decision ("outcome data") recording the outcome on infringement and validity, unfair competition, opposition proceedings[8] and non-opposition proceedings of each trademark in dispute. This distinction is important as there are several kinds of trademark disputes here the stakes and the issues of which are different. For each trademark enforcement decision we have also recorded, where applicable, the grounds on which a trademark owner failed, such as the non infringement grounds (i.e. the trademark was not used as a trademark or was not substantially identical or deceptively similar to the registered mark). Data in terms of awarded damages, number and cost of publication and ancillary sanctions were also collected. Finally, to complete our dataset, we have extracted from the *Datastream, Hoovers and Kompass* databases data on firms' characteristics (nationality, sector, date of creation, number of employees, turnover). While the dataset explored in this article presents several limitations[9], it allows us nevertheless to cast a look at trademark disputes.

II.2. Some Descriptive Statistics

Tables 1 and 2 provide some descriptive statistics on the trademark litigation course in France.

Insert Table 1

As stressed in Table 1, out of a total of 43 cases, the trademark's holder A is only successful in 44,19% of the cases (thus below the probability of 50% found by Klein & Priest, 1994). The average length of the first instance proceeding is of 424.05 days in case of victory for A and of 374.05 days when A is unsuccessful in proving validity/infringement.

Insert Table 2

Table 2 gives us the average value of the different variables. It allows us to give some insights on which characteristics presumably make it easier or not for A to win the litigation process.

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[8] A registered trademark owner who becomes aware of an application for registration of a mark that will be, as they perceive it, too close to their own, may oppose registration of that mark, thus heading off at an early stage a dispute that might otherwise become a fully-fledged infringement suit. Such opposition proceedings are an important means by which trademark owners enforce their rights.

[9] There is no doubt that the cases that make it all the way to judgement are not a representative sample of all trademark disputes.

Interestingly, our descriptive statistics show that the proportion of trademark's holder A that are individuals rather than firms is higher in the subset of cases where A is successful (11%) compared with the subset of cases where A is unsuccessful (8%). Accordingly, being an individual rather than a firm seems to act in favour of A. In the same way, being an individual rather than a firm seems to act in favour of B. Regarding the nationality of the parties, non national and non European trademark's owners are clearly more often encountered in the subset of cases where A is unsuccessful. This result stresses the existence of a possible national bias. The cases where A has won are cases where the trademark(s) at stake are the oldest in average. However, cases where A lost are those where the trademark covers many classes. Finally, it turns out that the less favourable configuration for the trademark's holder is when both the turnover of A and B are large. In the same ways, cases where A looses are those where A has a larger size (as measured by the number of employees) than B.

As previously underlined, one of the main drawbacks with such an univariate analysis is that it disregards the joint effects of variables. Obviously, before inferring any conclusive remarks, it is necessary to get more robust statistical results and therefore to develop an econometric test. To do so, we need to model the duration and outcome of the litigation process. But first, it is important to understand the specificities of the litigation course in France which may impact the set up of our model.

II.3. The litigation course

It is perhaps commonplace to suggest that civil litigation in France is very different from litigation in common-law jurisdictions[10]. For example, to commence proceedings[11], the plaintiff must serve summons on the opposing party (the defendant). The plaintiff has to register the summons before the Court office. The claims have to be initiated within a short time (6 months) and should seem to be serious. The parties then exchange pleadings (there is no limitation in the number of written pleadings exchanged) and exhibits (including expert reports) under the control of a judge in charge of case management. An oral hearing takes place before the court issues its decision. However, it should be noted that the oral advocacy part of proceedings carries far less weight than in common-law jurisdictions and the matter is decided principally on the basis of the exchange(s) of written submissions prior to the trial. Compared say to the USA, there are no juries at Civil hearings. The judge managing the case controls the instruction of the procedure but the timetable is rather flexible. The pleadings are systematic. For all comparative intents and purposes, cross-examination of witnesses does not

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[10] *Cf.* Figure 1 for a summary.

[11] The imitated firm proceed to a full trial. We do not examine out of court agreements.

exist either. The time taken for a matter to come to trial, i.e. with effect from the service of the writ or claim form, often depends on the geographical location within France (it is observable that the delays in many matters are often longest in the southern part of the country). However, it would not be unusual in most of France for a period of between 16 and 22 months to elapse between the service of the writ and the trial at First Instance. Finally, large scale punitive damages are never awarded, and what is more, class-actions do not exist.

In infringement cases[12], the first instance judgment usually decides only the validity and the infringement issues. Infringement can be proven by any means. The search and seizure ("*saisie-contrefaçon*") is the usual preliminary of nearly all infringement cases in France and an efficient measure to prove infringement. A search and seizure may be performed upon authorization of the Presiding judge of the local court, obtained *ex parte*. With this Court order, the bailiff can enter into the premises of any person which detains evidence of the infringement and, to perform the authorized investigations, he can be accompanied by any person(s) skilled in the art chosen by the patentee.

The appeal suspends the enforcement of the first instance judgment except for provisional measures and unless otherwise decided. It consists in a full re-hearing of the case as to the facts and the points of law. There is a possibility of bringing additional exhibits. The Court of Appeal decides *de novo*. The Paris Court of appeal also rules on a very specific type of litigation: appeals brought against decisions of the director of the French Industrial Property Institute (INPI). The appeal before the Supreme Court ("*Cour de Cassation*") consists in a review of the judgement of the Court of Appeal and is limited to the points of law only.

Insert Figure 1

III. THE MODEL

III.1. Inferring information from the decision to go to trial

Following a well known strand of literature, we assume that the decision to go to trial rather than to settle is the outcome of a rational trade-off made by the plaintiff A between the

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[12] In legal terms, counterfeit trademark goods are defined in TRIPs as having two key features : the infringer uses an identical mark to the registered trade mark and the infringer uses the mark in relation to the same goods as those for which the trademark is registered. To win an infringement suit, a trademark owner must show there is a likelihood of mistake, confusion, or consumer deception by the defendant's use of the similar mark. The basic questions in a trademark infringement action tend to turn largely on issues of facts. The key factors are whether the marks are confusingly similar, and whether they are used on the same or "related" goods. This includes goods or services into which the trademark holder's business is reasonably likely to expand.

associated expected gains and losses. More precisely, we assume that the current situation, or *status quo* situation, corresponds to a duopoly since the trademark of the plaintiff A is counterfeited by the defendant B. If A wins the trial, his benefit compared to the *status quo* situation amounts to the sum of two terms. The first term is the discounted sum of the difference between monopoly and duopoly profit flows from the end of the trial onwards. If the current date is the date of end of the trial, this term is given by

$$B_A = \sum_{t=0}^{\infty} \frac{\pi_M - \pi_D}{(1+r)^t} \quad \text{or} \quad (\pi_M - \pi_D)\frac{r}{1+r} \tag{1}$$

where π_M and π_D respectively denote the monopoly and duopoly profit flows. r is the interest rate[13]. The second term is associated with the reimbursement of the discounted sum of the same difference between monopoly and duopoly profits flows from the date T where B started to counterfeit A's trademark to the date where the trial ends. It is given by the following damage expression:

$$D = \sum_{t=-T}^{0} \frac{\pi_M - \pi_D}{(1+r)^t} \quad \text{or} \quad B_A \frac{(1+r)^{T+1} - 1}{1+r} \tag{2}$$

If the trademark's holder A decides to go to trial, A's objective is to maximise his expected gain with respect to an initial investment I_A that influences the duration and outcome of the trial due for instance to the more or less good reputation of the attorney he chooses. To keep things simple, we assume that this investment is only incurred at the beginning of the trial. The objective of A may then be described by the following maximisation program

$$\underset{I_A}{Max} \left\{ \sum_{\tau=0}^{\infty} \Pr_A^{\tau}(I_A, I_B) \frac{B_A(1+\delta)}{(1+r)^{\tau}} - I_A \right\} \tag{3}$$

where δ denotes the coefficient of B_A in (2). τ stands for the date at which the lawsuit is resolved in favour of A. The probability that A wins at date τ is denoted by $\Pr_A^{\tau}(I_A, I_B)$ and is influenced not only by the investment I_A made by A but also by the investment I_B made by the defendant B.

If the verdict goes against the defendant, the cost of a trial for B compared to the *status quo* is the sum of two terms. The first term is associated with the reimbursement of the

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[13] Note that we assume that A's trademark will not be counterfeited again. Actually, introducing the possibility of new counterfeits as the outcome of an exogenous random Poisson process would just result in an increase of the relevant discount factor.

difference between monopoly and duopoly profit flows to the plaintiff. This term is given by the damage expression (2). The second term is associated with the loss of the duopoly profit flow from the end of the trial onwards compared to the *status quo*. This second term reads as

$$C_B = \sum_{t=0}^{\infty} \frac{\pi_D}{(1+r)^t} \quad \text{or} \quad \pi_D \frac{r}{1+r} \tag{4}$$

The objective of the defendant B is to minimise his expected total cost of the trial with respect to his own investment I_B that influences the duration and outcome of the trial. The corresponding minimisation programme is

$$\underset{I_B}{Min} \left\{ \sum_{\tau=0}^{\infty} \Pr_A^{\tau}(I_A, I_B) \frac{B_A \delta + \pi_D r/(1+r)}{(1+r)^{\tau}} - I_B \right\} \tag{5}$$

The solutions $\hat{I}_A(I_B)$ and $\hat{I}_B(I_A)$ to (3) and (5) define the reaction functions characterising the strategic choice of investment amounts. Let I_A^* and I_B^* be the associated Nash equilibrium. The plaintiff A prefers to go to trial if his objective function in (3) evaluated at I_A^* and I_B^* exceeds his expected gain S_A from settlement. Rearranging this condition, we obtain that A goes to trial if

$$\frac{B_A(1+\delta)}{S_A + I_A^*} \geq \frac{1}{\sum_{\tau=0}^{\infty} \frac{\Pr_A^{\tau}(I_A^*, I_B^*)}{(1+r)^{\tau}}} \tag{6}$$

The left hand side of (6) may be thought of as an index of return from trial if the verdict goes in favour of the plaintiff. Indeed it yields the ratio between the gross gain from the trial if A wins and the cost of the trial which is given by the sum of the direct cost I_A^* and the opportunity cost that amounts to the expected gain S_A from settlement. The right hand side of (6) yields the multiplicative coefficient for the transition from the gain if A wins (the numerator in the left hand side) to the expected gain whatever the outcome of the trial. As already outlined by Choi (1998) for instance, some information is revealed by the condition (6). Indeed, whereas we are generally not able to obtain data on the elements of the left hand side of (6), we are able to estimate the elements of the right hand side from data on the duration and outcome of trials. Assuming an *ex ante* distribution function for the left hand side, we can derive the *ex post* distribution from an estimate of the right hand side. This is illustrated by Figure 2 where the grey area distinguishes the part of the *ex ante* distribution function that is no more relevant according to condition (6). Moreover, if the right hand side is estimated as both a function of the characteristics of the plaintiff and defendant and the characteristics of the case and/or of the trademark at stake, then we are able to determine for which trademark owners the value of the legal protection is the highest compared with its cost. Assume for instance that one of the characteristics positively influence the value of the threshold. Then the grey area in Figure 2 expands to the right so that the expected value of the left hand side (6) increases. This means that plaintiffs with a high value of this characteristic have a higher rate of return from legal suits.

Insert Figure 2

II.2. Trial as a duration model

In order to infer information from the decision to go to trial as described above, an estimate of the probability that the lawsuit is resolved in favour of the plaintiff at each given date τ is required. For this purpose, we analyse the length of a trial as a duration model, the main feature of which is that the end of the process depends on the realisation of one of two events rather than a sole event. Our point of departure for this duration model is a complete information framework. In such a context, the judge in charge of the case immediately knows whether the plaintiff A is in his right or, conversely, if the defendant B is in his right so that the duration of the trial is infinitely close to zero. Let W_A denotes the scenario where the verdict goes in favour of A and W_B denotes the scenario where the verdict goes against A and thus in favour of B. To deal with a more realistic approach where the trial lasts for a non infinitesimal period, we turn to an incomplete information framework. More precisely, we consider a discrete time framework and assume that between two consecutive dates the judge receives one information. Information consists on a message which may be of two types. It may be either a message of type M_A in favour of A or a message of type M_B in favour of B. Moreover, both types of messages are noisy. This means that between two consecutive dates a message M_A is received with probability $p_A > 1/2$ if the scenario W_A is the correct one in the complete information framework and with probability $1 - p_B < 1/2$ otherwise and, conversely, a message M_B is received with probability $p_B > 1/2$ if the scenario W_B is the correct one in the complete information framework and with probability $1 - p_A < 1/2$ otherwise. The conditional probabilities of the two types of messages are then as follows

$$\begin{pmatrix} \Pr[M_A/W_A] & \Pr[M_A/W_B] \\ \Pr[M_B/W_A] & \Pr[M_B/W_B] \end{pmatrix} = \begin{pmatrix} p_A & 1 - p_B \\ 1 - p_A & p_B \end{pmatrix} \tag{7}$$

We are not interested as such in the probabilities of the two types of messages but rather in the probabilities of the two scenarios. With this aim in view, we denote by X_t the subjective probability associated with scenario W_A for the judge at time t. This probability describes the beliefs of the judge on the true scenario. The judge puts an end to the suit as soon as X_t takes a value outside the interval $]1-\overline{X}, \overline{X}[$ where $\overline{X}$ is an exogenously given threshold. The judge gives a verdict in favour of the plaintiff A if X_t exceeds the threshold $\overline{X}$ and, conversely, gives a verdict against A if X_t is lower than $1-\overline{X}$. The threshold value is exogenously determined and measures the degree of certainty required to end a trial. The higher $\overline{X}$, the higher the degree of certainty required. When starting a trial, the judge has no *a priori* on the true scenario so that $X_0 = 1/2$. The belief of the judge, and thus the value of X_t, changes from date to date due to the arrival of new noisy messages of type M_A or M_B. In order to obtain the new probability X_{t+1} given X_t we use Bayes' rule to compute the probabilities of the two scenarios conditionally on the type of message received between t and $t+1$ and the value of X_t:

$$\begin{pmatrix} \Pr[W_A/M_A] & \Pr[W_A/M_B] \\ \Pr[W_B/M_A] & \Pr[W_B/M_B] \end{pmatrix} = \begin{pmatrix} \dfrac{p_A X_t}{\Pr_A^t} & \dfrac{(1-p_A) X_t}{\Pr_B^t} \\ \dfrac{(1-p_B)(1-X_t)}{\Pr_A^t} & \dfrac{p_B (1-X_t)}{\Pr_B^t} \end{pmatrix} \tag{8.a}$$

with

$$\Pr_A^t = p_A X_t + (1-p_B)(1-X_t) \tag{8.b}$$
$$\Pr_B^t = (1-p_B) X_t + p_A (1-X_t) \tag{8.c}$$

as the unconditional probabilities of receiving respectively a message of type M_A or M_B. The first line in (8.a) yields the new subjective probability X_{t+1} associated with scenario W_A if a message M_A is received between t and $t+1$ (first column) or if a message M_B is received between t and $t+1$ (second column). The second line in (8.a) yields the corresponding values for $1-X_{t+1}$.

From a computational point of view, it is more convenient to use the process Z_t defined by

$$Z_t = \ln\left(\frac{X_t}{1-X_t}\right) \quad \Leftrightarrow \quad X_t = \frac{\exp(Z_t)}{1+\exp(Z_t)} \tag{9}$$

Indeed, the stochastic process Z_t corresponding to the natural logarithm of the likelihood ratio of the two scenarios evolves according to the relatively simple following rule:

$$Z_t = \begin{cases} \Delta^{+}Z & \text{with probability} \quad \mathrm{Pr}_A^t\left(Z_t\right) \\ \Delta^{-}Z & \text{with probability} \quad \mathrm{Pr}_B^t\left(Z_t\right) \end{cases} \tag{10.a}$$

with

$$\Delta^{+}Z = \ln\left(p_A/1 - p_B\right) > 0 \tag{10.b}$$

$$\Delta^{-}Z = -\ln\left(p_B/1 - p_A\right) < 0 \tag{10.c}$$

and where the probabilities $\mathrm{Pr}_A^t\left(Z_t\right)$ and $\mathrm{Pr}_A^t\left(Z_t\right)$ are obtained by substituting the expression of X_t as a function of Z_t given in (9) in (8.b) and (8.c). The magnitudes of the positive and negative shocks differ from each other and only depend on the two probabilities p_A and p_B. The probabilities of these shocks correspond to the unconditional probabilities of the receipt of a message M_A and a message M_B and depend on p_A and p_B but also on the current value of Z_t. The process Z_t starts at the initial value $Z_0 = 0$ and increases with X_t for $X_t \in [0, 1]$. Therefore, the law suit ends in favour of the plaintiff A as soon as Z_t exceeds $\overline{Z} = \ln\left(\overline{X}/1 - \overline{X}\right) > 0$ or in favour of the defendant B as soon as Z_t lies behind $-\overline{Z} < 0$. The main interest of the process Z_t is that it may be illustrated by the tree form in Figure 3 where the horizontal axis is associated with time while the vertical axis is associated with the value of the process.

Insert Figure 3

Accordingly, the process Z_t has $t+1$ possible values at time t which are referred to as $Z_t^i = i\,\Delta^{+}Z + (t-i)\Delta^{-}Z$ with $i \in \{0, \cdots, t\}$. Thus Z_t^i exceeds $\overline{Z}$ if and only if $i > \left(\overline{Z} - t\,\Delta^{-}Z\right)/\left(\Delta^{+}Z - \Delta^{-}Z\right)$. Conversely, Z_t^i lies behind $-\overline{Z}$ if and only if $i < \left(-\overline{Z} - t\,\Delta^{-}Z\right)/\left(\Delta^{+}Z - \Delta^{-}Z\right)$. Let $\Theta(Z)$ be the dummy variable defined by

$$\Theta(Z) = \begin{cases} 1 & \text{if} \quad Z \in \left[-\overline{Z}, \overline{Z}\right] \\ 0 & \text{if} \quad Z \notin \left[-\overline{Z}, \overline{Z}\right] \end{cases} \tag{11}$$

The probability $\overline{\mathrm{Pr}}_\tau\left[Z_\tau^i\right]$ that the process Z_t takes the value Z_τ^i at time τ knowing that it has never taken values outside the range $\left[-\overline{Z}, \overline{Z}\right]$ before τ is given by

$$\overline{\mathrm{Pr}}_\tau\left[Z_\tau^i\right] = \begin{cases} P^{-}\left[Z_\tau^i + \Delta^{+}Z\right] & \text{if} \quad i = \tau \\ P^{-}\left[Z_\tau^i + \Delta^{+}Z\right] + P^{+}\left[Z_\tau^i + \Delta^{-}Z\right] & \text{if} \quad i \in \{1, \cdots, \tau - 1\} \\ P^{+}\left[Z_\tau^i + \Delta^{-}Z\right] & \text{if} \quad i = 0 \end{cases} \tag{12.a}$$

with

$$P^{+}\left[Z_{\tau}^{i}+\Delta^{-}Z\right]= \Theta\left(Z_{\tau}^{i}+\Delta^{+}Z\right)\overline{\Pr}_{\tau-1}\left[Z_{\tau}^{i}+\Delta^{+}Z\right]\Pr_{B}^{\tau-1}\left[Z_{\tau}^{i}+\Delta^{+}Z\right] \tag{12.b}$$

$$P^{-}\left[Z_{\tau}^{i}+\Delta^{+}Z\right]= \Theta\left(Z_{\tau}^{i}+\Delta^{-}Z\right)\overline{\Pr}_{\tau-1}\left[Z_{\tau}^{i}+\Delta^{-}Z\right]\Pr_{A}^{\tau-1}\left[Z_{\tau}^{i}+\Delta^{-}Z\right] \tag{12.c}$$

Indeed, if $i \in \{1,\cdots,\tau-1\}$ the process Z_t may reach the value Z_{τ}^{i} at time τ following either a negative shock from the value $Z_{\tau}^{i}+\Delta^{+}Z$ (with probability $P^{+}\left[Z_{\tau}^{i}+\Delta^{-}Z\right]$) at time $\tau-1$ or a positive shock from the value $Z_{\tau}^{i}+\Delta^{-}Z$ (with probability $P^{-}\left[Z_{\tau}^{i}+\Delta^{+}Z\right]$) at time $\tau-1$. If $i=0$, the process Z_t may only reach the value Z_{τ}^{i} at time τ following a negative shock from the value $Z_{\tau}^{i}+\Delta^{+}Z$ (with probability $P^{+}\left[Z_{\tau}^{i}+\Delta^{-}Z\right]$) at time $\tau-1$. Conversely, if $i=\tau$ the process Z_t may only reach the value Z_{τ}^{i} at time τ following a positive shock from the value $Z_{\tau}^{i}+\Delta^{-}Z$ (with probability $P^{-}\left[Z_{\tau}^{i}+\Delta^{+}Z\right]$) at time $\tau-1$. Accordingly, the probability $\Pr_{A}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)$ used in condition (6) for the plaintiff to prefer to go to trial rather than to settle is computed as

$$\Pr_{A}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)=\begin{cases} 0 & \text{if} \quad \tau < \overline{Z}/\Delta^{+}Z \\ \sum\limits_{i=I}^{\tau}\overline{\Pr}_{\tau}\left[Z_{\tau}^{i}\right] & \text{if} \quad \tau \geq \overline{Z}/\Delta^{+}Z \end{cases} \tag{13.a}$$

with I the lower integer value above $\left(\overline{Z}-\tau\Delta^{-}Z\right)/\left(\Delta^{+}Z-\Delta^{-}Z\right)$. Similarly, the probability $\Pr_{B}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)$ that the defendant wins the trial at time τ is computed as

$$\Pr_{B}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)=\begin{cases} 0 & \text{if} \quad \tau < -\overline{Z}/\Delta^{-}Z \\ \sum\limits_{i=0}^{J}\overline{\Pr}_{\tau}\left[Z_{\tau}^{i}\right] & \text{if} \quad \tau \geq \overline{Z}/\Delta^{+}Z \end{cases} \tag{13.b}$$

with J the higher integer value behind $\left(-\overline{Z}-\tau\Delta^{-}Z\right)/\left(\Delta^{+}Z-\Delta^{-}Z\right)$. These two last expressions serve as a basis for the estimation of the duration model.

IV. ESTIMATION METHOD AND RESULTS

IV.1. Estimation method

Prior to describing the estimation method, note that a key feature of the process Z_t is that it only depends on two parameters, namely p_A and p_B. However, it is assumed that the plaintiff and the defendant may at least partly influence the duration and outcome of the trial and, thus, the probabilities $\Pr_{A}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)$ and $\Pr_{B}^{\tau}\left(I_{A}^{*}, I_{B}^{*}\right)$. In order to take into account this assumption, we thus have to assume that the two parameters p_A and p_B are themselves influenced by I_{A}^{*} and I_{B}^{*}. This means that each protagonist is able to make messages in his favour less noisy and messages in favour of the other protagonist more noisy. Finally, since we do not directly observe the investments made by the two protagonists, we suppose that they are functions on the one hand of both observed characteristics of the plaintiff and defendant and characteristics of the case and/or the trademark at stakes and, on the other hand, of some unobserved factors intrinsic to each case. Since p_A and p_B are probabilities, we use a logistic functional form to make sure that they take values inside the range $[0, 1]$. Hence, for each case $n \in \{1, \cdots, N\}$ we have

$$p_A^n = \exp\left(\sum_{k=1}^{K} \alpha_k\, v_k^n + \varepsilon_A^n\right) \Big/ 1 + \exp\left(\sum_{k=1}^{K} \alpha_k\, v_k^n + \varepsilon_A^n\right) \tag{14.a}$$

$$p_B^n = \exp\left(\sum_{k=1}^{K} \beta_k\, v_k^n + \varepsilon_B^n\right) \Big/ 1 + \exp\left(\sum_{k=1}^{K} \beta_k\, v_k^n + \varepsilon_B^n\right) \tag{14.b}$$

where v_n^k ($k \in \{1, \cdots, K\}$) are variables measuring one of the K characteristics of protagonists or of the case, α_k and β_k ($k \in \{1, \cdots, K\}$) are real parameters to be estimated. $\{\varepsilon_A^n, \varepsilon_B^n\}$ is a two dimensional random vector with a null expected value and a variance covariance matrix given by

$$\Omega_{AB} = \sigma_A^2 \begin{pmatrix} 1 & \rho\,\gamma \\ \rho\,\gamma & \gamma^2 \end{pmatrix} \tag{14.c}$$

where ρ and γ respectively stand for the coefficient of linear correlation between ε_A^n and ε_B^n and the ratio (σ_B / σ_A) between the standard deviations of the two random terms. ε_A^n and ε_B^n typically capture the influence of unobserved factors that are specific and/or common to each equation. Specific factors may correspond to unobserved characteristics of the parties while common factors may results from unobserved characteristics of the case. ρ measures how much common to the two equations (14.a) and (14.b) are the unobserved factors. For estimation purposes, expression (14.a) and (14.b) are rearranged as

$$\ln\left(p_A^n / 1 - p_A^n\right) = \sum_{k=1}^{K} \alpha_k\, v_k^n + \varepsilon_A^n \tag{15.a}$$

$$\ln\left(p_B^n / 1 - p_B^n\right) = \sum_{k=1}^{K} \beta_k\, v_k^n + \varepsilon_B^n \tag{15.b}$$

The parameters α_k and β_k ($k \in \{1, \cdots, K\}$) in equations (15.a) and (15.b) may be estimated by a maximum likelihood method for given values of ρ and γ. This concentrated likelihood is then computed for each element in a grid of values for ρ and γ. The estimated values of these two parameters are finally obtained as the combination in the grid that maximises the concentrated likelihood. A crucial step prior to this estimation is to obtain values for p_A^n and p_B^n and thus for the dependant variables. For this purpose, note that the likelihood of the outcome and duration of case n is

$$L_n = \prod_{\tau=0}^{\infty}\left(\Pr_A^{\tau}\left(p_A^n, p_B^n\right)^{w_A^n}\Pr_B^{\tau}\left(p_A^n, p_B^n\right)^{1-w_A^n}\right)^{w_\tau^n} \tag{16}$$

where w_A^n is a dummy variable taking value 1 if the verdict is in favour of A and value 0 if B wins the trial while w_τ^n is a dummy variable taking value 1 is the trial ends at date τ and value 0 otherwise. The two values used for p_A^n and p_B^n in (15.a) and (15.b) are those that maximise the likelihood (16). Since we do not have an analytical expression of the probabilities $\Pr_A^{\tau}\left(p_A, p_B\right)$ and $\Pr_B^{\tau}\left(p_A, p_B\right)$, this maximisation is based on numerical methods. More precisely, the probabilities $\Pr_A^{\tau}\left(p_A, p_B\right)$ and $\Pr_B^{\tau}\left(p_A, p_B\right)$ have first been computed for each element $\{p_A, p_B\}$ of a grid a values generated for p_A and p_B taking values from 0.5 to 1 with a step equal to 0.05. We then used the *ListInterpolation* instruction on *Mathematica® 5* to obtain $\Pr_A^{\tau}\left(p_A, p_B\right)$ and $\Pr_B^{\tau}\left(p_A, p_B\right)$ as functions of p_A and p_B. Note that in order to make these two expressions relatively smooth functions of p_A and p_B we have assumed that the basic time period separating two dates in the duration model was one month but we have divided this period on a daily basis so that 30 messages of type M_A or M_B are received on each time period. Figure 4 displays the resulting graphic of $\Pr_A^{\tau}\left(p_A, p_B\right)$ as a function of p_A and p_B for $\tau = 4$ months.

Insert Figure 4

IV.2. Estimation results

The estimation method described above has been implemented to the dataset introduced in part II. The values of p_A^n and p_B^n that maximise the likelihood of the outcome and duration of each case in the database are reported on Figure 5. The mean of p_A^n amounts to 0.648919 and its standard deviation is equal to 0.160028 while the corresponding values for p_B^n are respectively 0.752394 and 0.0896362. Thus, the trials considered in our database are generally characterised by messages in favour of the plaintiff that are noisier than those in favour of the defendant. Although Figure 5 exhibits a slightly upward linear relation between p_A^n and p_B^n, their correlation coefficient only amounts to 0.0489139.

Insert Figure 5

The estimation results for equations (15.a) and (15.b) are reported in Table 3. The grid of values used to estimate ρ and γ is the grid obtained by assuming that ρ and γ respectively take values between -1 and 1 and $0.1\,\sigma_B^{OLS}/\sigma_A^{OLS}$ and $10\,\sigma_B^{OLS}/\sigma_A^{OLS}$ where σ_A^{OLS} and σ_B^{OLS} are the standard deviations obtained when estimating equations (15.a) and (15.b) separately by an ordinary least square method. Estimation results show that the correlation between the random terms of equations (15.a) and (15.b) is not statistically significant. Indeed, the value of the Chi square statistic for a likelihood ratio test of the restriction $\rho = 0$ is clearly less that the critical thresholds at any conventional significance level. As a result, estimation results for all the other parameters are almost identical to those obtained with a separate estimation of the two equations by ordinary least squares. A possible explanation is that unobserved characteristics of the two parties and/or of the case either affect the value of p_A or the value of p_B but do not have a simultaneous influence on p_A and p_B.

A striking result in Table 3 is that p_B is better explained by observed variables than p_A. This means that the strategic investments made by the two protagonists are intended to affect (increase for A and reduce for B) the noise on messages in favour of the defendant rather than to affect the noise on messages in favour of the plaintiff. Indeed, almost half of the variance of the dependent variable in equation (15.b) is explained by the model whereas this part is slightly inferior to one third for equation (15.a). This results also stresses the role of unobserved intrinsic characteristics of the cases to determine the value of p_A. Another striking result is that the variables that significantly affect the value of p_A differ from those that significantly affect the value of p_B. This in line with the absence of a significant correlation between the unobserved factors affecting p_A and p_B. As regards p_B, there is a significant and negative impact of the fact that the case is a case of counterfeit, of opposition proceedings or of non opposition proceedings rather than a case of unfair competition[14]. Accordingly messages in favour of the defendant are less noisy for the first three types of cases compared with the last type. p_B is also significantly and negatively affected by the fact that the defendant B is an individual rather than a firm and by the fact that B has an extra-European nationality. Finally, the bigger A in terms of employees compared to B, the noisier the messages in favour of B. By contrast, the only two variables that have a significant and positive impact on p_A are the age of the trademark at stake and the number of trademarks owned by the plaintiff. The higher these two variables, the less noisy are the messages in favour of the plaintiff. Otherwise stated, it seems that it is *ceteris paribus* easier for a trademark owner to present his arguments to the judge if his trademark is an old one and if he possesses a large trademark portfolio. In this sense, we are able to conclude that the legal value of a trademark for a plaintiff is strengthened by the importance of its trademark portfolio (number of trademarks and age of the trademark at stake). However, the results displayed in Table 4 partly confirm these conclusions.

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[14] The sum of the corresponding dummy variables does not yield 1 because a same case may be coded with 1 for several of the dummies (for instance for unfair competition and counterfeit)

Table 4 displays the estimation results for elasticity or quasi elasticity (evaluated at the sample mean) of the threshold on the right hand side of (6) with respect to the explanatory variables used in equations (15.a) and (15.b)[15]. Since these elasticities and quasi elasticities are highly non linear functions of the estimated parameters α_k and β_k ($k \in \{1, \cdots, K\}$), their estimates have been computed by using a Monte Carlo simulation method with 5000 random draws for the vector of α_k and β_k. The resulting distributions of elasticities and quasi elasticities generally exhibit a strong asymmetry, thus leading to high values of their standard deviation distribution and complicating the interpretation[16]. As a result, the focus is made on those elasticities or quasi elasticities with respect to variables that have a significant impact in Table 3. The significant and negative impact on p_B of the fact that the case is a case of counterfeit, of opposition proceedings or of non opposition proceedings outlined in Table 3 plays in favour of A and logically induces a positive expected quasi elasticity of the threshold in (6) with respect to the corresponding variables. Table 4 also highlights that an increase by one percent of the age of the trademark induces a rise of 0.023% of the threshold in the right hand of conditions (6). Similarly, an increase of one percent of the number of trademarks in the portfolio of the plaintiff results in an increase by 0.34% of the critical threshold. These two results are in line with the positive impact on p_A already detected in Table 3. The age and importance of the trademark portfolio thus implies an increase of the rate of return expected from going to trial for an infringed trademark owner. The impact of the ratio between the number of employees of the two parties is more ambiguous. Indeed the estimated elasticity is close to zero with a high value of the standard deviation and a distribution that does not seem to clearly range on one side or the other with respect to zero. There is also an ambiguous result as regards the fact that B is an individual and the fact that B has an extra-European nationality since the associated quasi elasticity exhibits a positive expected value but most of the distribution lies on the negative side.

Insert Table 3

Insert Table 4

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[15] A quasi elasticity measures the variation of the threshold (in percent) that results *ceteris paribus* from setting a dummy variable at 1 rather than 0.

[16] The student statistics is no longer relevant to assess whether the estimates are significantly different from zero. It also appears that the expected value of the elasticity or quasi elasticity may be negative whereas more than half of the distribution is associated with a positive value and conversely.

V. CONCLUDING REMARKS

It is now well known for firms that along with intellectual property reward comes IP risk. Indeed, if IP are an opportunity for firms to boost their bottom lines, they also constitute an exposure for firms that may face an IP litigation suit and have to pay high damage awards or worst may have their IP rights be declared invalid. This explains, in part, why many SMEs are willing to subscribe an insurance against loss due to infringement of their IP rights[17]. This also explain why both the European Commission and Member States have recently introduced measures intended to improve and step up the fight against counterfeiting but have also strengthen the means of enforcing IPRs rights[18]. However, our paper suggests that the judicial system may not be so neutral as supposed. Indeed, contrary to standard theory, we show that in France the outcome and duration of the litigation process may be influenced by the characteristics of the parties. We also show that the devise of a trademark portfolio strategy strengthens the legal value of each peculiar trademark. Indeed, the return on the legal protection as defined by the ratio between the gain in case of trial victory and the opportunity cost of the trial increases with the importance of the trademark portfolio. In other words, if firms want to avoid the expense, inconvenience and confusion that occur from the fact that a trademark right is only “presumed” to be valid, they should recognize that a comprehensive, well-crafted and cost-effective trademark portfolio can be of substantial value and is likely to reward them with positive returns for years to come.

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[17] *Cf.* the study for the European Commission (January 2003), Patent litigation insurance : the possible insurance schemes against patent litigation risks.

[18] *Cf.* Directive 2004/48/EC of the European Parliament and of the Council of 29 April 2004 on the enforcement of intellectual property rights.

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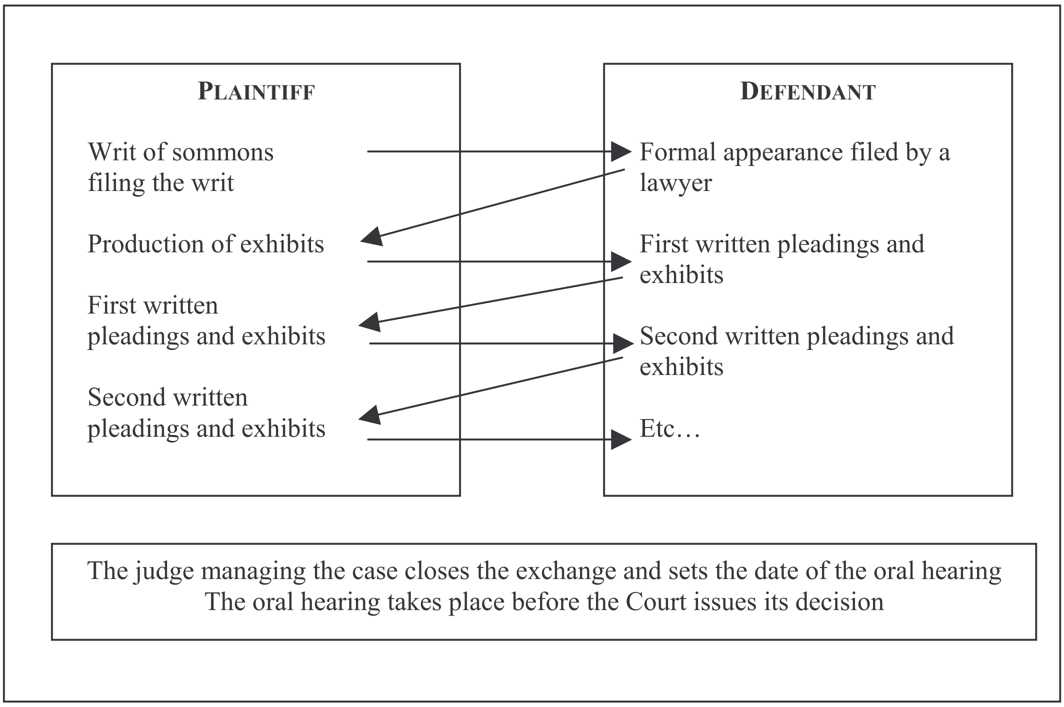
Figure 1
The first instance proceedings



☐

Figure 2
Inferring information from the decision to go to trial

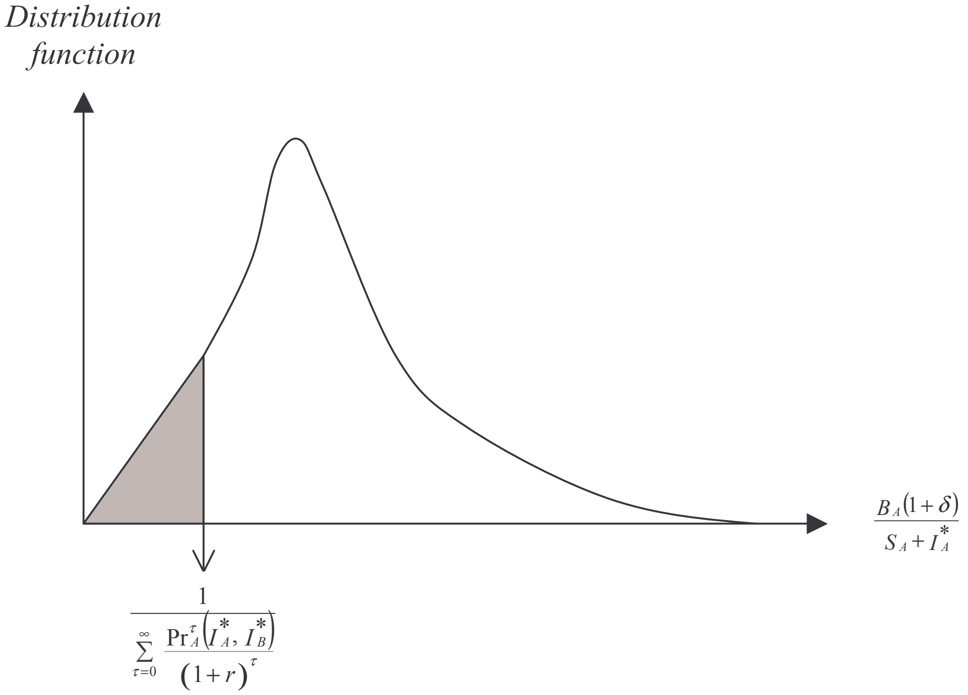


Figure 3
The tree form evolution of the process Z_t

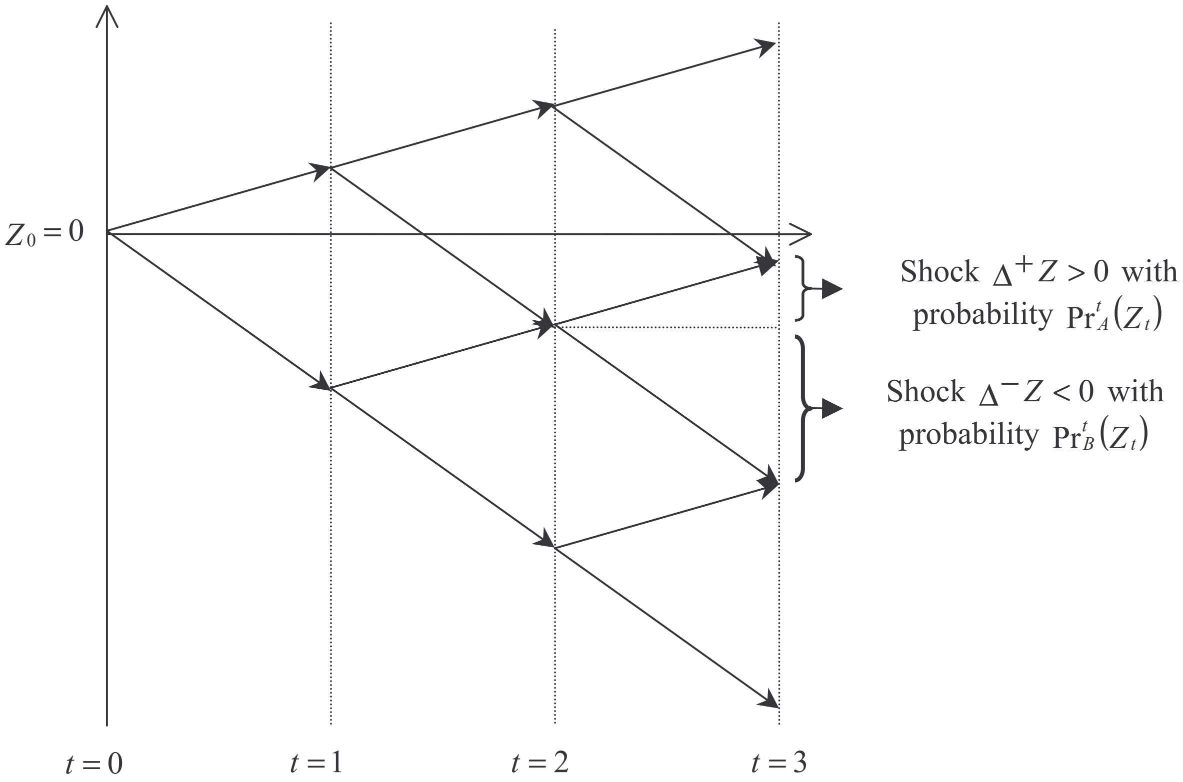


Figure 4

$\Pr_A^{\tau}\left(p_A, p_B\right)$ *as a function of* p_A *and* p_B *for* $\tau = 4$ *months*

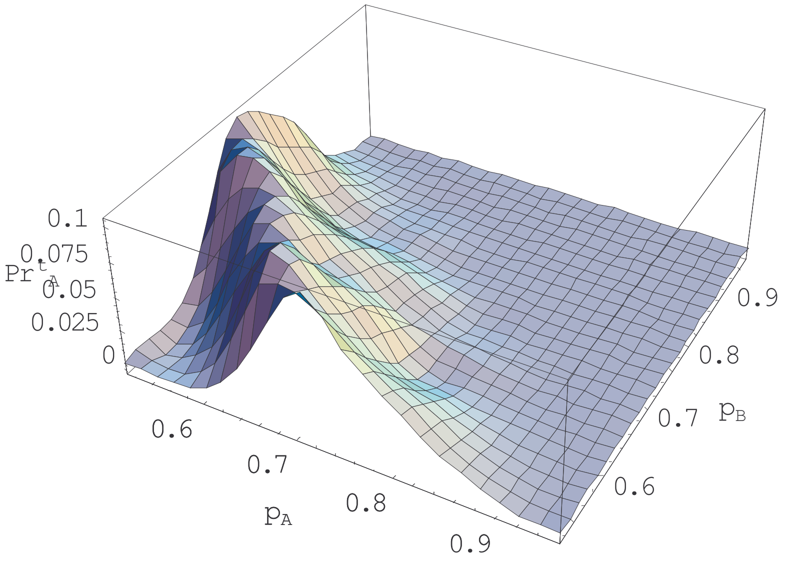
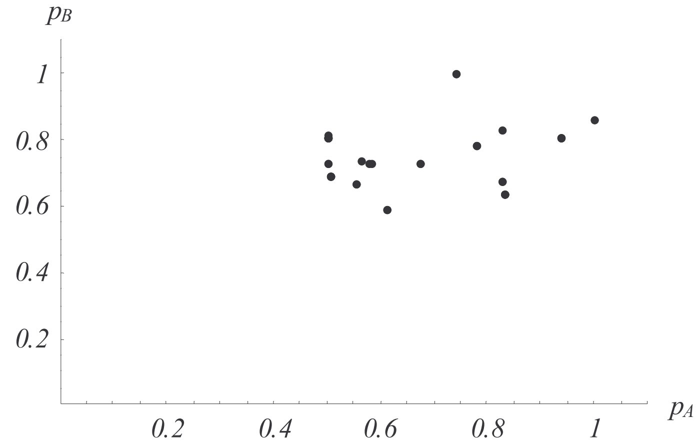


Figure 5

Values of p_A^n and p_B^n that maximise the likelihood of the outcome and duration of each case



nb: several points may overlap, causing the increase of the point size

<u>Table 1</u>: basic statistics

	Cases in which the trademark's holder A wins the trial	Cases in which the trademark's holder A looses the trial	Total
Number of cases	19	24	43
% of cases	44,19%	55,81%	100,00%
Average length (in days)	424,05	374,50	396,40

<u>Table 2</u>: average value (or % of occurrence) of variables

	Cases in which the trademark's holder A wins the trial	Cases in which the trademark's holder A looses the trial	Total
Duration (in days)	424.05	374.50	396.40
Dummy variable equal to 1 if A is an individual, 0 otherwise	11%	8%	9%
Dummy variable equal to 1 if B is an individual, 0 otherwise	11%	38%	26%
Dummy variable equal to 1 if A is a non national but European firm, 0 otherwise	16%	13%	14%
Dummy variable equal to 1 if A is a non national and non European firm, 0 otherwise	16%	33%	26%
Dummy variable equal to 1 if B is a non national but European firm, 0 otherwise	11%	8%	9%
Age of A (in years)	51.00	55.33	53.42
Age of the trademark at stake (in days)	4633.11	3810,08	4173.74
Number of trademarks owned by A	1.00	2.00	1.67
Number of IPC classes of the trademark at stake	1.31	4.00	2.83
Turnover of A (in €)	2310052393	5428370623	4069103702
Turnover of B (in €)	145590551	2519911557	1258553523
Ratio between the turnovers of A and B	140.33	844.26	533.22
Number of employees of A	19691	43468	31989
Number of employees of B	22910	8967	16374
Ratio between the number of employees of A and B	1047.29	2137.65	1655.86

Table 3: Estimation results

	Dependant variable: $\ln\left(p_A^n/1-p_A^n\right)$			Dependant variable: $\ln\left(p_B^n/1-p_B^n\right)$		
	Estimated coefficient	Standard deviation	t-stats	Estimated coefficient	Standard deviation	t-stats
Intercept	-36.1575	27.5855	-1.31074	66.5889 **	22.395	2.97339
Dummy variable equal to 1 in the case of counterfeit, 0 otherwise	-10.6763	25.541	-0.418007	-43.0756 **	20.7352	-2.07742
Dummy variable equal to 1 in the case of unfair competition, 0 otherwise	6.7673	28.0539	0.241225	-6.56399	22.7753	-0.288207
Dummy variable equal to 1 in the case of opposition proceedings, 0 otherwise	-5.95635	32.5679	-0.18289	-49.6389 *	26.4399	-1.87742
Dummy variable equal to 1 in the case of non opposition proceedings, 0 otherwise	-1.58415	24.8928	-0.063639	-47.7328 **	20.2089	-2.36197
Ratio between the turnovers of A and B	-0.0013032	0.0128355	-0.101531	0.0132844	0.0104203	1.27485
Ratio between the number of employees of A and B	-0.000227936	0.00485648	-0.0469344	-0.0066396 *	0.00394268	-1.68404
Turnover of A (in €)	$1.6865*10^{-9}$	$2.32818*10^{-9}$	0.724385	$2.26371*10^{-9}$	$1.8901*10^{-9}$	1.19766
Number of employees of A	0.00003499	0.000342695	0.102102	-0.00002921	0.000278213	-0.104994
Dummy variable equal to 1 if A is an individual, 0 otherwise	10.9448	30.8625	0.35463	-18.7929	25.0554	-0.750054
Dummy variable equal to 1 if B is an individual, 0 otherwise	8.42416	23.4283	0.359572	-39.5362 **	19.02	-2.07866
Age of A (in years)	-0.140833	0.203044	-0.693609	-0.185831	0.164839	-1.12735
Age of the trademark at stake (in days)	0.00248784 *	0.00131809	1.88745	0.000146655	0.00107008	0.137051
Number of trademarks owned by A	30.0152 *	16.4751	1.82186	-5.30417	13.3751	-0.39657
Number of IPC classes of the trademark at stake	-0.63943	0.871365	-0.733825	-0.0754425	0.707408	-0.106646
Dummy variable equal to 1 if A is a non national but European firm, 0 otherwise	-19.1528	29.011	-0.660192	33.3268	23.5522	1.41502
Dummy variable equal to 1 if A is a non national and non European firm, 0 otherwise	-13.7042	25.6147	-0.535012	11.7349	20.795	0.564312
Dummy variable equal to 1 if B is a non national but European firm, 0 otherwise	26.5993	35.0667	0.758535	-50.3951 *	28.4685	-1.77021
R² (with OLS)		0.290461			0.454189	
Estimated ρ	0.018115					
Estimated γ	1.07157					
Log likelihood (global model)	-424.746					
Log likelihood (with $\rho = 0$)	-424.751					

**: significantly different from zero at 5%
*: significantly different from zero at 10%

Table 4: Elasticities or quasi elasticities (for dummy variables) of the critical threshold $1 \Big/ \sum_{\tau=0}^{\infty} \frac{\Pr_A^{\tau}\left(I_A^*, I_B^*\right)}{\left(1+r\right)^{\tau}}$

With respect to	Expected value at sample mean	Standard deviation	Percentage of simulated values with a negative sign
Dummy variable equal to 1 in the case of counterfeit, 0 otherwise	251.538	8352.58	79.06%
Dummy variable equal to 1 in the case of unfair competition, 0 otherwise	5262.4	38584.1	61.54%
Dummy variable equal to 1 in the case of opposition proceedings, 0 otherwise	7.81802	278.834	91.88%
Dummy variable equal to 1 in the case of non opposition proceedings, 0 otherwise	29.1804	1926.55	85.44%
Ratio between the turnovers of A and B	0.00216617	0.0550176	59.44%
Ratio between the number of employees of A and B	-0.0022821	0.0508238	36.38%
Turnover of A (in €)	0.0265204	0.259048	70.10%
Number of employees of A	0.00945993	0.153073	51.50%
Dummy variable equal to 1 if A is an individual, 0 otherwise	118.641	4734.16	79.18%
Dummy variable equal to 1 if B is an individual, 0 otherwise	18.0769	541.231	73.72%
Age of A (in years)	-0.00563167	0.140419	32.38%
Age of the trademark at stake (in days)	0.0235558	0.268389	70.00%
Number of trademarks owned by A	0.349794	4.63917	66.12%
Number of IPC classes of the trademark at stake	-0.00186166	0.0423776	38.18%
Dummy variable equal to 1 if A is a non national but European firm, 0 otherwise	1862.42	21359.9	83.84%
Dummy variable equal to 1 if A is a non national and non European firm, 0 otherwise	3306.23	37992.2	77.40%
Dummy variable equal to 1 if B is a non national but European firm, 0 otherwise	62.6839	3544.83	78.20%

Not invented here:

Knowledge transfer and technology licensing from a German public research organization

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This version: September 2007
This printout: September 10, 2007

Preliminary – do not cite or quote without authors' permission

Abstract:
Using a new dataset encompassing more than 2,000 inventions made by Max Planck Society researchers from 1980 to 2004, we study the effects of information asymmetry and imperfect knowledge transfer on the licensing and successful commercialization of technologies from public research, distinguishing among types of licensees as well as invention and inventor characteristics. Technologies licensed to foreign firms and spin-offs are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. Our findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

Keywords: Licensing, public science, uncodified knowledge, collaborative invention, spin-offs.
JEL classifications: L26, O32, O34.

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[*] Corresponding author. We are grateful to Max Planck Innovation GmbH for granting us access to their data. For helpful comments and discussions, we thank Joerg Erselius, Astrid Giegold, Bernhard Hertel, Evelyn Kaiser, Lionel Nesta, and Dieter Treichel. Wolfgang Ziegler and Sebastian Schmidt at the Patent Information Office of the University of Jena helped us assemble the patent database. Wolfhard Schumann provided valuable research assistance. The usual caveat applies.

Introduction

Throughout the developed economies, public attention and policy measures are increasingly focusing on the transfer of knowledge and technologies from public research to the private sector. Following the Bayh-Dole Act in the U.S. and similar legislative changes in other countries, technology transfer has been recognized as a primary objective of universities and other public research organizations (Mowery et al, 2001; Phan and Siegel, 2006). Notwithstanding the importance of alternative transfer channels (Bozeman, 2000; Zellner, 2003), commercialization of scientific results based on patents, licensing, and spin-off entrepreneurship has found particularly intensive scrutiny. Yet in spite of the increased emphasis on the protection of universities' intellectual property rights (IPRs) and IPR-based commercialization, we still know little about the underlying processes of knowledge transfer and innovation.

Academic inventions are typically far from being readily marketable. Existing research suggests that the commercialization of results from public science is complicated by uncertainty stemming from the early-stage character of most university inventions (Jensen and Thursby, 2001), information asymmetries between inventor and potential licensee (Shane, 2002), and the uncodified nature of important elements of the knowledge base underlying the traded technology (Lowe, 2002; Agrawal, 2006).

Reflecting this non-trivial nature of technology transfer, conclusive evidence on the effectiveness of alternative kinds of commercialization is lacking. For example, the relative commercialization performance of university spin-offs vis-à-vis external licensees is a contested issue (Shane, 2002; Lowe and Ziedonis, 2006). Other issues, including the effectiveness of international licensing, as well the relationships between alternative channels of technology transfer such as collaborative research and technology licensing, are largely unexplored. Furthermore, most empirical studies are based on U.S. data, and it cannot be taken for granted that their results generalize to other countries and institutional settings.

In the present paper, we exploit a newly assembled dataset with detailed information on the licensing activities of the Max Planck Society, Germany's largest non-university public research organization dedicated to basic science. Unlike German universities, the Max Planck Society has consistently been subject to a Bayh-Dole-like IPR regime since the 1970s. This enables us to draw on a rich set of inventions and licensing activities, which encompasses more than 2,000 inventions and about 700 license agreements closed since 1980. In addition to licensing agreements, the data also contain information on royalty payments, indicating whether or not the technology was successfully commercialized in the marketplace.

We use this dataset to analyze a set of specific issues. First, we study how licensing and commercialization are affected by licensee characteristics. Specifically, we look at licensing across national boundaries as well as spin-off versus external licensees. While less relevant in the U.S. context, licensing to foreign firms is a pertinent issue in the smaller and more open European economies, which has received little prior attention in the research on technology transfer. The effectiveness of inventor spin-offs as commercializers of technologies from public research is an unresolved issue in the existing literature to which we add new evidence. Second, we investigate the effects on technology characteristics on the effectiveness of license-based technology transfer. In this context, we study whether inventions based on collaborative research with private firms differ from "pure" university inventions in their licensing and commercialization patterns. We also analyze whether technologies (co-) invented by senior scientists differ in their licensing and commercialization odds.

Our analysis indicates that information asymmetries and problems in transferring uncodified knowledge indeed are critical determinants shaping the success of license-based technology transfer from public research. Inventions licensed to foreign firms are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. The findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

The paper is structured as follows. The next section discusses the role of information asymmetry and the transfer of uncodified knowledge in the licensing and commercialization of academic inventions. In section 3, hypotheses are derived as to how these factors influence licensing and commercialization outcomes for different types of licensees and inventions. Section 4 provides background information on the technology transfer activities of the Max Planck Society, while section 5 describes the data and methodology of the empirical analysis. Results are presented in section 6 and discussed in section 7.

2. Technology transfer through licensing of academic inventions

Inventions by scientists in public research often provide the foundations of commercially viable innovations. Academic inventions may arise as joint products of research activities (think of instrumentation or lab equipment first used for the researcher's own use), or the same results can both be published in a scientific journal and applied commercially (such "patent-paper pairs" are widespread in the life sciences; cf. Murray and Stern, 2005). In a Bayh-Dole-like institutional setting, academic inventions have to be disclosed to the scientist's employer and become its property. If they are to be used for commercial purposes, the prospective innovator has to obtain a license. Most universities and public research organizations have established technology transfer offices (TTOs) that organize the protection of their IPRs and actively market their inventions.

In addition to their strong links to current science, a common characteristic of academic inventions is their early stage nature. In most cases, they have not been developed beyond the proof-of-concept or prototype stage (Jensen and Thursby, 2001). Accordingly, licensees need to engage in substantial further development efforts to obtain a marketable product. Successful commercialization often hinges on the continued involvement of the academic inventor (Agrawal, 2006). The combination of being science-based and early-stage gives rise to at least three kinds of difficulties for the licensing and commercialization process: uncertainty, information asymmetry, and the need to transfer uncodified knowledge.

Like all inventions, university technologies cannot always be turned into successful products in the marketplace. Potential innovators obtaining licenses for technologies from public science face substantial uncertainty as to whether (i) they will be able to develop a functioning product, (ii) they will do so faster than potential competitors, and (iii) the product will be sufficiently successful with customers to justify the costs of licensing and development.

Problems of asymmetric information further complicate innovation activities based on technology transfer from public science. As opposed to technologies developed in-house, potential licensees lack in-depth knowledge of the prior research and development efforts that underlies the academic invention. This limits their ability to evaluate its commercialization prospects. On the other hand, licensees typically have better knowledge of the markets for the prospective products than the inventor or the TTO representing her. To some degree, these problems of asymmetric information can be reflected in the design of licensing agreements and the payment schemes they provide for (Jensen and Thursby, 2001; Lowe, 2006). However, there is no guarantee that a licensing agreement is closed at all. Typically, only a few potential licensees are interested in a particular technology, and licensing is based on small-numbers bargaining.

Asymmetric information arises as a problem in negotiating licensing agreements because both parties have incentives to withhold information, because this may increase their share in future innovation rents. However, even if both parties faithfully try to share their knowledge (for example, after a licensing agreement providing for sales-based royalties is closed so that inventors have an interest in successful commercialization), substantial obstacles in communicating this knowledge typically have to be overcome. They derive from the nature of the knowledge to be communicated, which tends to be complex and imperfectly codified. Agrawal (2006) argues that academic inventions often draw on multiple fields of knowledge. Potential licensees are unlikely to have substantial prior knowledge in all these fields. Accordingly, their absorptive capacities (Cohen and Levinthal, 1990) may be insufficient to fully understand information related to the invention, even if the inventor and or the TTO disclose all their knowledge. In addition, relevant elements of that knowledge may be uncodified (even if they would in principle be codifiable; in which case they can be characterized as "latent," Agrawal, 2006; cf. also Lowe, 2002). For example, knowledge that the inventor gained from failed and therefore unreported experiments may frequently be latent and inaccessible for an external licensee.

While some degree of uncertainty about innovative success is irreducible, information asymmetries and communication problems are not equally pronounced for all licensing and commercialization processes. In the next section, we derive hypotheses on how differences in the types of licensees and kinds of technologies affect the severity of these problems. These hypotheses are then tested empirically.

3. Hypotheses

Both information asymmetries and problems of knowledge transfer depend on the cognitive "distance" between licensor (the academic inventor represented by her employer's TTO) and licensee. This distance is plausibly related to observable characteristics of the licensee and the technology, which consequently are expected to affect the likelihood of closing a licensing agreement and successfully commercializing the invention.

Likelihood of successful licensing

We consider differences in the types of licensees along two dimensions: domestic versus foreign licensees, and inventor spin-offs versus external licensees. As regards the first dichotomy, information asymmetries are expected to be more pronounced in licensing negotiations across national boundaries. Information is harder to obtain for foreign licensees, particularly if they do not come from countries speaking the same language, and the design and monitoring of contracts is more difficult internationally. IPR protection for the target technology may not have been obtained in the county of the potential foreign licensee, exposing it to an enhanced risk of imitation by competitors. The likelihood of agreements with foreign licensees may be further reduced by biases in the TTO's marketing efforts. Possibly, such biases are even due to strategic considerations or political pressure motivated by the goal of maximizing the national payoffs from public science.

These arguments suggest that licensing negotiations with foreign firms are less likely to be successful than negotiations with domestic firms. We cannot test this hypothesis directly since we only have information on the pool of inventions and on licensing agreements that were actually closed. However, we can investigate the relative frequency of licensing agreements with foreign firms, and also their timing as compared to agreements with domestic firms. The following relationship is predicted:

Hypothesis 1: At any given time, the hazard of closing a licensing agreement with a foreign firm is lower than that of closing an agreement with a domestic firm.

The likelihood of successful licensing may also depend on the organizational nature of potential licensees. Following the earlier work on U.S. universities, we study differences between inventor spin-offs and external licensees (established firms and startups without inventor involvement). In the case of spin-offs, information asymmetries should largely be mitigated since inventors licensing back their own inventions know these technologies rather well. This should increase the chances and the speed of arriving at a license agreement:

Hypothesis 2: At any given time, the hazard of closing a licensing agreement with an inventor spin-off is higher than that of closing an agreement with an external licensee.

However, licensing to inventor spin-offs is sometimes characterized as some kind of "last resort" utilized only when attempts to find an external licensee have failed (e.g., Shane, 2002). If this temporal order is widespread, it might compensate the positive relationship predicted by Hypothesis 2.

In addition to the effects of licensee characteristics, we also expect that licensing is affected by the time that a potential licensee learns about a nascent university technology. Particularly relevant in this context appear collaborative inventions based on industry-sponsored research or joint research projects between public and industry partners. Industry involvement at an early stage of technology development is likely to mitigate information asymmetries and problems of knowledge transfer. In a research project sponsored by a commercial firm, the firm will bring some related prior knowledge (motivating its interest in the project), and it will try to monitor the ongoing research efforts. Joint research projects with industry partners likewise presuppose some relevant prior knowledge of the industry partner, and some communication of knowledge between both partners. Both forms of collaborative research therefore come with an increased capacity of industry partners to evaluate the potential of inventions made in the project. If their assessment of the technology is low, they may withdraw from the cooperation even before an invention is arrived at, which would increase the average quality of inventions from sponsored and joint research. In addition, knowing the inventor from the collaborative research project helps to build mutual trust, enhancing the willingness to close a licensing deal in the absence of fully symmetric information. Reputation effects and the prospect of future cooperation further reduce the attractiveness of opportunistic behavior. These considerations lead us to the following hypothesis:

Hypothesis 3: Academic inventions from sponsored research or collaborations with industry partners are more likely to be licensed than other inventions.

Lowe (2002) has suggested an effect that might countervail the prediction of Hypothesis 3. He argues that in the process of collaborative research, industry partners may acquire sufficient knowledge of the invention to render subsequent licensing unnecessary. This argument presupposes that the firm is able to design its innovation around the public partner's intellectual property rights, or that the public partner is unable to enforce them.

Finally, we can also conjecture about an effect of inventor seniority on the likelihood of closing a licensing agreement. The superior reputation and more extensive personal network of senior researchers should enhance the credibility of technologies (co-) invented by them, thus increasing the willingness of potential licensees to enter into a contractual agreement. If negotiations are mediated by a technology transfer office (as is the case in our empirical sample), it is likely that senior scientists have more influence on their employer institution than more junior ones. This may further increase the likelihood of a successful licensing agreement. We accordingly conjecture:

Hypothesis 4: Technologies (co-)invented by senior scientists are more likely to be licensed than those by more junior researchers.

Commercialization of licensed technologies

Not only the likelihood of closing an agreement, but also the likelihood of successfully bringing the technology to the market can be expected to differ according to licensee, technology, and inventor characteristics. Post-agreement inventor involvement in the development efforts has been demonstrated to increase the likelihood of successful commercialization (Agrawal, 2006). If a royalty-based contract has been closed, bringing the product to the market is the interest of both licensor and licensee (Jensen and Thursby, 2001). Accordingly, academic inventors harm themselves if they do not cooperate in post-licensing development efforts. They may nonetheless exert less effort than would be called for because of competing demands on their time, particularly when primarily motivated by the reward mechanisms of public science (Stephan, 1996). Equally important for successful commercialization appears their ability to communicate their knowledge to the licensee.

In the case of foreign licensees, geographic distance and language barriers complicate the transfer of uncodified knowledge. Post-agreement inventor involvement is more costly and possibly less effective if national boundaries have to be crossed. This consideration leads us to predict the following:

Hypothesis 5: Inventions licensed to foreign firms are less likely to be commercialized successfully than inventions licensed to domestic firms.

Spin-offs represent an extreme form of inventor involvement. Transfer of uncodified knowledge to the spin-off firm is mostly realized by personal migration of the inventor and/or associates from her laboratory to the new firm. Even though senior scientists frequently do not enter the active management of spin-offs (co-) founded by them (cf. Buenstorf, 2006), inventor-founders nonetheless have strong incentives for engaging in the spin-off's development activities, and they typically assume at least consulting positions in the new venture. Staff members of the spin-off may moreover be able to informally contact their prior co-workers in the inventor laboratory when in need of additional knowledge.

Commercialization activities by spin-offs are expected to benefit from the facilitated transfer of uncodified knowledge. In addition, given a smaller product portfolio, spin-off survival is typically more dependent on specific technologies than survival of established firms. Spin-offs consequently face stronger incentives for successful commercialization (Lowe and Ziedonis, 2006), and are unlikely to license a technology for purely strategic reasons (i.e., to prevent others from using it). Based on these considerations, we predict the following:

Hypothesis 6: Inventions licensed to inventor spin-offs are more likely to be commercialized successfully than inventions licensed to external licensees.

Effective knowledge transfer clearly is not sufficient to ensure successful commercialization. Existing evidence on the commercialization performance of spin-offs is inconclusive. Counter to Hypothesis 6, Shane (2002) stipulates that spin-offs are inferior in commercialization because they lack the required complementary assets (Teece, 1986). He suggests that licensing to spin-offs is primarily observed when patents are ineffective. In contrast, for their sample of licensed inventions from the University of California system, Lowe and Ziedonis (2006) find neither lower commercialization odds nor lower licensing income for spin-off licensees.

In the case of collaborative research projects, knowledge transfer between inventor and licensee is facilitated by absorptive capacities and shared understandings developed in the prior research process. Pre-existing familiarity with the technology also provides the licensee with a speed advantage, enhancing the odds of successful commercialization (Markman et al., 2005). In addition, licensees that were involved in collaborative research leading to the licensed technology have superior information about this technology. Their ability to evaluate its merits should thus be enhanced, which increases the likelihood that licensed inventions can also be commercialized (the selection effect already suggested above). We accordingly expect the following positive effect:

Hypothesis 7: Inventions from sponsored research or collaborations with industry partners are more likely to result in commercially viable products and processes than others.

Agrawal (2006) studies the same issue in the U.S. context, using a sample of 124 licensed inventions from MIT's mechanical engineering and electrical engineering / computer science departments. He finds positive effects for sponsored research both on the likelihood of successful commercialization and on the level of revenues generated thereby. Neither effect is statistically significant, however.

Finally, the successful commercialization of a university invention may also depend on the seniority of the inventor(s). The more senior an inventor is, the higher are her opportunity costs of post-agreement involvement. *Ceteris paribus*, senior scientists are therefore expected to spend less time on their inventions, which will lower their chances to be successfully commercialized. This will be particularly true for inventions licensed to external licensees. We expect senior scientists to be more willing to spend time with their spin-off firms, the success of which is more relevant both to their income and their reputation. This leads us to the last hypotheses:

Hypothesis 8a: Technologies (co-) invented by senior scientists are less likely to be commercialized than inventions by more junior scientists.
Hypothesis 8b: If senior scientists engage in spin-off activities, the commercialization odds of their inventions increase over those of technologies they license to external licensees.

4. Technology transfer at the Max Planck Society

Public research in Germany is characterized by a distinctive division of labor between universities and non-university public research organizations. The Max Planck Society, whose roots go back to the early 20th century, is the country's largest non-university public research organization dedicated to basic research. It receives more than 80 per cent of its budget from public, institutional funding (Max Planck Society, 2005). 78 individual Max Planck Institutes are dispersed all over the country (in addition, three institutes are located abroad). They currently employ some 4,000 researchers.

The Max Planck Society's mission is to complement the university system by taking up large-scale, interdisciplinary, or particularly innovative activities that are out of reach for individual universities. Its research activities encompass the whole spectrum of the sciences and the humanities. Institutes are organized into three sections: the biomedical section, the chemistry, physics and technology section, as well as the humanities and social sciences section.

The Max Planck Society's internal organization is unique. Its strategy – known as the Harnack Principle – is to put its highest-level researchers, the Max Planck directors, in a particularly autonomous and powerful position. Directors are recruited from the most successful researchers of both German and foreign universities. Their mission is research-oriented, with substantial long-term, institutional funding. Currently, there are roughly 260 active directors in the Max Planck Society.

Academic inventions and technology transfer activities from the Max Planck Society have historically been treated differently from those of German university researchers. In general, employees of German firms are subject to the *Arbeitnehmererfindungsgesetz*, which mandates that employees must disclose inventions to their employer, and assigns the property rights in these inventions to the employer. University researchers used to be exempt from this law. They retained the intellectual property rights (IPRs) in their inventions. This so-called *Hochschullehrerprivileg* or "professors' privilege" was abolished in 2002. Since then, German universities have been the legal owners of the inventions made by their researchers. Consequently they are now responsible for patent applications and the licensing of inventions. In particular they have to bear all costs of the patenting process. The inventing researcher is entitled to 30 per cent of the gross licensing revenues from her invention.

The new IPR regime for inventions by German university researchers essentially replicates the rules that Max Planck researchers have always been subject to. They are required to disclose all their inventions to the Max Planck Society, which can then claim ownership of the technology. In this case, the Society organizes the patent protection for the invention (if possible and deemed adequate), as well as the subsequent negotiation and administration of licenses. The inventing researcher receives 30 per cent of all revenues from licenses and patent sales, and the Max Planck Institute employing the researcher gets an additional third of all income.

To organize the patent application and the marketing of Max Planck technologies, the Society in 1970 established a legally independent technology transfer subsidiary that recently was renamed Max Planck Innovation GmbH (before, its name was Garching Innovation after one of the Society's research campuses). After some early and largely unsuccessful attempts of constructing and selling prototypes based on Max Planck inventions, Max Planck Innovation has for the past three decades focused on patenting and licensing activities.

Disclosure of inventions is actively solicited at the individual institutes. Patents are applied for if the invention is patentable and considered sufficiently promising, even if no licensee for the technology has been identified.[1] Technologies are marketed to both domestic and foreign firms. Systematic support and counseling of spin-off activities was taken up in the 1990s, and spin-off numbers have strongly increased since then. Total returns from the licensing activities amount to some € 180 million, with the bulk of income resulting from a small number of highly successful blockbuster technologies. Annual license revenues contribute 1 to 2 per cent to the Max Planck Society's overall budget (Max Planck Society, 2005).

5. Dataset and econometric approach

Sources

This study is primarily based on two sets of data made available by Max Planck Innovation. The first dataset contains all inventions disclosed by Max Planck researchers from the early 1970s to 2004.[2] In total, it encompasses 2,726 inventions. 1,754 resulted in at least one patent application

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[1] In this regard, Max Planck Innovation's patenting policy thus appears to be closer to that of the MIT than that of the UC system (cf. Shane, 2002; Lowe and Ziedonis, 2006)

[2] Researchers employed on a scholarship basis, mostly PhD students and international postdocs, are not subject to the German law on employee inventions. To the extent that these individuals made inventions without other Max Planck researchers being involved, they do not show up in the data.

(Table 1). The database includes the title of the invention, names and institute affiliations of the inventors, day of disclosure and (if eligible) patent application, as well as various information regarding further use of the invention.

We linked these data with a second dataset assembled from Max Planck Innovation's licensing agreements. 793 inventions (583 patented inventions) have been licensed, and because some non-exclusive contracts have multiple licensees, there are in total 1,014 licensing agreements. For each contract, information is available on the licensee name and address, dates of closure and (possibly) termination of the contract, arrangements on licensing fees and royalties, as well as actual dates and amounts of payments. The Max Planck inventions are similar to other datasets on commercialized inventions in that payments (in particular, royalties) are extremely skewed. One single Max Planck invention accounts for more than 75 % of the overall returns.

Patent data is used to control for heterogeneity in the quality of (patented) inventions. Our primary proxy for patent quality is the number of members in the patent family. It indicates the geographical breadth of the IPR protection sought by the patent application and is a widely accepted measure of patent quality (Harhoff et al., 2003). We also experimented with the number of IPC classes and granted patents in the family as quality indicators, but they were less predictive.

To obtain this information, we constructed a unique patent database using *Depatisnet*, the publicly available patent search site of the German Patent Office. First, some 8,000 patent applications by the Max Planck Society were identified. These were grouped according to their priority patents, which were then matched to the patents listed in the invention database.

About one third of the patented inventions could not be found in this way because they were not assigned to the Max Planck Society. For these inventions, the patent listed in the inventions dataset was searched in *Depatisnet*, and the corresponding patent family was retrieved. This procedure yielded about 2,800 additional patents.[3]

We restrict our empirical analysis to the 2,261 inventions disclosed in or after 1980. Earlier inventions are excluded for three reasons. First, the earliest entries in the inventions dataset are not consistently inventions by Max Planck researchers, since at the time Garching

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[3] In about 70 cases, no patent information was found even though the inventions database identified them as patented. We suspect that most of these cases reflect cancelled applications. On the other hand, for another 70 inventions patents were found that closely matched the disclosed inventions in terms of title and inventor names, but the respective patents do not show up in the inventions database. We do not use this information in the subsequent analysis.

Innovation was offering its services to a variety of other public research organizations and even commercial firms, whose inventions show up in our data. Second, the quality of the earliest data was below that related to later inventions. Third, systematic support of spin-off activities out of the Max Planck Society only began around 1990, and spin-off activities were of little import in the earliest years of the data.

Variables

Two dependent variables are used in the subsequent models. First, we study whether or not an invention was licensed. Licensing can readily be inferred from the existence of a licensing agreement. 699 (31 per cent) of all inventions disclosed after 1980 have been included in a licensing agreement. This number is comparable to U.S. institutions studied before. For example, Lowe and Ziedonis (2006) study 734 licensing agreements closed by the UC system between 1981 and 1999. Second, we are interested in the factors conditioning successful commercialization. While this information is not directly contained in the data, we derive it from the existence of positive royalty payments. Of course, this restricts the sample for studying commercialization to those inventions where licensing agreements provided for royalty payments (not only fixed fees). In the post-1980 sample, there are 644 cases of this kind, of which 307 (48 per cent) have resulted in positive royalties.

As central explanatory variables, the analysis uses four indicator variables identifying, respectively, foreign licensees, spin-off licensees, collaborative inventions, and senior inventors. To study effects of international licensing, licensees were classified into domestic versus foreign according to the postal address given in the data. Accordingly, German branches and subsidiaries of foreign companies are classified as German licensees. This is in line with our primary interest in potential difficulties arising from information asymmetries and the transfer of uncodified knowledge, which we would expect to depend more on the licensee's physical location than to whether or not it is foreign-owned. International license agreements are commonplace in the Max Planck Society. Of the 896 license agreements for inventions disclosed since 1980, 273 are with foreign licensees. Spin-offs among the licensees were identified on the basis of Max Planck Innovation's spin-off database. There are 211 cases of licenses to spin-offs in the sample.

Collaborative inventions are identified on the basis of patent applications. We define as collaborative all inventions that were not exclusively assigned to the Max Planck Society (i.e., they are either assigned to the Max Planck Society and a private-sector firms, or they are exclusively assigned to a private-sector firm). Their total number is 349. Finally, senior scientist involvement is proxied by technologies (co-) invented by one or (in rare cases) several Max Planck directors, which is justified by the distinctive position directors have in the Max Planck hierarchy. We identified the directors using published sources (Henning and Ullmann, 1998; Max Planck Society, 2000) and information provided by the Max Planck Society's human resource department.

A set of control variables is used. Existence and quality of patents related to an invention is proxied by patent (application) family size. We also control for discipline-specific factors with a dummy variable denoting inventions from the biomedical section of the Max Planck Society. This dummy is zero for inventions out of the chemistry, physics and technology section.[4] Time effects are captured by distinguishing two cohorts of inventions (those disclosed up to and after 1990, respectively).

Methods

To study the incidence of licensing events, two sets of competing risks models are used, which are both based on semi-parametric Cox regressions (Lunn and McNeil, 1995). We alternatively interpret licensing to foreign versus German firms (models 1-3), or licensing to spin-offs versus external licenses (models 4-6), as competing risks. Cox regressions are attractive because as hazard rate models, their coefficient estimates are based on both the occurrence of the event and the time elapsed before it occurs, thus making full use of the available information. Right censoring imposed by the end of the observation period is also taken into account in the Cox regressions. Cox models are preferred over fully parametric hazard models because no assumptions need be made about the time-dependence of the hazard, which would be hard to justify in the present context. The proportionality assumption underlying the Cox regression is in line with the actual shapes of the survivor functions (cf. the Kaplan-Meier graphs in Figures 1 and 2). Since we have daily data, interval censoring and ties are no relevant issues, and continuous-time Cox regressions can be applied. An invention enters the risk pool at the day of

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[4] There are a handful of inventions that cannot be assigned to one of these sections, mostly because they were disclosed by staff of the Max Planck Society's general administration. The dummy variable is zero for these inventions. No inventions were disclosed out of the humanities section. We also experimented with individual dummy variables denoting the top seven institutes in the number of commercialized inventions (five of which are from the biomedical section). This had little effect on the results.

disclosure or initial patent application, whichever comes first.[5] It leaves the risk pool at the day that the initial licensing agreement is concluded.

The likelihood of successful commercialization is studied in two steps. First, we estimate a set of logit models where commercialization is the dependent variable, using the set of licensing agreements as our sample.[6] As noted above, commercialization is defined as the existence of positive royalty payments. Obviously, this restricts the sample to those licensing agreements that contain provisions for royalty payments. A shortcoming of this approach is that it does not account for selection effects: Technologies licensed to different kinds of licensees may differ in their characteristics, and these differences may affect their subsequent commercialization odds. To illustrate, it might be possible that a researchers retains her best inventions for spin-off activities, while inferior technologies are licensed to external licensees.

As can be seen from Table 2 for the case of spin-off versus external licensing, there are indeed substantial differences in the values of the explanatory variables for the different subsets of technologies, suggesting that selection into the different kinds of licensing contracts (domestic versus foreign, spin-off versus external) may not have been random. To test whether differences in the commercialization likelihood of different types of licensees are due to differences in observables, we interpret specific kinds of licensing agreements as treatments, and estimate how being treated affected the commercialization likelihood using propensity score matching (Rosenbloom and Rubin, 1983; Heckman et al., 1998; cf. also Sianesi, 2001; Wooldridge, 2002, ch. 18). Specifically, two propensity score matching estimators are employed: in the first one, the treatment consists in being licensed to a foreign licensee. In the second one, licensing to a spin-off is the treatment.

The intuition underlying propensity score matching is as follows. In non-experimental data, for each observation only one outcome (here: commercialization success) is observed. If Y_{i0} denotes observation i's outcome without treatment, Y_{i1} denotes observation i's outcome with treatment, and $T \in \{0, 1\}$ denotes treatment, we would like to know the treatment effect $Y_{i1} - Y_{i0}$,

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[5] Particularly for patented inventions that were not assigned to the Max Planck Society, we found a number of instances where the disclosure date is later than the date of patent application. This is explicable by the fact that the industrial partner may have processed the patent application independent of the disclosure process initiated by the Max Planck inventor. The time gap between the dates was mostly small. In a small number of cases, licensing agreements were (technically) concluded before either disclosure or application dates, mostly because options for licenses on nascent technologies were negotiated, or new inventions were included into existing licensing agreements. These cases are excluded from the analysis of licensing hazards.

[6] We also experimented with the corresponding probit models, which yielded very similar results.

but can only observe one of the two outcomes. If selection into treatment is nonrandom, the effect of treatment on the outcome cannot be separated from the selection effect in the data.

Propensity score matching uses the available information on individual observations to generate a counterfactual control group from the untreated observations, such that differences in observable characteristics are minimized between the treated observations and the members of the control group. The basic approach is to calculate the probability of receiving treatment for each observation based on its observable characteristics, using probit or logit models. This conditional probability is the propensity score, which is then used for matching the treated observations to similar non-treated ones. Under the assumption that selection into treatment only depends on observables, the average effect of treatment can then be estimated at the population level. Specifically, both the *average treatment effect* (ATE), $E(Y_{i1} - Y_{i0})$, and the *average treatment effect on the treated* (ATT), $E(Y_{i1} - Y_{i0} \mid T = 1)$, can be estimated.

Various propensity score-based matching methods have been proposed. When large samples of non-treated observations are available, each treated observation can be matched to an "identical twin," i.e. a non-treated observation that is very similar in its propensity score, and the outcomes of both observations are then compared. Alternatively, each treated observation can be matched to a weighted average of untreated observations, where the weights are determined by how similar the propensity scores of the untreated observations are to that of the treated one. We adopt the latter approach below. We report results obtained by estimating propensity scores with logit models, using a Gaussian kernel for matching, where the weights of the untreated observations follow a normal distribution around the propensity score of the respective treated one. The estimations were performed using the *psmatch2* routine for Stata 9.0 (Leuven and Sianesi, 2003).

6. Results

Hazard of licensing

Hypothesis 1 posits that licensing agreements are less likely to be closed with foreign licensees than with domestic firms. This is supported by Figure 1 and by the results of Models 1-3 (Table 3), which find a large and significantly negative coefficient estimate for the variable indicating foreign licensees. The models also find that in the biomedical section of the Max Planck Society, inventions are significantly less likely to be licensed to foreign firms than in the chemical-physics-technology section. In contrast, the effects of neither the size of the patent family nor of the time period of the invention are systematically different for foreign versus domestic inventions.

Models 4-6 (Table 4) find that, overall, the likelihood of licensing to spin-offs is significantly lower than that of licensing to external licensees, which contradicts Hypothesis 2. A possible interpretation of this finding is that spin-off licensing is indeed turned to only when prior attempts to find external licensees have been unsuccessful (Shane, 2002). Again, there are systematic differences in how the control variables in the estimation affect the alternative types of licensees. Inventions from the biomedical sections are not only more likely to be licensed in general, but even more so in the case of spin-off licensees (Model 4). There has moreover been some substitution of spin-off licensing for agreements with external licensees, as the former became more likely after 1990, while the latter became less common (Models 4-6). Finally, the coefficient estimates for patent family size do not suggest that licensing to spin-offs is less affected by patent protection than licensing to external firms, which would be expected if spin-offs were primarily turned to in situations of ineffective property rights protection (Shane, 2002).

As regards collaborative inventions, the evidence from the competing risks models is mixed. Models 2 and 3 indicate that collaborative inventions are less likely to be licensed, but this effect is restricted to domestic licensing. Likewise, Models 5 and 6 (Table 4) find a significantly negative effect of industry cooperation on spin-off licensing, but not on licensing by external firms. Thus, we find that collaborative inventions are disadvantaged in specific licensing situations (domestic, spin-offs), but not in others (foreign, external licensees). Apart from a marginally significant positive coefficient estimate in Model 6, however, no evidence is obtained in support of Hypothesis 3, which predicted a higher licensing likelihood for collaborative inventions.[7] These findings suggest that reduced information asymmetry through prior joint research does not systematically increase the chances of the respective technology to be licensed. They may be explicable by Lowe's (2002) argument suggesting that knowledge transfers during the collaborative project may render licensing unnecessary. Possibly, selection enabled by better information is also counteracting the effect of reduced difficulty in negotiating, and only the most promising technologies from collaborative research are actually licensed.

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[7] These findings are corroborated by estimating separate coefficient estimates for the competing risks in stratified models (Lunn and McNeil, 1995, Method B).

In both Model 3 and Model 6 a large and significantly positive effect of director-inventors on the licensing hazard is obtained, indicating that senior scientists are more successful in licensing their inventions, as predicted by Hypothesis 4. Model 6 moreover suggests that the director effect is even stronger in the case of spin-off licensing. In contrast, while the coefficient estimate for director-inventors is positive in the case of foreign licensees, it is not significantly different from zero.

Likelihood of commercialization

As predicted by Hypothesis 5, logit models estimating the likelihood of successful commercialization suggest that foreign licensees are significantly less likely to commercialize a licensed technology (Models 7-11 in Table 5).[8] They thus lend support to the conjecture that international knowledge transfer causes problems hindering the successful development of university technologies. This finding is corroborated by the results of the propensity score matching, which are reported as Model 12 in Table 6.[9] In the original dataset, the commercialization likelihood of technologies licensed to foreign firm is -.133 lower than that of technologies licensed within Germany. Comparing the technologies licensed to foreigners with similar technologies licensed at home reduces this difference to -.105, which is significant at the .05 level. If the whole population of licensed technologies is considered, the average effect of treatment is -.113. We thus conclude that the observable disadvantage of technologies licensed abroad is not primarily due to selection.

Logit models also find that spin-offs are less likely to commercialize inventions than external licensees (Models 9-11). Apparently, enhanced inventor involvement in spin-off licensees is not sufficient to ensure the success of these firms. However, propensity score matching indicates that the poorer commercialization record of spin-offs reflects substantial effects of selection. When selection into spin-off licensing is controlled for (Model 13 in Table 6), the average treatment effect on the treated (ATT) is reduced from -.174 to -.049, which is not significantly different from zero. In contrast, the average treatment effect on all population members is -.112 and significant at the .05 level.

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[8] All logit models were alternatively estimated as probit models, which yielded qualitatively identical results.

[9] To obtain propensity scores, a logit model for the likelihood of being licensed to a foreign licensee was estimated first, using as explanatory variables the patent family size, dummies denoting collaborative inventions, director-inventors, post-1990 invention and inventions from the biomedical section, as well as seven additional dummy variables denoting the institutes that had the largest number of commercialized inventions. Kernel-based matching of treated and untreated observations was then adopted (cf. also section 5).

In line with Hypothesis 7, we find that collaborative inventions have significantly higher chances of being commercialized (Models 8-11). This indicates that knowledge transfer is indeed facilitated by prior joint research activities. It is moreover consistent with the possibility that licensed collaborative inventions are a pre-selected sample from all collaborative inventions.

If Max Planck directors are among the inventors of a technology, its subsequent commercialization odds are reduced, which is consistent with the opportunity cost argument underlying Hypothesis 8a (Model 10). Adding the director-inventor variable to the model reduces the coefficient estimate of the spin-off dummy by less than 20 per cent, suggesting that spin-off licensees may be inferior in commercialization even when controlling for the involvement of senior scientists.

To probe this further, in Model 11 we replace the overlapping dummy variables denoting spin-off licensees and director-inventors by three separate, non-overlapping dummies denoting, respectively, director-inventions licensed to spin-offs, other inventions licensed to spin-offs, and director-inventions licensed to external licensees. The results indicate that these three groups of inventions are all similarly disadvantaged in their commercialization likelihood (relative to non-director inventions licensed to external licensees, and after controlling for the other explanatory variables). Thus, if inventions by directors are licensed to spin-offs, the negative effects found for both variables do not seem to be cumulative. While these findings are not consistent with Hypothesis 8b, a weaker version of the Hypothesis would be supported: in the case of director inventions, licensing to a spin-off does not reduce the commercialization likelihood further. Possibly, this result is due to two counteracting influences: higher incentives for inventor collaboration, but less business experience by the spin-off. Relatively speaking, spin-offs are then more suited to commercialize inventions by senior scientists than those made by more junior ones.

Even though they are not in the focus of the study, the control variables finally deserve some attention. Patent family size, our proxy of invention quality, has no effect on commercialization. Inventions from the biomedical section, which were licensed more often, seem to have lower odds of commercialization (Models 7 and 8), but this effect loses its significance after controlling for spin-off licensees and director-inventors, both of which are more widespread in the life sciences. Finally, all commercialization models find a sizeable and highly significant negative effect of later inventions. This is to be expected since later inventions had less time to be commercialized, particularly since the logit model cannot control for right censoring. It cannot be ruled out, however, that at least some of the difference in commercialization odds between older and younger inventions may reflect a decreasing trend in the commercial values of Max Plank inventions.

7. Discussion

Our findings on foreign licensees and collaborative inventions are largely in line with the theoretical considerations of sections 2 and 3. They suggest that license-based technology transfer from public research is complicated by information asymmetry and problems of ensuring post-agreement inventor involvement, which is essential due to the partially uncodified character of knowledge in early-stage technologies.

Licensing agreements with foreign licensees were found to be less frequent and less successful in commercialization than agreements with domestic firms. In contrast, our findings paint a largely positive picture regarding the licensing of cooperative inventions. While they are less likely to be licensed to spin-offs and to (undifferentiated) domestic licensees, no negative effects could be discerned regarding the licensing of collaborative inventions to domestic incumbents or foreign firms. In addition, they consistently had higher chances of commercialization than "pure" university inventions. In evaluating these findings, it has to be considered that industry cooperation may itself lead to the transfer of knowledge to the private sector (irrespective of subsequent licensing), thus the present results can be considered as lower bound estimates of effective knowledge transfer through collaborative research. A caveat also has to be made in this context: our identification strategy based on patent applications underestimates the extent of industry cooperation, as we cannot identify collaborative inventions unless they result in patent applications.

In contrast, the results on spin-off licensees are less compatible with the conjectured role of information asymmetry and uncodified knowledge, as spin-offs had lower licensing hazards than external licensees, and were not more likely to commercialize licensed technologies. While this pattern might be consistent with interpreting spin-offs as a kind of last resort licensees, we found spin-off licensing to be unaffected by the extent of patent protection. This is not in line with Shane's (2002) suggestion that spin-offs are turned to when knowledge transfer problems frustrate the negotiation of contracts with established firms.

Propensity score matching suggests that selection effects underlie the inferior commercialization performance of spin-offs. The trend toward spin-off licensing instead of external licensing discernible in the data may nonetheless be problematic. This is because our results indicate a conflicting relationship between industry cooperation on the one hand and domestic licensing, particularly to spin-offs, on the other. Possibly, cooperative research, a successful form of technology transfer, is adversely affected by the increasing spin-off activities. In our view, such interdependencies between the different forms of technology transfer warrant closer scrutiny in the future.

Finally, when singling out the most senior scientists of the Max Planck Society, we found their inventions more likely to be licensed, yet less likely to be commercialized. Again, this pattern is easy to reconcile with the theoretical considerations. Network and reputation effects enhance the chances of finding a licensee, while senior scientists face the highest opportunity costs of engaging in post-agreement involvement.[10]

The findings on director-inventors may also provide a new perspective on the spin-off process. Director-inventions are particularly likely to be licensed to spin-offs, and their commercialization likelihood is not further reduced by spin-off licensing. This suggests a specific role for spin-offs in the commercialization of the knowledge of "star scientists," (Zucker and Darby, 1996) who have little incentive to engage in more traditional forms of licensing.

A general limitation of this study was that commercialization success was not measured in monetary terms. A preliminary analysis of the payments flows based on licensing of Max Planck Society inventions indicates that alternative criteria of commercialization success, in our case the hazard of commercialization versus the flow of licensing revenues, do not necessarily move together. We will explore this more thoroughly in future work. There are of course further limitations. Among them is that the present analysis only covered a single organization, which moreover follows a dedicated mission to focus on basic research. This clearly restricts the possibility to generalize the results. Also on the agenda is a closer look at developments over time. Given that the Max Planck Society was a pioneer of IPR-based technology transfer even by international standards, we plan to study in more detail the evolution of these activities.

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[10] In the long run, this pattern should of course not be stable.

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Table 1: Inventions disclosed by Max Planck researchers, 1970-2005

	Full sample	*1980-2005 Inventions*
Inventions (patented)	2,726 *1,754*	2,261 *1,454*
Licensed inventions (patented)	793 *583*	699 *507*
Collaborative (patented only)	389	349
First licensed to foreign firm	206	178

Table 2: Descriptive statistics

	All inventions			*Licensing contracts providing for royalties*		
				All	*External licensees*	*Spin-off licensees*
	(mean)	*(min)*	*(max)*	*(mean)*	*(mean)*	*(mean)*
Collaborative invention	.151	0	1	.127	.139	.103
Director-inventor	.133	0	1	.408	.323	.595
Biomedical section	.600	0	1	.763	.732	.831
Patent family size	2.550	0	45	4.731	4.432	5.395
Post 1990 invention	.748	0	1	.669	.584	.856
Commercialization				.463	.517	.344
Spin-off licensee				.311	--	--
Foreign licensee				.301	.363	.164

Table 3: Licensing hazards 1: domestic versus foreign (competing risks Cox models)

	Model 1	*Model 2*	*Model 3*
Foreign licensee	-1.783*** (.274)	-1.724*** (.277)	-1.705*** (.269)
Collaborative invention		-.708** (.304)	-.608** (.279)
Collaborative*foreign		.793** (.333)	.732** (.310)
Director-inventor			1.398*** (.208)
Director*foreign			.298 (243)
Biomedical section	1.168*** (.211)	1.100*** (.210)	.924*** (.215)
Biomedical*foreign	-.619*** (.234)	-.542** (.234)	-.606** (.246)
Patent family size	.066*** (.007)	.079*** (.009)	.055*** (.010)
Patent family*foreign	-.012 (.155)	-.026** (.011)	-.033** (.013)
Post 1990 invention	-.019 (.183)	.048 (.187)	-.155 (.190)
Post 1990*foreign	-.138 (.206)	-.212 (.210)	-.216 (.216)
Observations (events)	2245 (630)	2245 (630)	2245 (630)
Log-likelihood ($p > chi^2$)	-4926.874 (.0000)	-4923.125 (.0000)	-4789.436 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 4: Licensing hazards 2: spin-off versus external (competing risks Cox models)

	Model 4	*Model 5*	*Model 6*
Spin-off licensee	-2.499*** (.315)	-2.438*** (.319)	-2.353*** (.302)
Collaborative invention		.189 (.134)	.225* (.131)
Collaborative*spin-off		-.999*** (.352)	-.856*** (.288)
Director-inventor			1.407*** (.119)
Director*spin-off			.684*** (.214)
Biomedical section	.574*** (.107)	.598*** (.108)	.431*** (.110)
Biomedical*spin-off	.456** (.220)	.361 (.223)	.136 (.228)
Patent family size	.057*** (.005)	.053*** (.005)	.031*** (.007)
Patent family*spin-off	.007 (.008)	.028*** (.011)	.009 (.011)
Post 1990 invention	-.446*** (.102)	-.462*** (.102)	-.629*** (.102)
Post 1990*spin-off	1.573*** (.261)	1.664*** (.268)	1.499*** (.266)
Observations (events)	2245 (612)	2245 (612)	2245 (612)
Log-likelihood ($p > chi^2$)	-4790.771 (.0000)	-4784.471 (.0000)	-4649.138 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 5: Likelihood of commercialization (logit models)

	Model 7	*Model 8*	*Model 9*	*Model 10*	*Model 11*
Foreign licensee	-.547***	-.532***	-.658***	-.596***	-.588***
	(.192)	(.193)	(.199)	(.202)	(.202)
Collaborative invention		.586**	.518**	.518*	.541**
		(.260)	(.264)	(.266)	(.267)
Spin-off licensee			-.538***	-.438**	
			(.198)	(.204)	
Director-inventor				-.414**	
				(.186)	
Director*spin-off licensee					-.711***
					(.252)
Director * external licensee					-.649***
					(.227)
Non-director * spin-off licensee					-.780***
					(.277)
Biomedical section	-.425**	-.389*	-.340	-.284	-.268
	(.205)	(.206)	(.208)	(.211)	(.211)
Patent family size	-.007	-.014	-.011	-.005	-.006
	(.014)	(.014)	(.014)	(.015)	(.015)
Post 1990 invention	-1.143***	-1.110***	-1.080***	-1.051***	-1.087***
	(.183)	(.210)	(.191)	(.192)	(.195)
Constant	1.136***	1.098***	1.173***	1.204***	1.285***
	(.210)	(.210)	(.213)	(.214)	(.220)
Observations	628	628	628	628	628
Log-likelihood	-402.364	-399.798	-396.071	-393.605	-391.881
($p > chi^2$)	(.0000)	(.0000)	(.0000)	(.0000)	(.0000)
Pseudo-R^2	0.072	0.078	0.087	0.092	0.096

Standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 6: Likelihood of commercialization (propensity score matching)

	Model 12 (foreign vs. domestic)			*Model 13 (spin-off vs. external)*		
	Unmatched	*ATT*	*ATE*	*Unmatched*	*ATT*	*ATE*
Treated	.370	.370		.344	.344	
Untreated	.503	.476		.517	.392	
Difference	-.133	-.105	-.113	-.174	-.049	-.112
S.E. (bootstrapped)		.046	.047		.048	.048
95% Confidence interval		-.197	-.206		-.016	-.207
		-.014	-.021		.047	-.145

Note: Kernel matching (Gaussian kernel; bandwidth = .06); standard errors obtained through bootstrapping (n = 100)

Figure 1: Licensing hazards: domestic (0) versus foreign (1) licensees

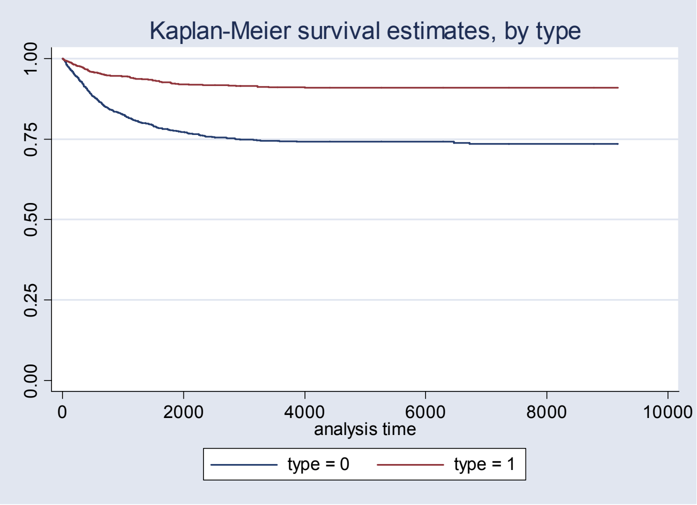
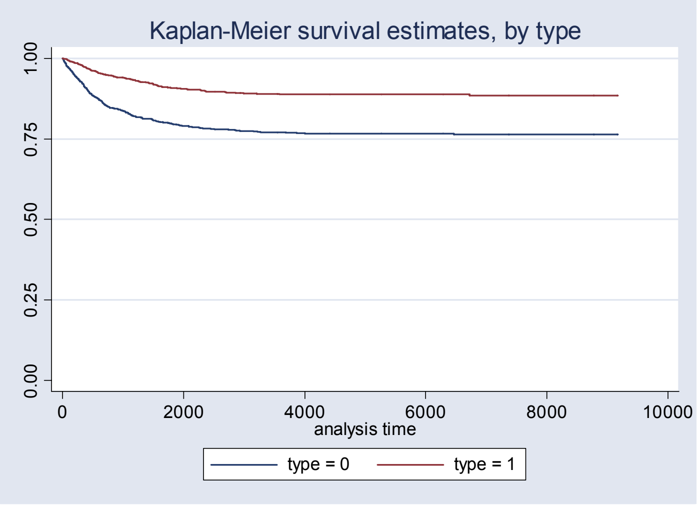


Figure 2: Licensing hazards: external (0) versus spin-off (1) licensees



THE UNEQUAL BENEFITS OF ACADEMIC PATENTING FOR SCIENCE AND ENGINEERING RESEARCH

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Abstract

We analyzed the scientific productivity of a sample of academic scientists that contribute to the field of Materials Science in the post-patenting period, by means of several econometric techniques suitable to treat unobserved heterogeneity, excess zeros and incidental truncation. Although patents do not alter the track of publications in the overall sample, we show this effect to be generated by two opposite effects: Materials Engineers increase their publications after patenting, whereas Materials Chemists experience a decrease. Besides, Materials Engineers who were academic inventors have a higher impact factor than their non-inventors colleagues, although the positive effect tends to vanish both for very basic publications and for serial inventions. Finally, a clearly negative effect is registered when we consider only very basic publications made by Materials Chemists. We interpret our findings as depending on different epistemologies of scientific and engineering research and discuss the implications for both university managers and policy makers.

Keywords: academic patenting; science and engineering research; technology transfer; science policy; university management

JEL: O31; O33, I23; I28

1. Introduction

In recent years academic institutions have become increasingly involved with technology transfer and academic patenting. During the last two decades, institutional and legal changes similar to the 1980 USA Bahy-Dole Act have been debated and approved in many countries, mirroring the political consensus behind the new role given to universities of becoming professional traders of technologies and of applications for industry1.

Current US figures are impressive: according to the AUTM survey (AUTM, 2005), in 2005, US member universities have filed 15,115 patent applications (grown at an average rate of 55% year by year in the last 5 years), which resulted in 3,278 patents granted. They created 628 new companies (nearly two every day), held more than 28 thousands active licenses, nearly 5 thousands of which started in 2005, and were responsible for the launch of 527 new products on the market.

Although aggregate statistics are not available for European countries and generalization is made complicated by several differences in regulations and practices, European universities have experienced a similar trend, although perhaps reduced in magnitude (Geuna and Nesta, 2003; see also ProTon, 2007).

From both sides of the Atlantic, this overall trend has initially raised different feelings. On the one hand, many members of the academic community, especially the senior professors, have showed considerable reticence to immoderate commercial openness, for fear that the pressures of market might be at odds with freedom of science, and raised concerns that education of students might also be disregarded under the burden of more lucrative activities (see for instance Lee, 1996). On the other hand, academic patenting and technology transfer in general were seen as a viable way of easing communication between science and market, unlock science from an ivory-tower position that allowed considerable independence, but limited impact on social and economic wealth, and favored mutually beneficial exchange of ideas and competencies.

Along the years, the initial skepticism eventually faded and it is now common place for universities to advertise their linkages with industrial partners and their commercial activities as a signal of good quality and prestige of the institution. Among the reasons behind this shift were several pieces of evidence presented in the latest years, which reveal that, in fact, top-rated universities for both research and education were among the best performers for number of patents issued, and license income (Henderson et al., 1998; Milken Institute, 2006). Besides, several preliminary analyses conducted at the level of individual scientists, rather than institutions, have confirmed that patenting does not jeopardize publications and is even likely to increase productivity in the post-

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[1] After the 1980 Bahy-Dole Act, similar lows that assign de jure IPRs from publicly-funded research to the principal-investigator's institutions were approved in Canada, UK, and nearly all western European countries, except from Italy, Finland and Sweden (OECD, 2003).

patenting period. While a clear interpretation of this supposed "complemetarity effect" is still debated, the evidence provided so far suffered several limitations. First, the lack of good metrics to measure the character of research (quality, scope, decay, etc.) does not allow to rule out the existence of unobserved effects, such as, for instance, the advocated deterioration in the generality and scope of research. Second, empirical analyses are disproportionately based on Life Sciences and lack an appreciation of the differences related to aim and scope of the sub-field to which a scientist contributes. Our work aims at contributing to the latter point, by offering an empirical analysis of the post-patenting effect on productivity and character of research, based on a sample of researchers in Materials Science.

We use an unbalanced panel of 1276 Italian scientists working in the field of Science of Materials of which we gathered complete data on scientific activity (number, level of basicness ad impact of publications), patent applications, subfield and other personal data (gender, seniority, affiliation). Our time-span window covers since the conventional entrance in the academic career (23rd year for all) until the end of 2003. The effect of post-patenting on scientific performance is studied by means of several econometric techniques suitable to treat different problems that usually affect this kinds of analysis, given the characteristics of the experimental design (endogenous selection into patenting activity, unobserved heterogeneity) and the features of the dependent variable (positive integers with excess zeros, incidental truncation). In particular, given lack of good instrumental variables in this setting, we adopted the Inverse Probability of Treatment Weighted (IPTW) approach (Azulay et al., 2006; Breschi et al. 20067), in order to address the problem of endogenous selection into patenting

By separating our Materials scientists among the sub-samples of Materials Chemists and Materials Engineers, we show that Engineers get benefits form patenting, while Chemists do not. We further disentangled our analysis by considering both qualitative effects and serial vs. occasional patenting.

The paper is organized as follows. Section §2 describes the terms of the debate upon the effect of academic patenting on scientific publication, presents the results of the empirical investigations provided so far and states the research question addressed in following sections. In Section §3 we describe the dataset, in Section §4 we present the indicators and the models used to address unobserved heterogeneity, excess zeros and incidental truncation affecting this kind of analyses. Section §4 presents the models and results. Section §5 summarizes the findings and draws conclusion and policy implications.

2. The state-of-art debate and our research hypothesis

University patents have increased drastically in the last 25 years. In the USA, the post-Bahy Dole Act period was characterized by a steep surge of university patents (steeper than the surge of corporate patents) (Henderson et al., 1998). From the one side, this trend was shown to be largely supported by increased opportunities to patent in biotechnology and ICT sectors that opened-up new areas of patentability[2] and convinced researchers of the opportunity to patent their discoveries (Mowery et al., 2001; Hall, 2005). From the other side, internal universities policies provoked an increasing number of disclosures that resulted in more patents issued and licensed (Thursby and Kemp, 2002).

With regard to patent quality, empirical investigations based on both USPTO and EPO data have indicated that universities and public research organizations (PROs) produced patents of higher quality, when compared to the private sector patents (Henderson et al., 1998; Mowery and Ziedonis, 2002; Bacchiocchi and Montobbio, 2006). The methodology developed to draw this conclusions is based on citation analyses of patent data developed in the later 90s, that assess importance as the number of forward citations received by a patent, and generality as the number of different patent classes from which a patent receives citations (Trajtenberg et al., 1997). This difference was shown to be caused mostly by patents produced by USA universities in chemical, drug and medical classes, while European and Japan academic patents do not substantially differ from corporate patents (Bacchiocchi and Montobbio, 2006).

Comparisons of the pre and post Bahy-Dole Act figures have shown that, whereas the top performing institutions per number of patents were concentrated among the top research universities both before and after the 1980, smaller and newcomer institutions (i.e. universities that never patented before 1980) started to produce patents of lower importance and generality later on (Henderson et al., 1998)[3].

Because the higher quality of university patents was seen as depending on the wider scope and longer decay rate of academic inventions versus firms inventions, this evidence provoked concern that commercialization of science was associated to a deterioration of the breadth and basicness of academic research.

The debate upon the independence of science from markets to protect the natural sources of curiosity of scientists and their long term benefits has deep roots in science policy (for a complete

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[2] Among the key determinants were the US supreme courts decisions to allow patentability of genetically-modified organisms (Diamond vs. Chakrabarthi, 1980), software codes (Diamond vs. Dieh, 1981) and business methods (State Street & ATT vs. Excel, 1998). See Hall (2005).

[3] Mowery and Ziedonis (2002) find a non-decrease in generality and importance in a study limited to Stanford, Berkeley and Columbia universities. Although Columbia started patenting only after 1980, they found no evidence of lower quality, such as those found by Henderson, Jaffe and Trajtenberg (1998).

discussion see Nelson, 2004). The terms of the debate, as discussed by many contributions of the last years, can be briefly sketched as follows: academic institutions traditionally received funds from public and non-profit sources in exchange of scientific discoveries, later to become technological change, economic development and eventually increased social wealth. Discoveries were disseminated through publications in open-science, which, in principle, ensured free access to everybody, but at the same time, created an appropriability problem (Arrow, 1962). Policies such as the Bahy-Dole Act indeed rely on the assumption that direct firm investments in technologies disclosed by universities were going unexploited because of lack of incentives to bear the costs of development, when knowledge was set open to everybody's use. Consequently, potentially valuable applications were left on book's pages because of lack of incentives for firms to take them up. In contrast, patents would offer the advantage of temporary monopoly concession, while at the same time ensuring some kind of disclosure.

The concern of those that see patenting and publishing as rival activities is based on a number of arguments. To begin with, the problem of going beyond simple open-science dissemination, is that open science dissemination, despite several limitations and pitfalls[4], also incorporates a number of unwritten rules regulating the functioning of the scientific community in a certain desirable fashion, including a) incentives to prompt disclosure, b) a mechanism for validation strictly internal to the community of peers, and c) a distribution of rewards based on scientific merits (Dasgupta and David, 1987).

Overcoming open science publications as the main scientist's goal -it is warned- will imply diverting from the previous rules, with potentially negative consequences, especially in the long term. With regard to point a), the argument goes that, while it is always in a scientist's interest to disseminate as much as possible his or her own publications, it is generally the interest of a patent holder that patents stay unnoticed, even after publication ceases to jeopardize novelty. Hence, a first matter of concern is that patenting may refrain scientists to publish or at least slow down dissemination thus reducing the pace of knowledge advance[5]. Point b) relates to the fact that patent, unlike publications, are not being discussed and validated by the scientific community, because patent examiners are called to check novelty and replicability, rather than validity, importance and scientific method, and this might jeopardize the quality and reliability of the

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[4] By way of example, well documented effects of cumulative advantages (such as the "Matthew Effect"), causing unequal returns of effort and merit are attributed to the fact that articles are much more numerous than what a scholar can read, which gives known names more chances to be picked-up (Merton, 1968). The so-called Plank's Principle (Levin et al., 1995) also reinforces the idea that attribution of scientific merits is affected by political influence (Hagstrom, 1965).

[5] In principle, publications are delayed as a minimum until the filing of a patent, in those systems such as EPO and WIPO that do not accept the "grace period" exception. In practice, this is likely to occur also in countries that recognize the grace period if the inventor wants to keep the option to extent patents beyond the national borders later on.

knowledge disclosed (Myer, 1995). Finally, the concern raised under point c) is based on the fact that science and market differ in their appraisal of fundamental contributions. Hence market payoffs, such as those associated to a successful patent, may divert scientists from their traditional goals of pure research and teaching. As Merton was first to articulate, the fact that scientists produce knowledge that is diffused as a public good does not exempt them from chasing their (private) benefits resulting from discovery (Stephan, 2004). The strength of the scientific community was ultimately based on providing a regulating mechanism (alternative to market), to distribute merits and recognition in a way that fosters the production of fundamental knowledge, for which market alone offers little incentives. Allowing commercialization of scientific results hence looked to many like discarding this strength from its very basic foundations.

In addition to the previous, concerns were raised with regard to the problem known as the "anti-commons effect", which arises when some relevant resource, such as a research method or material, is property of many different owners, having rights to exclude others from its use. In this case, multiple and conflicting ownership and transaction costs may cause underuse of the resource, since no one person can use the whole (Heller and Eisenberg, 1998)[6].

Several empirical investigations have been recently conducted to test the effect of patenting on subsequent scientific activity, based on both comparisons of institutions and individuals and on both cross-sections and longitudinal data. So far, two main findings have emerged quite consistently. First, by looking cross-sectionally at the group of scientists that ever patented vs. those that didn't, all studies show that the academic inventors, despite representing a small proportion of the population (10-15%), are disproportionately concentrated among the most productive in research. Fabrizio and Di Minin (2005) find a positive correlation between actual and lagged numbers of papers and patents, in a sample of 150 inventors and 150 controls. Breschi, Lissoni and Montobbio (2007) show that the academic inventors published on average one paper more than a matched-pair sample of researchers that never patented and that this difference is higher for serial inventors. Stephan, Black, Sumell and Gurmu (2007) run a zero-inflated negative binomial regression in a large sample of doctorate-recipients and find that patent counts and publication counts are positively related after controlling for field, seniority and other institutional and job characteristics. Carayol (2007) finds similar results for a sample of scientists at Louis Pasteur University. Among the institution-level analyses, Van Looy et al. (2004) find that

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[6] In the USA increasing concern upon the availability of research instruments was raised after the Madey vs. Duke decision (*Madey v. Duke U.*, F.Supp. 2d 420 (M.D.N.C. 2001)), that substantially reduced the experimental use exception, i.e. the right of a third party to "use a patented invention without inventor authorization for purposes of philosophical experimentation, to satisfy curiosity, or ascertain functionality of the patent" (*Whittemore v. Cutter*, 29 F.Cas. 1121). The reason to reject the experimental exception right raised by Duke was indeed that the university was no longer recognized as having a non-profit, educational mission (Lowry, 2005).

researchers who were systematically involved in contract research published more than the colleagues in the control sample and argue for a complementarity of research and application[7]. Although longitudinal evidence is still preliminary and suffered of several problems in the treatment of data, available studies to date hinted that patents might not only be invented by the most productive in research, but can also be associated to an increase of publications (Azoulay et al, 2006; Breschi et al, 2006; Fabrizio and Di Minin, 2005)[8]. The effect seems non-negligible, in terms of magnitude, and occurs either in the year of the invention, or in the following one or two years, which by and large corroborated the idea that patenting and publishing may be complementary, mutually sustaining, activities (Azoulay et al., 2006; Breschi et al. 2005; Fabrizio and Di Minin, 2004).

With regard to the spectrum of university activities, the previous investigations were based upon various scientific fields of S&E (Chemistry, Physics, Life Sciences, Computer Sciences, Mechanical and Electronic Engineering), although, at present, Life Sciences happens to be the most widely analyzed field, which advices some cautions in the generalization of results to other disciplines. With regard to the anti-commons hypotheses, a survey of Walsh, Cho and Cohen conducted among biomedical scientists revealed that scientists did not claim to suffer any strong change in the attitude to share materials and methods (Walsh et al., 2006). Besides, evidence that the citations received from papers associated to patented materials and methods decreased after the patent was being issued were found by Murray and Stern (2007), in a sample of patent-paper pairs in biotechnologies.

The empirical evidence discussed so far has made a very impressive job in putting forth new issues and discarding unsupported preconceptions. At the same time, several issues are left open and deserve further investigation. Our idea is that two areas of improvement demand specific attention: first, very few analyses encompass assessments of the character of the knowledge disclosed in the post-patenting period[9], and this mirrors a fundamental paucity of both metrics and theoretical concepts to characterize research beyond sheer productivity. Second, little consideration has been devoted to how differences in the nature and scope of the various fields of S&E to which a researcher contributes might affect the relation between his/her scientific and inventive work. Among the empirical analyses mentioned before there was no attempt to separate

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[7] They compare the performances of a unit departments rather than of individuals. The departments were part of the contract research units of Catholic University of Leuven (BE) and the department controls were made of (pure research) faculties of the same university in the same research fields.

[8] An exception is the study by Agrawal and Henderson (2002), that finds no statistically significant effect in a sample of MIT scholars.

[9] To the best of authors' knowledge, only Azoulay, Ding and Stuart (2006) and Breschi, Lissoni and Montobbio (2006) use metrics specifically aiming at measuring qualitative features of research. Agrawal and Henderson (2002) and Fabrizio and Di Minin (2005) make use of citations counts, which however depend on the article age, as well as on the patterns of citations that in turn are journal-specific. As such, their use as an indicator of quality is debated.

the effect according to field or subfield, in part due to the small numbers of patents found, that did not advice further breakdowns.

Our paper is especially aimed at addressing the latter issue. We expect that no unique impact is linking the inventive activity of a scientist with the post-patenting performance, but rather that this relation is at least partially field-dependent. The starting point to build our hypothesis would be to consider that not all disciplines stand in the same relation and earn equal benefits from serving practical ends. A first rough, but quite clear-cut distinction can be made between Hard Science and Engineering.

Although Epistemology of Engineering is still regrettably quite-undeveloped, a key difference of doing research in engineering, as opposed to hard science, is that, whereas science is aimed at the understanding of phenomena, and somehow sees technology as instrumental to that end, engineering is in its fundamental and epistemological essence a science applied in scope, i.e. a discipline that addresses and aims to solve problems of industrial (practical) relevance, by means of a rigorous scientific method (Vincenti, 1990). By "applied in scope" we do not mean to suggest that engineering is a an applied science, in the sense of being deductive, i.e. a discipline that applies findings of a hierarchically-dominant scientific domain into practice, such as conventional wisdom suggests[10]. Rather, we mean that the application to solving a practical problem is the engine that moves the investigation.

For instance Walter G. Vincenti says:

> *I have never attempted to design an airplane in my entire career as a research engineer (although I participated in planning and designing large aeronautical research facilities). The atmosphere in which I worked, however, and the knowledge I helped produce, were conditioned by the needs of airplane designers who visited our laboratory. My collegues and I were keenly and continuously aware of the practical purposes we served.* [Vincenti, 1990:7]

In a survey of university and firm collaboration, Mansfield (1995) found that university scientists were very frequently conducting academic research on problems and ideas that they became aware of while doing industrial consulting. In the interviews (a large proportion of interviewed scientists in fact happened to be engineers), researchers reported that the contribution of firms and users could vary from being very marginal up to being fundamental in indicating the problems and the direction of research.

Following this line of reasoning, it is hence consequent that working on practical problems such as those posed by inventing a new functional tool can be in principle more fertile of ideas for engineering than for science. Our hypothesis is hence that engineers would be more likely to benefit from working on practical problems than their chemists colleagues.

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[10] An epistemological discussion of the argument would exceed the purposes of the present work. See Walter G. Vincenti (1990) and Edwin T. Layton (1974) for a more comprehensive discussion.

3. Sample and Data

The database used for the present study was based on a list of scientists members of an Italian association for research in Materials Science, called INSTM (Consortium of Italian Universities for Science and Technology of Materials). The association gathered, at the end of 2003, over 1660 researchers, belonging to 42 Italian universities and public research centers, which virtually represent all universities and public research units working in the field of Science of Materials throughout Italy.

According to the Carnegie Mellon Survey, academic research in Materials Science is perceived by firms among those that contribute more substantially to industrial R&D (Cohen et al., 2002). Given that admittance of researchers to INSTM association is individual and voluntary, and requires paying an annual membership fee, scientists are self-selected as those working in the area of Materials Science. We took all members at the end of 2003 that were born in 1954 or later, which resulted in a final list of 1323 names and eliminated the lab engineers and technician, which leaves us with a list of 1276 names. Materials Science is a considerably homogeneous field, and its scientific community gathers contributions from several mother disciplines: mainly Chemistry, Engineering, Physics, and, more rarely, Mineralogy and Geology. Our sample of scientists mirrors this organization: observed scientists resulted to be distributed in the following proportions: 919 Materials Chemists (72%), 309 Materials Engineers (34%), 35 Materials Physics (3%), plus 12 scientists (1%) from several other sub-fields[11].

Our sampled scientists were in 2003 tenured professors, as well as untenured researchers, PhD students and research assistants, thus providing a good representation of the variety of roles and types of professionals working for the Italian public research system. To the best of our knowledge, we are not aware of any selection bias affecting stratification of our sample.

For each of the 1247 names we collected all papers published in open science journals (as listed by ISI Science Citation Index) and all USPTO or EPO patent issued (from Delphion Thomson)12. See patent descriptive statistics in Table 1.

We take as a conventional starting observation time (t_{i0}) the year in which the scientist was 23 (which is the minimum age to obtain an MS degree in the Italian education system) and collected all information from that year to the end of 2001. Publication lags in Materials Science range from four weeks to six months; therefore, we can take the publication year as a proxy of the discovery date. Similarly, we take patent priority date as the proxy of the invention date. Given that the ISI

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[11] Based on classifications of the Italian Ministry of Research (http://sito.cineca.it/murst-daus/docenti/docenti.shtml)

[12] Extensions of patents from EPO to WIPO or vice versa were checked and duplicates were eliminated (only the original patent was kept).

database allows only querying for full surname, plus name initials of the author, the case of including homonyms is highly frequent. To cope with this problem, we filtered the resulting list of papers on the basis of coherence of scientific fields (Materials Science) of the reviews, according to the ISI Journal of Citation Report (JCR) taxonomy (multidisciplinary fields included).

We apprised basic/fundamental vs. applied orientation of research by means of the IpIQ ranking of journal Level, which is an indicator expressed in a 1 to 4 rank, where "very basic, untargeted research" is set equal to Level 4 (Narin et alt. 1967).

In order to appraise the quality of the scientific papers, we used the Impact Factor (IF) of the scientific journals where the articles were published[13] (for general information on the index and on citation-based indicators see Diamond, 1986; Narin and Hamilton, 1996). Usage of the journal's Impact Factor as a proxy of quality of the published article equals to making the assumption that good journals only publish good papers and vice versa.

Table 2 (a and b) provides a complete explanation and summary statistics of the dataset variables.

4. Methods and results.

In this section we study the effect of post-patenting on the scientific performance by means of a number of econometric techniques in order to account for the multiple problems that usually affect this kind of analysis, given the characteristics of the experimental design and the nature of the dependent variable under study in each of the settings considered.

In general, the estimation of the causal effect of a treatment (patenting) on a variable of outcome (quantity, basicness and quality of scientific production) can be difficult in non-controlled studies for the presence of confounding variables (or confounders) which both affect the outcome of interest and the probability of being treated.

We then adopt the Inverse Probability of Treatment Weighted (IPTW) approach (Azulay et al., 2007; Breschi et al. 2007), a method that is widely accepted in biostatistics for estimating Average Treatment Effects (ATE) in observational studies (Robins et al., 2000; Hernan et al. 2001), which address the problem of endogenous selection into treatment in a similar way to others propensity-scores matching techniques (Rosembaum and Rubin, 1983).

This method relies on the crucial assumption that the selection into treatment is based on observables variables and that the modeling structure of selection is correctly specified (see Azoulay at al. 2007 for details). It nonetheless brings the considerable advantage of non requiring exclusion restrictions for identification, unlike in the Instrumental Variable approach, so that there is no need of instruments (which are not easy to find in this context).

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[13] Impact Factor figures were taken from the 2002 edition of JCR.

With IPTW the role of confounders is neutralized by weighting each observation with its (stabilized) inverse-probability of treatment and it can be interpreted as the inverse of a subject's conditional probability of receiving her treatment history up to time *t*, given past treatment history and others "prognostic" factors.

We implement this procedure by estimating a logit model on the probability of applying for a patent for the first time. Logit formulation and estimates are reported in Table 10-11.

Weights obtained from the logit analysis will then be used to weight each observation, when regressing the outcome variable of interest Y on the set of covariates X and on the treatment variables Z.

The set of covariates X will include SENIORITY_{it}, which measures the number of years a scientists had spent in academia up to year t , EXPTTOMA_{it}, which proxies the experience of the institution in patenting, and hence captures environmental effects (measured as the total number of patents granted to the institution in the previous 5 years), and a dummy variable for gender (GENDER_{i}). The set of treatment variables Z includes PAT_{it} (flow treatment indicator), expressed as the number of patents granted to scientist *i* at time *t* (where *t* is the year of priority of the first application for patents that has scientist *i* among the inventors), POSTPAT_{it}, (regime treatment indicator), a dummy equal to 1 if scientist *i* has at least one patent up to year *t*, and CUMPAT_{it} (cumulative treatment indicator) as the total number of patents granted to scientist *i* up to year *t*.

4.1 Scientific productivity: quantity of scientific production.

The first question we want to investigate is the effect of patenting on the quantity of scientific production measured by the number of articles published in a year.

We first consider the raw number of (authored and co-authored) scientific papers published by scientist *i* in year *t* (PUBL_M_{it}). As visible from Since this is a count variable showing a disproportional amount of zeroes (more than 40%) (see Table 2) the natural choice for modeling it is a Zero Inflated Negative Binomial (ZINB) model. This model entails two different regressions because it assumes two different processes governing the dependent variable: one for the inflation part (zero outcome) and the other for the count outcome (without extra-zeroes). Moreover it allows for unobserved heterogeneity among subjects by assuming individual gamma distributed random effects. This model is estimated via iterative Maximum Likelihood techniques (Wooldridge, 2002) with robust standard errors clustered across subjects. Table 13 shows the estimating results. Looking at the whole sample no statistically significant effect is exerted by either the lagged patent regime variable (POSTPAT(-1)_{it}) and by the cumulative number of past patents (CUMPAT(-1)_{it}).

However, since the average number of annual scientific publications depends largely on the researcher's scientific field (see Table 6), we run separate regressions for the two sub-samples (ENGINEERS and CHEMISTS) that offer a fairly numerous number of observations. The results of this estimates are reported in Table 13. After the first patent, engineers tend to have a greater yearly number of publications than non-patenters (although the positive estimate on POSTPAT$_{it-1}$ is significant only at 10% level). Conversely, for chemists we find a negative impact, significant at 10%. Besides, we also see a positive effect of past cumulated patents (CUMPAT) on articles productivity, which tends to overwhelm the former negative effect after the 3-4th patent granted, although this counter-effect of CUMPAT is relevant only for a small proportion of the observations (for instance, in 2001, only the 2% of chemists had more than 3 patents granted, as shown in Table 9).

The estimated sign of the controls are quite simply explained: articles productivity first increases with seniority (SENIORITY$_{it}$) and eventually declines at a later stage of career (SENIORITYsq$_{it}$). Men tend to have a higher productivity than their female colleagues (GENDER$_{it}$,), while the overall number of past patents owned by the institution of affiliation (EXPTTOMA$_{it}$), which captures the institutional/environment effect, has a positive impact on a scientist's productivity. The calendar-time dummies (DUMYEAR*$_{it}$) show that, on average, publications have increased in recent years.

We then consider a different measure of scientific productivity which takes into account co-authorships, i.e. shared articles, and build an alternative weighted indicator of publications by dividing the number of yearly publications by the average number of authors (WPUBL_M$_{it}$). Because this new variable is no longer a positive integer, we are free to use a standard linear model. We partially recover its skewedness (due to the excess of zeroes) by means of the following transformation LWPUBL_M$_{it}$ = log(WPUBL_M$_{it}$ + 1). For the sake of comparison, we also estimate a similar model for the original un-weighted variable LPUBL_M$_{it}$ = log(PUBL_M$_{it}$ + 1). This "linearization" of the former model has the advantage of allowing the application of a linear Fixed Effect (FE) estimation method which is more robust (although less efficient) than ML methods. The results are reported in Table 15-16. The linear model with the weighted dependent variable basically confirms the findings of the ZINB model, whereas the comparison model with the un-weighted dependent variable confirms the findings only for the engineers, while for the chemists the estimated relation of publications and patents is not statistically significant.

4.2 Scientific productivity: basicness of scientific production.

The second question we want to investigate is whether patenting hampers or boosts basic scientific research. We follow an approach similar to the previous subsection, but take as dependent variables the raw number of scientific papers authored (or co-authored) by scientist *i* in year *t*, which resulted to be ranked as "very basic" (level 4) in the IpIQ classification (PUBLBAS4$_{it}$), its log-linear transformation (LPUBLBAS4$_{it}$) and its author-weighted version (LWPUBLBAS4$_{it}$) which takes into account co-authorship. Again the analysis is further disentangled between engineers and chemists and models are estimated by ZINB-ML (Table 14) and standard linear OLS-FE (Tables 17-18) techniques respectively. The only notable and statistically significant effect relates to the sub-sample of chemists. While in fact patenting does not seem to impact the basic scientific output of engineers, for chemists we find in both the equations a negative impact of patenting on the basic scientific output.

4.3 Scientific productivity: quality of scientific production.

The final question of our analysis concerns the effect of patenting on the quality of a scientist's research. To answer this question, we first have to overcome the problem of finding an appropriate measure of scientific quality. Several approaches has been proposed by the scholars, the most common of which is to capture the quality of a researcher's output by counting the total number of citations received (Agrawal and Henderson, 2002; Breschi et al. 2006; Fabrizio and Di Minin, 2007). However this method is not immune from drawbacks, since it can be dramatically affected by the specific characteristics of the scientific field considered such as different publications rates, different cross-citing practices, different citation trajectories along time and so on.

Azoulay et al. (2007) tried to overcome such drawbacks by constructing two alternative metrics: the first is based on the proportion of publications in which the researcher appears in first and last position of the authors' list. The second (also adopted by Calderini et al., 2007) is based on the average journal impact factor (IF) of the articles published in a given year. We follow the latter approach, although in a slightly different way.

Given the different distribution of the average IF among journals of different scientific field (as outlined by Table 3), in addition to run separate regression according to the researcher's main scientific field (as in the previous sub-sections), we also standardize the IF score assigned to each publication as follows: STDIFAC = [(IF$_{it}$-mean(IF))/std. dev(IF)], where the mean and the standard deviation of IF are calculated with respect to the journal scientific field on which the article appeared. Thus STDIFAC$_{it}$ is the average of the standardized journal impact factor index (STDIFAC) for the articles published in year *t* by scientist *i*.

This dependent variable is clearly affected by incidental truncation, since it the Impact Factor is only observable when the researcher has at least one publication in year t (i.e. if the dummy variable DUMPUBL_{it} is equal to 1). We treat truncation by means of a Heckman selection equation (based on DUMPUBL_{it} as dependent variable) and a truncated regression (based on STDIFAC_{it} as dependent variable) that are estimated simultaneously along with the variance of the error component u_1 of the outcome equation σ (the variance of the error component in the selection u_2 is set to 1) and the correlation ϱ between u_1 and u_2 (see Heckman, 1979 and Amemiya, 1985 for details). Results are reported in Table 19[14].

In the estimates based on all observation we find that researchers, after the first patent granted, tend to publish in journals with (average) higher IF scores than non-patenters, which mirrors an increase in their ability to publish on higher-impact journals.

However, for engineers, we find that the positive and significant coefficient associated to (DUMPAT_{it}) is counterbalanced by the negative and significant coefficient of the cumulative number of patents granted (CUMPAT_{it}), which suggests that this increase in performance comes at a decreasing marginal rate, and would eventually be neutralized and overwhelmed after about the 3rd patent granted.

5. Comments of results and conclusions

In recent years academic institutions have become increasingly involved with technology transfer and academic patenting. The reasons behind this institutional and managerial shifts of universities have been largely discussed by the scholars of science and innovation, which have also debated extensively the potential benefits and risks. From a broader perspective, science is less and less seen as an instrument of political competition between nations worldwide, as during the second half of the XX Century, and is more and more perceived as a means to foster the competitiveness and wealth of the economies at a national and local level. To ensure a high degree of communication and exchange of knowledge between science and market is as important as having a first-class research to support local firm's competitiveness.

In the European Union, a considerable number of policy actions of the last decade have been addressed to increasing the dissemination of fundamental research results, based on the (true or mistaken) assumption that the quality of basic science itself was satisfying, while much of the potential of new knowledge made available got unexploited and never left the labs.

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[14] We included individual dummy variables (estimates not reported) in the outcome equation to control for potential sources of unobserved heterogeneity (gender is omitted to avoid multicollinearity, given its non-time varying nature).

All those policies have been based on the assumption that collaboration between science and market does not significantly jeopardize the ability of scientists to do fundamental research, disclose their achievements on open-science journals and chose their own topics of inquiry independently. Scientists –it is believed- can in principle patent and *sell* IPRs as a by-product of their normal activity, as much as they *sell* teaching and education services to their colleges.

This assumption has proved to hold in preliminary empirical evidence (Agrawal and Henderson, 2002), which additionally highlighted an unexpected boosting effect on publications in the post-patenting period (Azoulay et al., 2006; Fabrizio and Di Minin, 2005; Breschi et al., 2006).

However, we claimed that at least two important pieces of information are missing to enlighten those findings: 1) qualitative assessments of the knowledge disclosed in the post-patenting period, and 2) an appreciation of the differences of the aim and scope of the sub-field to which a scientist contributes. Besides, the state-of-art evidence is disproportionately based on the field of Life Sciences, which in the last decades experienced a pretty unique contamination of private and public R&D (Mowery and Ziedonis, 2002).

This paper has contributed to both points, by offering an empirical investigation based on a large sample of scientists in Materials Science, an academic discipline deemed of key importance by industry (Cohen et al., 2002) and at the same time gathering contributions from Chemistry, Physics and Engineering. Indicators of quality of publications used include impact factor and level of the journal.

Figure 1. Summary of post-patent effects: sign and significance.

		QUANTITY			BASICNESS			QUALITY
		IPTW - ZINB	IPTW - OLS_FE	OLS_FE weighted	IPTW - ZINB	IPTW - OLS_FE	OLS_FE weighted	HECK_ML
ALL	**postpat**	+	+ ***	+	−	−	−	+ **
	cumpat	+	−	+	−	−	−	−
ENGINEERS	**postpat**	+	+ ***	+ **	−	−	−	+ **
	cumpat	−	−	−	−	−	+	− ***
CHEMISTS	**postpat**	− **	+	− **	− **	− **	− ***	+
	cumpat	+	+	+	−	+	+	+

The models we run were suitable to treat unobserved heterogeneity, excess zeros and incidental truncation. A summary of the effects estimated through the diverse models is presented in Figure 1. Our results on the overall sample suggest that patenting does not substantially alter a scientist's publication track. However, when we separate the sample by sub-fields groups and run separate analyses for Engineers and Chemists, we found that Materials Engineers experience an increase of quantity and quality of publications after the invention, while Chemists of Materials might experience a decline in quantity of overall publications (not supported by all estimating techniques) and quantity of very basic level publications.

We showed that the scientists that were contributing to the Engineering-side of Material Science research were experiencing improved performances when working on industrial applications, whereas this was not the case for those that were contributing to Materials Science as Chemists. We interpreted our results to be depending on the different epistemology of science and engineering. Although Epistemology of Engineering is still regrettably undeveloped, a key difference of doing research in engineering, as opposed to hard science, is that, whereas science is aimed at the understanding of phenomena, and somehow sees technology as instrumental to that end, engineering is in its fundamental and epistemological essence a science applied in scope, i.e. a discipline that addresses and aims to solve problems of industrial (practical) relevance, by means of a rigorous scientific method (Vincenti, 1990). Engineering in fact is inherently scoped to problems of industrial relevance, while this is not necessarily the case of disciplines, such as Physics and Chemistry, aimed at the general understanding of processes.

In principle, an alternative explanation of the findings could be that scientists and engineers have a different attitude or policies in the disclosure of research associated to patenting, for instance that Chemists might overlook publishing in open science the content of patented research. We however consider the latter explanation less plausible.

Our results are based on Italian academia and on the field of Materials Science and allow therefore limited generalization. If similar results would be confirmed by other studies, several important implications should be derived for university managers and policy makers alike. For instance frequent and intense collaborations of faculties and firms, share of research project and joint funding should be more actively encouraged in the engineering schools, than in non-engineering departments. In principle, it is plausible that similar results of different returns from industrial inspiration to different subfield-disciplines would be found in other subject domains, such as mathematics and computing, or biology and biotechnology, which might derive unequal inspiration from scoping research to industrial problems.

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Appendix: IPTW computation and “robustness” checks.

Given the logit estimates of Tables 10, let $\hat{p}_{it}$ the predicted probability for subject *i* of being treated for each year *t*. Our regime of treating specification assumes that the status of “patenter” for each researcher lasts until the end of the “follow-up”, then $\hat{p}_{it}$ equals one for each year after the first patent. The denominator[15] of the weights are computed as follows:

1) Calculate the probability of each subject *i* to receive the observed treatment at time *t* :

$$IPTW_{it}* = \hat{p}_{it} * POSTPAT_{it} + (1-\hat{p}_{it}) * (1-POSTPAT_{it})$$

2) Estimate each subject’s probability of complete treatment history up to each year *t*:

$$IPTW_{it} = \prod_{k=0}^{t-1} IPTW_{it-k} *$$

As stated in section 4 the reliability of the IPTW approach relies on the strong assumptions that there are no unobserved confounders and that the selection equation used to estimate the weights is correctly specified. Although the first assumption cannot be tested, we can relax the second one by re-estimating the predicted probabilities $\hat{p}_{it}$ by means of nonparametric approach which do not require any specification of the likelihood structure of the model (eg. logit distribution) nor any specific functional form which links the regressors to the dependent variables (eg. additive linear, with quadratics, with interactions, an so on). Several kernel estimators for categorical data has been proposed in literature (Aitchison and Aitken, 1976), in particular we follow the method proposed by Li and Racine (2004) which is for estimating density function defined over both discrete (x^d) and continuous (x^c) variables using the following joint kernel density estimator:

$$\hat{f}(x^d, x^c) = \frac{1}{nh_x} \sum_{i=1}^{n} L(X_i^d = x^d) W\left(\frac{X_i^C - x^C}{h_x}\right)$$

where $L(X_i^d = x^d)$ is a categorical data kernel function, $W\left[\left(X_i^C - x^C\right)/h_{x^C}\right]$ is a continuous data kernel function and h_x is the bandwidth for the continuous variable chosen via cross-validation methods (see Li and Racine, 2004 for further details).

Given the computationally intensive nature of these procedures which complexity increases exponentially with the sample size, we estimated the nonparametric version of the IPTW only for the subset of the engineers and the chemists and not for the whole sample.

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[15] The numerator is computed similarly using the predicted probabilities according to the model in Table 11.

We then re-run all the ZINB-ML, OLS-FE and Heckman-FE models with robust IPTW estimated non-parametrically. The findings are similar to the previous ones[16] and are summarized in Figure 2 below:

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[16] Detailed results and estimation routines are available upon request.

Tables

Table 1 - Distribution of patent per year in classes of applicants and inventor age at the time of priority.

year	inventor	research institution	private company	inventor age at priority date							total
				24 - 30	31 - 35	36 - 40	41 - 45	46 - 50	51 - 55	56 - 59	
1971	0	0	0	0							0
1972	0	0	0	0							0
1973	0	0	0	0							0
1974	0	0	0	0							0
1975	1	1	0	2	0						2
1976	0	0	2	2	0						2
1977	0	0	0	0	0						0
1978	1	0	2	2	1						3
1979	0	0	2	0	2						2
1980	0	0	2	2	0	0					2
1981	0	0	1	0	0	1					1
1982	1	1	2	1	1	2					4
1983	0	3	3	1	2	3					6
1984	1	2	1	1	3	0					4
1985	0	4	10	6	1	6	1				14
1986	0	3	6	6	1	2	0				9
1987	0	0	4	3	0	1	0				4
1988	0	0	8	2	3	3	0				8
1989	1	0	19	5	5	6	4				20
1990	1	0	10	2	7	0	1	1			11
1991	1	2	19	6	5	4	6	1			22
1992	0	3	18	6	6	5	4	0			21
1993	0	1	21	5	9	3	3	2			22
1994	0	2	15	6	6	2	1	2			17
1995	0	1	20	5	3	7	1	4	1		21
1996	1	1	17	0	8	6	3	1	1		19
1997	0	2	36	9	10	6	9	4	0		38
1998	0	2	17	4	8	4	3	0	0		19
1999	0	0	18	6	3	2	3	2	2		18
2000	0	2	8	2	0	4	2	2	0	0	10
2001	0	2	4	2	3	0	0	0	1	0	6
total	**8** (2.62%)	**32** (10.49%)	**265** (86.89%)	**86** (28.20%)	**87** (28.52%)	**67** (21.97%)	**41** (13.44%)	**19** (6.23%)	**5** (1.64)	**0** 0%	**305**

Table 2(a) - Summary of variables used in the analysis.

Variable	Description
Time varying	
T	Year
Scientific productivity	
publ_m	Number of scientific publications (authored & co-authored) in year t
publ_msq	Publ_m squared
cumpubl_m	Total number of scientific publications since entering in academia (authored & co-authored) up to year t
publbas4	Number of scientific publications (authored & co-authored) in year t in basic research
aut_m	Average number of authors for scientific pubblications in year t
aut_m4	Average number of authors for scientific pubblications in year t in basic research
wpubl_m	Publ_m/aut_m (=0 if publ_m =0)
wpublbas4	publbas4/aut_m4 (=0 if publbas4=0)
lpubl_m	log(publ_m+1)
lpublbas4	log(publbas4+1)
lwpubl_m	log(wpubl_m+1)
lwpublbas4	log(wpublbas4+1)
dumpubl_m	= 1 if she has at least 1 pubblication in year t; = 0 otherwise
Stdifac	Average journal IF (standardized by scientific field of the journal) for publications in year t
Patenting activity:	
Pat	Number of patents in year t
Postpat	= 1 for years during and after the first patent; = 0 for years before the first patent
Control variates:	
Seniority	Years spent in academia up to year t
Senioritysq	seniority squared
Cumpat	Total number of patents up to year t
Expttoma	Total number of patents assigned to the institution of affiliation between year t-4 and year t
Expttomasq	expttoma squared
dumyear75_79	= 1 t is between 1975-1979 (calendar effect); = 0 otherwise
dumyear80_84	= 1 t is between 1980-1984 (calendar effect); = 0 otherwise
dumyear85_89	= 1 t is between 1985-1989 (calendar effect); = 0 otherwise
dumyear90_94	= 1 t is between 1990-1994 (calendar effect); = 0 otherwise
Non time varying	
Gender	= 1 if male, = 0 if female
Scientific field dummies:	
dumSF1	= 1 if CHEMISTRY; = 0 otherwise
dumSF2	= 1 if ENGINEERING; = 0 otherwise
dumSF4	= 1 if PHYSICS; = 0 otherwise
dumSF3	= 1 if OTHER; = 0 otherwise

Table 2(b) - Summary of variables used in the analysis.

Variable	ALL (1276 scientists)					ENGINEERS (309 scientists)					CHEMISTS (919 scientists)				
	Obs	**Mean**	**Std.**	**Min**	**Max**	**Obs**	**Mean**	**Std.**	**Min**	**Max**	**Obs**	**Mean**	**Std.**	**Min**	**Max**
Time varying															
t	22385	1992.73	7.55	1975	2003	5341	1992.8	7.509	1975	2003	16092	1992.6	7.589	1975	2003
Scientific															
publ_m	22385	1.27	2.25	0	25	5341	0.771	1.756	0	25	16092	1.457	2.379	0	25
publ_msq	22385	6.66	25.18	0	625	5341	3.678	19.54	0	625	16092	7.783	26.843	0	625
cumpubl_m	23284	11.17	21.43	0	292	5492	5.973	13.01	0	127	16188	13.615	23.670	0	292
publbas4	22385	0.58	1.51	0	25	5341	0.097	0.464	0	7	16092	0.753	1.686	0	25
aut_m	9828	3.15	1.82	1	20	1654	3.296	1.982	1	20	7878	3.106	1.765	1	20
aut_m4	5493	4.86	1.89	1	20	328	5.461	2.667	1	20	5011	4.823	1.805	1	20
wpubl_m	22385	0.68	1.59	0	22.32	5341	0.402	1.235	0	21.55	16092	0.781	1.690	0	22.32
wpublbas4	22385	0.13	0.35	0	6.485	5341	0.021	0.108	0	1.750	16092	0.172	0.387	0	6.485
lpubl_m	22385	0.53	0.69	0	3.258	5341	0.343	0.580	0	3.258	16092	0.600	0.713	0	3.258
lpublbas4	22385	0.26	0.52	0	3.258	5341	0.054	0.227	0	2.079	16092	0.340	0.572	0	3.258
lwpubl_m	22385	1.68	1.59	1	23.32	5341	1.402	1.235	1	22.55	16092	1.781	1.690	1	23.32
lwpublbas4	22385	1.13	0.35	1	7.485	5341	1.021	0.108	1	2.750	16092	1.172	0.387	1	7.485
dumpubl_m	23284	0.59	0.49	0	1	5492	0.491	0.500	0	1	16188	0.647	0.478	0	1
stdifac	9296	-0.05	0.81	-1.90	8.530	1536	-0.272	0.678	-1.900	4.921	7475	-0.004	0.828	-	8.530
Patenting															
pat	19833	0.02	0.15	0	5	4723	0.019	0.169	0	3	14254	0.014	0.140	0	5
postpat	19833	0.07	0.25	0	1	4723	0.074	0.262	0	1	14254	0.068	0.252	0	1
cumpat	19833	0.14	0.72	0	16	4723	0.184	0.838	0	8	14254	0.133	0.637	0	10
Control variates:															
seniority	22385	12.61	8.53	1	38	5341	12.482	8.526	1	37	16092	12.687	8.573	1	38
senioritysq	22385	231.84	274.3	1	1444	5341	228.46	274.2	1	1369	16092	234.44	276.524	1	1444
expttoma	22385	3.05	5.13	0	30	5341	2.946	4.927	0	30	16092	3.075	5.204	0	30
expttomasq	22385	35.66	104.9	0	900	5341	32.947	99.64	0	900	16092	36.532	107.173	0	900
dumyear75_79	22385	0.07	0.25	0	1	5341	0.066	0.248	0	1	16092	0.069	0.254	0	1
dumyear80_84	22385	0.10	0.31	0	1	5341	0.101	0.301	0	1	16092	0.107	0.309	0	1
dumyear85_89	22385	0.15	0.35	0	1	5341	0.144	0.351	0	1	16092	0.147	0.354	0	1
dumyear90_94	22385	0.20	0.40	0	1	5341	0.195	0.396	0	1	16092	0.195	0.396	0	1
Time invariant															
gender	22385	0.69	0.46	0	1										
Scientific field															
dumSF1	21980	0.72	0.45	0	1										
dumSF2	21980	0.24	0.43	0	1										
dumSF4	21980	0.01	0.10	0	1										
dumSF3	21980	0.03	0.18	0	1										

Table 3

	Journal IF of published articles		
field	Mean	Std. Dev.	Freq.
CHEMISTRY	2.367	1.349	14704
ENGINEERING	1.166	0.878	3466
OTHER	1.884	0.823	695
PHYSICS	2.676	2.965	5869
Total	2.258	1.875	24734

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 3427.049; 3 d.f. prob = 0.0001
chi-sq with ties = 3427.720; 3 d.f.prob = 0.0001
Bartlett's test for equal variances:
chi2(3) = 9.1e+03 Prob>chi2 = 0.000

Table 4

	Journal level of published articles		
field	Mean	Std. Dev.	Freq.
CHEMISTRY	3.531	0.537	16656
ENGINEERING	2.264	0.582	3770
OTHER	3.015	0.908	883
PHYSICS	3.643	0.490	6011
Total	3.364	0.712	27320

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 7068.608; 3 d.f. prob = 0.0001
chi-squ with ties = 8616.147; 3 d.f.prob = 0.0001
Bartlett's test for equal variances:
chi2(3) = 831.3114 Prob>chi2 = 0.000

Table 5

	Age of scientists		
field	Mean	Std. Dev.	Freq.
CHEMISTRY	35.687	8.573	16092
ENGINEERING	35.482	8.526	5341
OTHER	35.394	8.060	254
PHYSICS	35.032	7.611	698
Total	35.614	8.528	22385

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 2.623; 3 d.f. prob = 0.4534
chi-sq with ties = 2.627; 3 d.f.prob = 0.4527
Bartlett's test for equal variances:
chi2(3) = 19.5610 Prob>chi2 = 0.000

Table 6

	Annual number of publications		
Field	Mean	Std. Dev.	Freq.
CHEMISTRY	1.457	2.379	16092
ENGINEERING	0.771	1.756	5341
OTHER	0.327	0.765	254
PHYSICS	1.014	2.198	698
Total	1.267	2.249	22385

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 536.295; 3 d.f. prob = 0.0001
chi-squ with ties = 653.910; 3 d.f.prob = 0.0001
Bartlett's test for equal variances:
chi2(3) = 932.9579 Prob>chi2 = 0.000

Table 7

	Annual number of patents		
field	Mean	Std. Dev.	Freq.
CHEMISTRY	0.014	0.140	14254
ENGINEERING	0.019	0.169	4723
OTHER	0.000	0.000	228
PHYSICS	0.008	0.105	628
Total	0.015	0.145	19833

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 0.300; 3 d.f. prob = 0.9600
chi-sq with ties = 7.934; 3 d.f.prob = 0.0474
Bartlett's test for equal variances:
chi2(3) = 379.2983 Prob>chi2 = 0.000

Table 8

	Cumulative number of patents in 2001		
Field	Mean	Std. Dev.	Freq.
CHEMISTRY	0.224	0.941	917
ENGINEERING	0.298	1.126	309
OTHER	0.000	0.000	13
PHYSICS	0.143	0.550	35
Total	0.237	0.977	1274

Test: Equality of populations (Kruskal-Wallis test)
Chi-squared = 0.608 ; 3 d.f. prob = 0.8946
chi-sq with ties = 2.191; 3 d.f.prob = 0.5338
Bartlett's test for equal variances:
chi2(3) = 32.3395 Prob>chi2 = 0.000

Table 9 Distribution of cumpat in 2001

ALL			
cumpat	**Freq.**	**Percent**	**Cum.**
0	1,143	89.72	89.72
1	71	5.57	95.29
2	19	1.49	96.78
3	16	1.26	98.04

4	9	0.71	98.74
5	5	0.39	99.14
6	5	0.39	99.53
7	2	0.16	99.69
8	3	0.24	99.92
10>	1	0.08	100
ENGINEERING			
cumpat	**Freq.**	**Percent**	**Cum.**
0	273	88.35	88.35
1	20	6.47	94.82
2	4	1.29	96.12
3	2	0.65	96.76
4	4	1.29	98.06
6	3	0.97	99.03
8	3	0.97	100
CHEMISTRY			
cumpat	**Freq.**	**Percent**	**Cum.**
0	825	89.97	89.97
1	49	5.34	95.31
2	15	1.64	96.95
3	13	1.42	98.36
4	5	0.55	98.91
5	5	0.55	99.45
6	2	0.22	99.67
7	2	0.22	99.89
10>	1	0.11	100

The following Logit-ML models are estimated using, for each scientist, only observations up to the year of the first patent (included).

Table 10 IPTW Estimation. Probability of patenting, logit ML regression (dep. Variable **postpat**)

	IPTW denominator (patent regime)								
	(all)			**(eng)**			**(chem)**		
	Coeff	**Se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.132	0.048	0.007	0.161	0.105	0.127	0.139	0.056	0.013
senioritysq	-0.005	0.002	0.002	-0.006	0.004	0.088	-0.005	0.002	0.004
gender	0.427	0.224	0.056	-0.389	0.435	0.372	0.666	0.272	0.014
expttoma(-1)	0.116	0.066	0.079	0.248	0.198	0.211	0.076	0.074	0.302
expttomasq(-1)	-0.010	0.006	0.112	-0.034	0.028	0.221	-0.006	0.006	0.320
publ_m(-1)	0.098	0.090	0.276	0.887	0.333	0.008	0.003	0.089	0.972
publ_msq(-1)	-0.008	0.009	0.329	-0.189	0.086	0.028	0.000	0.006	0.952
cumpubl_m(-1)	0.000	0.007	0.982	0.002	0.026	0.951	-0.002	0.008	0.773
constant	-6.016	0.335	0.000	-5.641	0.641	0.000	-6.125	0.418	0.000
	Number of obs = 17317			Number of obs = 4016			Number of obs = 12232		
	Wald chi2(12) = 33.18			Wald chi2(12) = 35.63			Wald chi2(12) = 25.50		
	Prob > chi2 = 0.0009			Prob > chi2 = 0.0004			Prob > chi2 = 0.0126		
	Pseudo R2 = 0.0163			Pseudo R2 = 0.0514			Pseudo R2 = 0.0201		
	Loglikelihood = -738.5563			Log likelihood = -181.48308			Log likelihood = -511.44665		

* Calendar dummy variables included

Table 11 Probability of patenting, logit ML regression (dep. Variable **postpat**)

	IPTW numerator (patent regime)								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.144	0.046	0.002	0.216	0.100	0.030	0.138	0.053	0.009
senioritysq	-0.005	0.002	0.001	-0.008	0.003	0.028	-0.005	0.002	0.003
gender	0.430	0.223	0.054	-0.375	0.438	0.393	0.661	0.271	0.015
expttoma(-1)	0.118	0.066	0.076	0.253	0.197	0.197	0.076	0.074	0.304
expttomasq(-1)	-0.010	0.006	0.109	-0.035	0.027	0.198	-0.006	0.006	0.322
constant	-6.044	0.332	0.000	-5.763	0.636	0.000	-6.119	0.413	0.000
	Number of obs = 17317			Number of obs = 4016			Number of obs = 12232		
	Wald chi2(9) = 29.36			Wald chi2(9) = 14.31			Wald chi2(9) = 25.04		
	Prob > chi2 = 0.0006			Prob > chi2 = 0.1118			Prob > chi2 = 0.0029		
	Pseudo R2 = 0.0155			Pseudo R2 = 0.0356			Pseudo R2 = 0.0200		
	Log likelihood = -739.13778			Log likelihood = -184.49896			Log likelihood = -511.48054		

* Calendar dummy variables included

Table 13	ZINB ML regression with clustered id robust SE dep. Variable **publ_m**								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.098	0.013	0.000	0.101	0.048	0.035	0.093	0.012	0.000
senioritysq	-0.002	0.000	0.000	-0.003	0.001	0.036	-0.002	0.000	0.000
gender	0.244	0.076	0.001	0.194	0.271	0.475	0.323	0.080	0.000
postpat(-1)	0.021	0.135	0.876	0.608	0.330	0.065	-0.224	0.115	0.052
cumpat(-1)	0.034	0.038	0.371	-0.022	0.077	0.775	0.075	0.040	0.062
expttoma(-1)	0.017	0.007	0.011	0.023	0.021	0.278	0.013	0.007	0.071
dumyear75_79	-0.619	0.115	0.000	-1.081	0.345	0.002	-0.609	0.119	0.000
dumyear80_84	-0.295	0.089	0.001	-0.727	0.255	0.004	-0.286	0.092	0.002
dumyear85_89	-0.200	0.064	0.002	-0.821	0.233	0.000	-0.158	0.065	0.015
dumyear90_94	-0.047	0.043	0.275	-0.483	0.123	0.000	-0.008	0.044	0.854
constant	-0.599	0.133	0.000	-0.684	0.499	0.171	-0.477	0.131	0.000
inflate	**Coeff**	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	-0.971	0.079	0.000	-0.829	0.170	0.000	-1.010	0.089	0.000
senioritysq	0.023	0.002	0.000	0.021	0.004	0.000	0.023	0.003	0.000
gender	0.477	0.206	0.021	-0.176	0.524	0.736	0.582	0.234	0.013
postpat(-1)	-1.924	1.655	0.245	1.089	2.432	0.654	-3.405	2.434	0.162
cumpat(-1)	-0.402	0.300	0.180	-1.450	3.033	0.633	-0.195	0.343	0.571
expttoma(-1)	0.009	0.033	0.789	-0.054	0.093	0.563	0.003	0.043	0.948
dumyear75_79	-1.117	0.343	0.001	-0.952	0.730	0.192	-1.214	0.383	0.002
dumyear80_84	-1.253	0.313	0.000	-0.831	0.801	0.299	-1.472	0.341	0.000
dumyear85_89	-0.755	0.265	0.004	-1.130	0.691	0.102	-0.828	0.289	0.004
dumyear90_94	-0.065	0.232	0.778	-0.368	0.555	0.508	-0.202	0.249	0.418
constant	4.087	0.315	0.000	4.699	0.598	0.000	4.163	0.369	0.000
/lnalpha	0.300	0.042	0.000	0.585	0.118	0.000	0.091	0.061	0.135
alpha	1.350	0.057		1.795	0.212		1.096	0.067	
	Number of obs = 18559 Nonzero obs = 8373 Wald chi2(10) = 330.39 Prob > chi2 = 0.0000 Log likelihood = -26330.38			Number of obs = 4414 Nonzero obs = 1374 Wald chi2(10) = 92.20 Prob > chi2 = 0.0000 Log likelihood = -4592.511			Number of obs = 13337 Nonzero obs = 6745 Wald chi2(10) = 280.57 Prob > chi2 = 0.0000 Log likelihood = -20415.4		

Tab 14 ZINB ML regression clustered id robust SE dep. Variable **publbas4**

	(all)			(eng)			(chem)		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.094	0.019	0.000	0.082	0.448	0.854	0.085	0.020	0.000
senioritysq	-0.002	0.001	0.000	-0.003	0.013	0.816	-0.002	0.001	0.001
gender	0.343	0.129	0.008	-0.869	0.469	0.064	0.485	0.131	0.000
postpat(-1)	-0.075	0.301	0.803	-0.326	0.696	0.639	-0.438	0.221	0.048
cumpat(-1)	-0.094	0.090	0.296	-0.072	0.161	0.654	0.012	0.077	0.877
expttoma(-1)	0.029	0.011	0.008	-0.017	0.160	0.916	0.025	0.011	0.023
dumyear75_79	-0.199	0.167	0.235	-0.070	1.019	0.945	-0.284	0.165	0.084
dumyear80_84	0.059	0.143	0.679	-0.312	0.931	0.737	-0.024	0.143	0.869
dumyear85_89	0.114	0.102	0.264	-0.454	0.331	0.170	0.061	0.102	0.549
dumyear90_94	0.137	0.070	0.051	-0.854	0.470	0.069	0.118	0.070	0.093
constant	-1.521	0.243	0.000	-1.274	5.217	0.807	-1.227	0.243	0.000
inflate	**Coeff**	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	-1.064	0.123	0.000	-0.624	0.824	0.449	-1.095	0.125	0.000
senioritysq	0.025	0.004	0.000	0.016	0.020	0.407	0.025	0.004	0.000
gender	0.241	0.308	0.435	-2.119	6.173	0.731	0.441	0.322	0.171
postpat(-1)	-5.340	6.819	0.434	-13.094	1.458	0.000	-14.210	4.473	0.001
cumpat(-1)	0.366	0.214	0.087	0.075	0.542	0.891	0.589	0.247	0.017
expttoma(-1)	0.025	0.057	0.659	-0.223	0.166	0.177	0.019	0.063	0.767
dumyear75_79	-1.353	0.491	0.006	0.454	2.224	0.838	-1.625	0.498	0.001
dumyear80_84	-1.627	0.472	0.001	-1.451	2.859	0.612	-1.946	0.471	0.000
dumyear85_89	-0.695	0.419	0.097	-0.265	1.204	0.826	-0.974	0.407	0.017
dumyear90_94	-0.260	0.383	0.497	-1.548	4.745	0.744	-0.527	0.360	0.143
constant	4.817	0.417	0.000	5.787	4.147	0.163	5.022	0.439	0.000
/lnalpha	1.132	0.023	0.000	1.896	1.492	0.204	0.759	0.032	0.000
alpha	3.101	0.070		6.659	9.937		2.137	0.068	
	Number of obs = 18559 Nonzero obs = 4744 Wald chi2(10) = 88.22 Prob > chi2 = 0.0000 Log likelihood = -17266.05			Number of obs = 4414 Nonzero obs = 270 Wald chi2(10) = 24.34 Prob > chi2 = 0.0067 Log likelihood = -1232.765			Number of obs = 13337 Nonzero obs = 4342 Wald chi2(10) = 92.84 Prob > chi2 = 0.0000 Log likelihood = -14609.22		

Table 15	OLS regression FE dep. Variable **lpubl_m**								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.077	0.003	0.000	0.064	0.006	0.000	0.083	0.004	0.000
senioritysq	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.001	0.000	0.000
postpat(-1)	0.096	0.037	0.009	0.283	0.067	0.000	-0.005	0.045	0.909
cumpat(-1)	-0.005	0.014	0.733	-0.011	0.020	0.593	0.005	0.018	0.784
expttoma(-1)	0.002	2.560	0.001	0.015	0.003	0.000	0.002	0.002	0.438
dumyear75_79	0.059	0.050	0.234	0.181	0.090	0.044	0.026	0.061	0.669
dumyear80_84	0.045	0.038	0.232	0.086	0.069	0.213	0.034	0.046	0.462
dumyear85_89	-0.017	0.027	0.527	-0.039	0.047	0.414	-0.012	0.033	0.707
dumyear90_94	-0.001	0.016	0.963	-0.024	0.029	0.398	0.009	0.019	0.658
constant	-0.217	0.025	0.000	-0.284	0.033	0.000	-0.185	0.031	0.000
	Number of obs = 18559			Number of obs = 4414			Number of obs = 13337		
	R-squared = 0.5507			R-squared = 0.5084			R-squared = 0.5450		

Table 16	OLS regression FE dep. Variable **lwpubl_m**								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.102	0.008	0.000	0.091	0.015	0.000	0.108	0.010	0.000
senioritysq	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.002	0.000	0.000
postpat(-1)	0.060	0.100	0.549	0.550	0.164	0.001	-0.293	0.121	0.015
cumpat(-1)	0.011	0.037	0.774	-0.062	0.048	0.192	0.078	0.051	0.127
expttoma(-1)	0.004	0.005	0.387	0.014	0.008	0.089	0.003	0.001	0.036
dumyear75_79	0.034	0.135	0.803	0.450	0.231	0.052	0.001	0.006	0.814
dumyear80_84	0.008	0.102	0.938	0.246	0.182	0.176	-0.097	0.166	0.560
dumyear85_89	-0.057	0.073	0.434	-0.035	0.118	0.768	-0.082	0.126	0.516
dumyear90_94	-0.014	0.043	0.748	-0.109	0.068	0.108	-0.079	0.093	0.392
constant	0.736	0.071	0.000	0.668	0.086	0.000	0.768	0.089	0.000
	Number of obs = 18559			Number of obs = 4414			Number of obs = 13337		
	R-squared = 0.4258			R-squared = 0.3701			R-squared = 0.4275		

Table 17	OLS regression FE dep. Variable **lpublbas4**								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.035	0.002	0.000	0.013	0.002	0.000	0.042	0.003	0.000
senioritysq	-0.001	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000
postpat(-1)	-0.026	0.026	0.314	-0.004	0.027	0.893	-0.077	0.035	0.027
cumpat(-1)	-0.001	0.008	0.938	0.001	0.006	0.900	0.010	0.012	0.406
expttoma(-1)	0.002	0.001	0.105	0.002	0.001	0.081	0.003	0.001	0.036
dumyear75_79	-0.055	0.039	0.157	0.038	0.042	0.368	0.003	0.002	0.155
dumyear80_84	-0.031	0.029	0.299	0.031	0.031	0.309	-0.079	0.051	0.118
dumyear85_89	-0.027	0.021	0.188	0.000	0.021	0.988	-0.049	0.039	0.206
dumyear90_94	-0.003	0.012	0.808	-0.008	0.013	0.505	-0.038	0.027	0.165
constant	-0.100	0.020	0.000	-0.051	0.014	0.000	-0.120	0.026	0.000
	Number of obs = 18559			Number of obs = 4414			Number of obs = 13337		
	R-squared = 0.5381			R-squared = 0.3521			R-squared = 0.5218		

Table 18	OLS regression FE dep. Variable **lwpublas4**								
	(all)			**(eng)**			**(chem)**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.019	0.002	0.000	0.005	0.001	0.000	0.024	0.002	0.000
senioritysq	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000
postpat(-1)	-0.019	0.019	0.301	-0.014	0.011	0.203	-0.073	0.020	0.000
cumpat(-1)	-0.004	0.005	0.350	0.004	0.003	0.164	0.004	0.007	0.571
expttoma(-1)	-0.001	0.001	0.349	0.001	0.001	0.200	-0.001	0.001	0.278
dumyear75_79	-0.027	0.029	0.355	0.011	0.022	0.619	-0.037	0.038	0.335
dumyear80_84	-0.004	0.022	0.862	0.014	0.014	0.315	-0.013	0.029	0.668
dumyear85_89	-0.010	0.016	0.555	-0.001	0.010	0.947	-0.017	0.021	0.441
dumyear90_94	-0.002	0.009	0.866	-0.005	0.006	0.388	-0.004	0.012	0.769
constant	0.977	0.013	0.000	0.983	0.006	0.000	0.974	0.018	0.000
	Number of obs = 18559			Number of obs = 4414			Number of obs = 13337		
	R-squared = 0.4830			R-squared = 0.3195			R-squared = 0.4647		

Table 19	HECKMAN ML regression Dummy Variable Model								
	Truncated equation: dependent variable **stdifac**								
	all			**engineers**			**chemists**		
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.158	0.008	0.000	0.019	0.013	0.141	0.146	0.008	0.000
senioritysq	-0.003	0.000	0.000	0.000	0.000	0.836	-0.003	0.000	0.000
postpat(-1)	0.159	0.062	0.011	0.278	0.118	0.018	0.035	0.075	0.638
cumpat(-1)	-0.010	0.020	0.627	-0.110	0.039	0.005	0.033	0.024	0.160
expttoma(-1)	0.012	0.003	0.000	-0.004	0.005	0.505	0.013	0.003	0.000
_cons	-0.844	0.067	0.000	-1.036	0.140	0.000	-0.676	0.072	0.000

	Selection equation: dependent variable **dumpubl_m**								
	Coeff	**se**	**P**	**coeff**	**se**	**P**	**coeff**	**se**	**P**
seniority	0.239	0.005	0.000	0.265	0.012	0.000	0.248	0.006	0.000
senioritysq	-0.006	0.000	0.000	-0.007	0.000	0.000	-0.006	0.000	0.000
gender	0.000	0.026	0.989	0.153	0.065	0.019	0.073	0.030	0.016
postpat(-1)	0.242	0.074	0.001	0.542	0.147	0.000	-0.166	0.141	0.239
cumpat(-1)	0.057	0.031	0.061	0.011	0.044	0.801	0.408	0.096	0.000
expttoma(-1)	0.018	0.003	0.000	0.030	0.007	0.000	0.018	0.004	0.000
dumyear75_79	-0.110	0.046	0.016	-0.484	0.120	0.000	-0.098	0.054	0.068
dumyear80_84	-0.001	0.035	0.971	-0.464	0.093	0.000	0.050	0.043	0.239
dumyear85_89	0.004	0.028	0.881	-0.327	0.082	0.000	0.045	0.035	0.197
dumyear90_94	0.000	0.023	0.987	-0.169	0.067	0.012	0.030	0.030	0.308
_cons	-1.742	0.041	0.000	-2.252	0.094	0.000	-1.694	0.048	0.000
rho	0.944	0.012	0.963	-0.010	0.064	0.115	0.924	0.015	0.948
sigma	0.804	0.021	0.847	0.498	0.017	0.534	0.786	0.021	0.828
lambda	0.759	0.028	0.814	-0.005	0.032	0.058	0.726	0.029	0.783
	Wald test indep. eqs.(ρ=0) $\chi^2(1)$ = 278.83: P > χ^2 =0 Number of obs = 14784 Log likelihood = -14523.46			Wald test indep. eqns. (ρ=0) $\chi^2(1)$ = 0.02: P > χ^2= 0.8745 Number of obs = 3433 Log likelihood = -2658.351			Wald test indep. eqns. (ρ=0) $\chi^2(1)$ = 263.35: P > χ^2 = 0 Number of obs = 10707 Log likelihood = -11063.57		

Non-overlapping Rights: A Patent Misconception

Andrew Christie[*] and Chris Dent[§]

1. INTRODUCTION

The quality of patents is the subject of much debate around the world. A great deal of work has been carried out by academics that has been aimed at assessing and improving the quality of patents granted by Patent Offices. The focus of this research has been on the quality of the end-product.[1] One of the criteria put forward by economists for a "quality" patent has been that patents provide 'non-overlapping rights'.[2] It is not clear, however, what is meant, from a legal standpoint at least, by the terms "overlapping patent rights".

This paper considers the problem of the potential overlap of patents by returning to the basic, legal, building blocks of patent rights – our goal is to investigate what may be meant by overlapping patent rights and to explore to what extent such overlap is allowed by law.[3] The law is clear on the matter; however, accessing the legal understanding is not necessarily easy. Legal textbooks, for example, effectively explain the limits and requirements of individual patents but do not offer detailed insight into the manner in which one patent relates to a previously granted patent (beyond the requirement that the later patent must evidence the requisite "novelty" and "inventive step" with respect to earlier inventions). This paper will

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[1] Work has been started, however, into the consideration of patent quality in terms of the patent examination process. See, for example, J. Straus (2005) 'The Concept and Meaning of Quality in the European Patent System' Conference Proceedings, Quality in the European Patent System Conference, The Hague, November 2005 and C. Dent (2006) 'Decision-Making and Quality in Patents' 28 *European Intellectual Property Review* 381

[2] D. Harhoff (2005) 'The Demand for Patents and the Evolution of Patent Quality', paper presented to Advancing Knowledge and the Knowledge Economy Conference, National Academy of Sciences. Dominique Foray repeated this call in a paper, 'The Art of Designing Incentives Systems for 21st Century Innovations', presented at the Innovation Europe 2005 Summit.

[3] A distinction may be drawn between "validly granted patents" and patents that have been granted that would not stand up to judicial scrutiny. The focus of this paper is on the former class. We recognise that not all patents granted are valid; however, the purpose of this paper is to highlight the manner in which the patent system allows for the notion of overlapping patent claims – rather than to explore issues around the examination of patent applications by patent examiners.

provide a legal perspective on the issue of overlap and will demonstrate that, for the law at least, overlapping patent rights, in certain circumstances, are not problematic.

Clarification of core legal points will form the basis of the presentation.[4] A patent is best seen as a bundle of rights that is limited by the grant of a national Patent Office. These rights relate to the invention that is defined by the claims contained in the patent specification. Claims are also fundamental to the question of whether a given product or process infringes a granted patent – infringement is assessed by comparing the product or process with the claims of the patent. If the product or process is within the limits described by the claims, then there is infringement. The focus of this paper, then, will be the explanation of the function of patent claims and the how the concept of "overlapping patent rights" may be understood in terms of the claims of patents.[5]

2. NATURE, EFFECT AND VALIDITY OF PATENTS

The first step in this analysis is to emphasise the need to focus on patent claims. One potential disconnect between economic understandings and legal practicalities with respect to overlapping patents relates to assumptions about the nature of the "thing" protected by a patent. It is tempting, from a non-legal viewpoint, to consider that a physical product, or process, is synonymous with the patent that is seen to protect that product or process. It is important to recognise that there is a legal distinction between the product or process and the patent itself.[6] The difference arises from the fact that while a product or process may have a physical existence, the invention(s) defined by the claims of a patent exist *only* in words – and, therefore, *cannot* have a physical existence. This difference has been acknowledged judicially: the 'conversion of machine to words allows for unintended gaps which cannot be

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[4] It may be noted that this paper is introductory. The goal is to detail the law as it relates to the potential for overlapping patents. Therefore, there will not be scope for an exploration of the impact of this understanding of overlap on notions of quality (or on the economy more broadly) – this work will form the basis of future research.

[5] There is also a potential disconnect between economists and lawyers in this area. Harhoff's call for non-overlapping patent *rights* is, arguably, misconceived. The right that a patent provides a patentee may be best seen as a capacity to commence an action for infringement in a court. It would, therefore, be more accurate to highlight a need for non-overlapping patent *claims*. Claims, then, and the potential for their overlap, are the focus of the rest of this paper.

[6] Patents are 'legally defined by the language of the patent's claims, not by what the patent owner has actually invented or built': M. Lemley, 'The Economics of Improvement in Intellectual Property Law' (1997) 75 *Texas Law Review* 989, 1000; or as phrased judicially, it is 'claims, not commercial embodiments, that are infringed': *Datascope Corp v SMEC Inc* 879 F.2d 820, 824 (Fed. Cir. 1989).

satisfactorily filled'.[7] The fundamental point of this paper is that it is the claims, the words, that define the patent and, therefore, the invention – any physical product or process becomes meaningless for the purposes of assessing the infringement of the patent. To test for overlap of such rights, a thorough understanding of the claims – the words – is necessary. This is addressed next.

2.1 NATURE OF THE PATENT SPECIFICATION

Patent laws around the world have been substantially harmonised. Specifically, the detail of the law relating to the validity, and infringement, of patents are very similar. The legal analysis contained in this paper, then, is applicable to virtually all countries. The examples used here are, therefore, chosen on the basis of the greatest clarity of expression – regardless of whether the example stems from the US, European, or even Australian, patent regimes.

The requirements for the application for, and validity of, patents are straightforward.[8] This section will deal with the key part of the application for the patent: the specification. The detail of the legal requirements for the validity of patents will be considered below.

Patent applications must be in writing and contain a specification and at least one claim. The specification shall contain a written description of the invention such that a person skilled in the relevant art could reproduce the invention.[9] This fulfils the public interest in expanding the body of knowledge – for some, the *quid pro quo* of the patent grant;[10] or, for economists, the "knowledge spill-over".

The claims contained in the application (which may either be independent or dependent[11]) must define the 'subject matter which the applicant regards as the invention'.[12] Further, 'each

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[7] *Autogiro v United States* 384 F. 2d 391, 397 (Ct. Cl. 1967) quoted in J. Miller, 'Enhancing Patent Disclosure for Faithful Claim Construction' (2005) 9 *Lewis and Clark Law Review* 188, 184n40. This process of translation can be seen as one of the bases of apparent uncertainty in the patent system; see, C. Dent, 'To See Patents As Devices Of Uncertain (But Contingent) Quality: A Foucaultian Perspective' (2007) *Intellectual Property Quarterly* 148.

[8] In the US, the requirements are included in 35 USC Chapters 10 and 11; in Europe, in the European Patent Convention; and in Australia, the *Patents Act 1990* (Cth).

[9] 35 USC 112 states that the application 'shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor of carrying out his invention'.

[10] *Dana Corp v IPC Ltd* 860 F.2d 415, 418 (Fed. Cir. 1988).

[11] 'A claim may be written in independent or, if the nature of the case admits, in dependent or multiple dependent form … a claim in dependent form shall contain a reference to a claim previously set forth and then specify a further limitation of the subject matter claimed. A claim in dependent form shall be construed to incorporate by reference all the limitations of the claim to which it refers': 35 USC 112.

claim of a patent is treated as if it was a separate patent'[13] – each has to meet the requirements for patent validity and each give rise to rights.[14] Therefore, from a legal perspective, all that matters is the claims contained in the granted patent – as it is the claims that underlie the defence of the rights granted to the patentee.

2.2 EFFECT OF PATENTS

(a) Exclusive Rights of a Patentee

Patents are deemed to have the 'attributes of personal property'.[15] The rights accorded to a patentee are set out in the patent legislation; for example, in the US, a patentee gains the 'right to obtain a reasonable royalty from any person who … makes, uses, offers for sale, or sells in the United States the invention as claimed in the patent application'.[16] When the grounds for infringement are considered (detailed below), the rights that attach to patents are rights to exclude others from using the subject matter of the patent.[17] These rights are, therefore, based on the claims of the patent. The US Supreme Court has 'likened patent claims to the description of real property in a deed',[18] therefore, it is to the 'claims of every patent … that we must turn when we are seeking to determine what the invention is'.[19]

For the purposes of overlapping rights, it is important to note that the

> existence of one's own patent does not constitute a defence to infringement of someone else's patent. It is elementary that a patent grants only the right to exclude others and confers no right on its holder to make, use or sell.[20]

Further, 'most lay people believe that once they receive a patent, their invention has been held unique and non-infringing. Lay persons are often surprised by the idea that they can still be responsible for infringing another dominating patent'.[21] To explain this possibility, a clearer

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[12] 35 USC 112.

[13] *Dollar Elec. Co v Syndevco Inc* 205 USPQ 949, 959 (E.D. Mich. 1979); alternatively, a patent may comprise of many 'individual claims, each of which is a separate invention': *Rutgers University v United States* 51 USPQ 2d 1642, 1643 n.1 (Ct. Fed. Cl. 1998).

[14] The requirements and the rights of patents and patent claims will be discussed below.

[15] 35 USC 261.

[16] 35 USC 154(d)(1)(A). It is also a requirement that the infringer had 'actual notice of the published patent application': 35 USC 154(d)(1)(B).

[17] *Kewanee Oil Co v Bicron Corp* 416 US 470, 477-78 (1973). Further, the patent does not grant the patentee an affirmative right to use the invention – though previous US patent acts did provide for such a right: see Chisum, §16.02[1].

[18] *General Foods Corp v Studiengesellschaft Köhle mbh* 972 F.2d 1272, 1274 (Fed. Cir 1991).

[19] *Motion Picture Patents Co v Universal Films Mfg Co* 243 US 502, 510 (1917).

[20] *Bio-Technology General Corp v Genentech Inc* 80 F.3d 1553, 1559 (Fed. Cir. 1996) citing *Vaupel Textilmaschinin KG v Meccanica Euro Italia SPA* 944 F. 2d 870, 879 n.4 (Fed. Cir, 1991).

[21] *Union Carbide Corp v Tarancon Corp* 742 F. Supp. 1565, 1577 (N.D. Ga. 1990).

understanding of how patents, or more particularly the claims within the patents, are infringed is needed.

(b) Infringement of Claims

According to the US Code, ‘whoever without authority makes, uses, offers to sell, or sells any patented invention … or imports … any patented invention during the term of the patent therefor, infringes the patent’.[22] The case law indicates that it is a ‘two-step process’ to determine infringement: the first requires the interpretation of the claims ‘in the light of the claim language, the other claims, the prior art, the prosecution history and the specification’;[23] and second, it must be assessed whether the allegedly infringing product falls within the claims as interpreted.[24] In terms of the second step, ‘what is crucial is that the structures must do the same work, in substantially the same way, and accomplish substantially the same result to constitute infringement’.[25] The importance of claims, and the content of the patent file that supports the claims, to the determination of infringement is reflected in our focus on claims in the exploration of overlapping patent rights.

2.3 VALIDITY OF PATENTS

(a) Validity Requirements

There are a number of requirements that must be met for a patent to be held to be valid. These include that the claimed subject matter is patentable, that the clamed subject matter is novel and that the claimed subject matter involves an inventive step, or in US terms, is non-obvious.[26] The latter two are of most relevance to this paper. The first is, however, worth noting in brief. Certain innovations are explicitly excluded from being awarded patents. Article 52(2) of the European Patent Convention (EPC) states, for example, that *inter alia* ‘discoveries, scientific theories and mathematical methods; (b) aesthetic creations; [and] (c)

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[22] 35 USC 271(a). The provisions relating to the infringement of process patents are included in 35 USC 271(g).

[23] *SRI International v Matsushita Electric Corp* 775 F.2d 1107, 1118 (Fed. Cir. 1985).

[24] A point on terminology may usefully be made here. In the US, it is said that if an allegedly infringing product incorporates all the claims of that patent, then, “reads on” to the patent – that is, it infringes the patent. ‘If the alleged infringer’s apparatus, process or product “reads on”, i.e. copies or duplicates, the claimed invention, “literal infringement” is established’: *Johns-Manville Corp v Guardian Industries Corp* 586 F. Supp 1034, 1051 (E.D. Mich. 1983). Courts elsewhere use the phrase “falls within the scope” of the claims of the allegedly infringed patent.

[25] *Autogiro v United States* 384 F. 2d 391, 401 (Ct. Cl. 1967).

[26] The terms ‘non-obvious’ and ‘inventive step’ are deemed synonymous by Article 27n5 of the Agreement of Trade-Related Aspects of Intellectual Property Rights (the TRIPs Agreement).

schemes, rules and methods for performing mental acts, playing games or doing business, and programs for computers' are not patentable.

To be patentable, an invention must be novel; that is, 'an invention shall be considered to be new if it does not form part of the state of the art'.[27] Each claim in a patent application must be shown to be novel when compared with the prior art.[28] The prior art includes any publicly available descriptions of the state of the technical art (whether written or oral), such as previously granted patents or literature, available anywhere in the world before the priority date of the application under examination.[29] Therefore, if a claim can be found in the prior art, then the claim is not novel and, therefore, not valid.

The requirement for inventive step is that an invention must be not obvious to a person skilled in the art.[30] This test requires that the advance defined in the claims is something that would not have been straightforward for someone who worked in the field. Again, this is assessed against the prior art available. Each claim has to "pass" both the novelty and inventive step tests in order to be valid claim in the granted patent.

(b) Priority Dates

The final detail of patentability that needs to be considered relates to the "priority date". This date is important because the tests for inventive step and novelty relate to the prior art available before the priority of an application. The priority date, in most circumstances, is the date on which an application was filed with the patent office or the date on which an application for the same invention was filed in another patent office.[31]

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[27] European Patent Convention, Article 54(1). The equivalent US provision is in 35 USC 102.

[28] One of the major purposes of patent claims is to distinguish the invention from the prior art: *Solomon v Kimberly-Clark Corp* 216 F. 3d 1372, 1380 (Fed. Cir. 2000).

[29] See, for example, European Patent Convention, Article 54(2).

[30] European Patent Convention, Article 56. The equivalent US provision is in 35 USC 103.

[31] See, for example, 35 USC 111(b)(4) and, with respect to foreign filings, 35 USC 119(a). It is said that the US has a "first-to-invent" patent system (as opposed to the "first-to-file" process found in the rest of the world), both systems, however, are used to establish the priority date for an application. Under the US system, the filing date is the provisional priority date, though the applicant may seek to establish that the invention took place earlier. In such a case, the applicant has the onus to prove the earlier date. In most cases, however, the issue of first-to-invent goes to matters of inventorship rather than validity and, therefore, is not relevant here.

3. OVERLAPPING PATENT RIGHTS

3.1 CONCEPT OF OVERLAPPING PATENT RIGHTS

(a) Meaning of Overlapping Rights

It is now possible to address the issue of what, exactly, it means to say that the rights of two patents "overlap". Given what was said above about claims, it follows that the issue of overlapping patent rights is, in practice, the issue of overlapping claims. We define claim overlap as follows. Two claims will be said to overlap if an embodiment falls within two separate claims. Put another way, two claims will overlap if there could exist one product or process that would constitute an infringement of both claims.[32]

(b) Possibilities for Claim Overlap

Consider two claims, A and B. Logically, there are four possibilities for "overlap" of these claims:

(i) the scope of claim A subsumes the scope of claim B ("Type I: A subsumes B");

(ii) the scope of claim B subsumes the scope of claim A ("Type II: B subsumes A");

(iii) part of the scope of claim A is common to part of the scope of claim B ("Type III: partial overlap"); and

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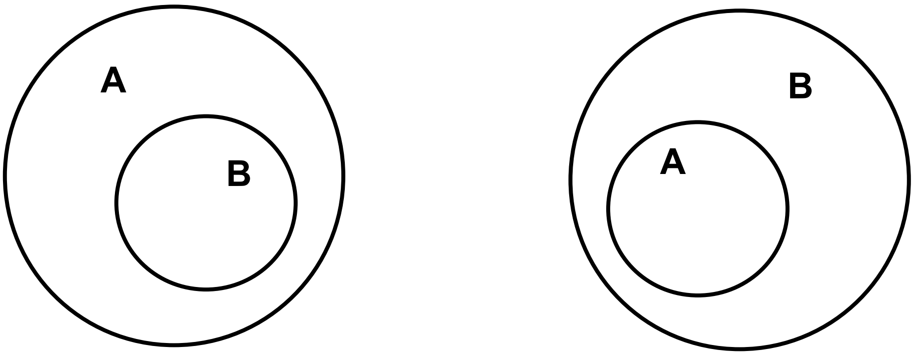
[32] As such, we focus here on 'literal infringement' rather than infringement under the doctrine of equivalents. Literal infringement covers the circumstances 'when an accused product or process falls within a patent's claims': Chisum §16.02[1][a][ii]. The doctrine of equivalents has a degree of controversy surrounding it. Commentators consider the doctrine has the capacity to 'expand patent scope beyond the rights literally claimed in the patent': M. Meurer and C. Nard, 'Invention, Refinement and Patent Scope: A New Perspective on the Doctrine of Equivalents' (2004) Boston University School of Law, Law and Economics Working Paper 04-03, 2. Further, Burk and Lemley appear to consider that under the doctrine 'patents are frequently broader than the products the inventors actually make': D. Burk and M. Lemley, 'Policy Levers in Patent Law' (2003) 89 *Virginia Law Review* 1575, 1614 – though as our paper is detailing, patents delimit the invention contained in the patent and may have nothing to do with what is actually made by the patentee. No evidence is provided as to the extent of the "problem" caused by this doctrine. Meurer and Nard, however, consider that the doctrine reflects the situation where 'inventors fail to obtain the full claim breadth they are entitled to because they fail to refine their claims sufficiently during patent prosecution': 'Invention, Refinement and Patent Scope' (2004) Boston University School of Law, Law and Economics Working Paper 04-03, 5. In other words, the doctrine protects the full extent of the inventive step taken by the inventor rather than just the extent of the claims contained in the patent application. A 'patentee should not be able to obtain, under the doctrine of equivalents, coverage which he could not lawfully have obtained from the PTO by literal claims': *Wilson Sporting Goods Co v David Geoffrey & Associates* 904 F.2d 677 (Fed. Cir. 1990). That is, the purpose of the doctrine is to minimise the risk of patentees losing out on a return on their investment through competitors producing a product virtually identical to the patented invention. The doctrine, therefore, may be seen to provide greater certainty to patent holders – balancing any greater uncertainty perceived by competitors or other inventors.

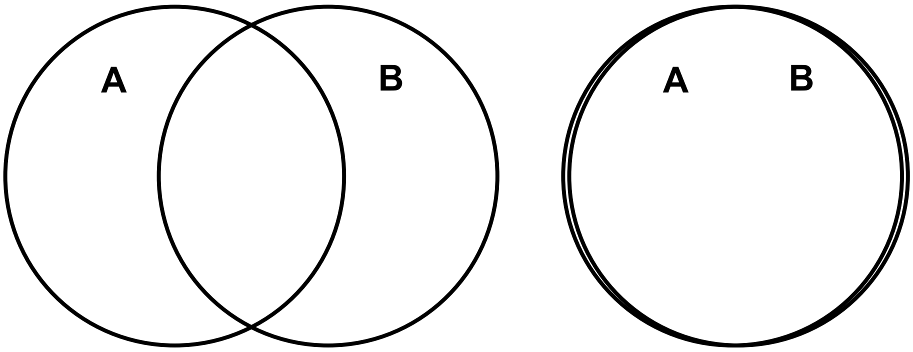
(iv) the scope of claims A and B are, or are effectively, identical (“Type IV: complete overlap”).

These four possibilities are illustrated in Figure 1.



Type I: A subsumes B

Type II: B subsumes A



Type III: partial overlap

Type IV: complete overlap

Figure 1: Possibilities of overlapping rights

(c) Hypothetical Overlapping Claims

Consider the following four hypothetical claims:[33]

Claim 1. A mixture X comprising substances Y and Z.

Claim 2. A mixture according to claim 1 wherein the proportion of X that is Z is in the range of 6-14%.

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[33] We acknowledge that, often, real claims are not this straightforward. Where claims are more complex, ‘claim interpretation is not always an exact science’: *Q-Pharma Inc v Andrew Jergens Co* 360 F.3d 1295, 1301 (Fed. Cir. 2004); and even when they are simple, ‘it is not unusual for parties to offer competing definitions of even the simplest claim language’: ibid? Simple claims, however, are sufficient to demonstrate the possibilities of overlap.

> Claim 3. A mixture according to claim 1 wherein the proportion of X that is Z is no less than 12%.
>
> Claim 4. A mixture X comprising substances Y and Z in any proportion.

It will be observed that:

> (i) the relationship between claims 1 and 2 is an example of Type I overlap, wherein claim 1 is claim A and claim 2 is claim B.
>
> (ii) the relationship between claims 2 and 4 is an example of Type II overlap, wherein claim 2 is claim A and claim 4 is claim B.
>
> (iii) the relationship between claims 2 and 3 is an example of Type III overlap, wherein claim 2 is claim A and claim 3 is claim B (or *vice versa*); and
>
> (iv) the relationship between claims 1 and 4 is an example of Type IV overlap, wherein claim 1 is claim A and claim 2 is claim B (or *vice versa*).

These examples will be used to assess the validity of overlapping patent claims.

3.2 VALIDITY OF OVERLAPPING PATENT CLAIMS

Now, let us determine which, if any, of the four logical possibilities for claim overlap may occur in practice and in law, and with what consequences. There are multiple scenarios to consider, given that, first, claims A and B can be claims either within the same patent or within different patents; and, secondly, where claims A and B are in different patents, those patents can be granted to either the same patentee or to different patentees.

(a) Claims within the Same Patent

For the sake of simplicity, in this scenario it will be assumed that every claim in the patent has the *same priority date*. It is, of course, possible, that some claims within the one patent will not have the same priority dates. This will happen where the source from which a claim derives priority is different from the source from which another claim derives priority and those sources do not themselves give rise to same priority date. Where the priority dates of two claims in the one patent are *different*, that scenario is, for legal purposes, the same as the scenario discussed in section 4.2(b), below.

(i) Type I: A subsumes B

Type I overlap (the scenario of one claim in a patent subsuming another claim within the same patent) is very common: it is the scenario where the second claim is drafted as being "dependent" on the first claim. Thus, where claim B is drafted in the form 'product/process according to claim A wherein …', claim B is subsumed by claim A and so it may be said that claim A overlaps claim B. As noted previously, this type of overlap is illustrated by the relationship between hypothetical claims 1 and 2.

It is clear that this scenario is legally permissible. Claim B is not redundant in light of claim A. Rather, claim B is a more refined form of claim A, in that claim B has at least one defining characteristic that makes it a sub-set of claim A. The legal consequence of this type of overlap is that claim A will read onto everything that claim B reads onto, but claim B will not read onto everything that claim A reads onto (claim B will not read onto a product/process within claim A that does not have the refining feature of claim B).

(ii) Type II: B subsumes A

Type II overlap is the converse of type I overlap. This scenario is possible, although unlikely, in practice. It is possible in that a patent could contain a subsequently-numbered claim that subsumes a previously-numbered claim (in the way that hypothetical claim 4 subsumes hypothetical claim 2). It is unlikely, however, in that this constitute an inefficient style of claim drafting. The efficient way for one claim to subsume another is to make the subsumed claim 'dependent' on the subsuming claim, by using the drafting form "according to claim A wherein …" (as is the style hypothetical claim 2 adopts in relation to hypothetical claim 1).

Although inefficient and inelegant as a mater of drafting style, this overlap scenario is legally permissible. There is nothing in patent law that precludes a subsequently-numbered claim from subsuming a previously-numbered claim.[34] The legal consequence of this type of overlap is the converse of type I overlap: claim B will read onto everything that claim A reads onto, but claim A will not read onto everything that claim B reads onto (claim A will not read onto a product/ process within claim B that does not have the refining feature of claim A).

(iii) Type III: Partial overlap

Type III overlap occurs in practice when both claims A and B refine another claim by way of a common feature, and the refinement of that feature in each claim is not mutually exclusive of the other. An example of this type of overlap is the relationship between hypothetical

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[34] In the US, though, s. 112 of the Code stipulates that an independent claim must be set out before any claims dependent upon it. If a dependent claim refers to a subsequent independent claim, the examiner may object to it or may renumber the claims in order that the dependent claim is subsequent to the independent claim at the time the application is allowed: USPTO, *Manual of Patent Examining Procedure* §608.01(n).

claims 2 and 3. Both claims 2 and 3 define a mixture of Y and Z wherein the proportion of Z is in the range of 12-14%.

This type of overlap is legally permissible. As we know from the legal permissibility of overlap types I and II, there is nothing in patent law that requires claims to be mutually exclusive. The legal consequence of this type of overlap is that claim A and claim B will read onto the same embodiment in some, but not all, situations.

(iv) Type IV: Complete overlap

The scenario of two claims in the one patent being identical is not found in practice, for the simple reason that it would be redundant to do so. Having multiple claims with the same scope achieves nothing beyond that achieved by having one claim of that scope.

Furthermore, this scenario is not legally valid in the US. Identical claims are contrary to Rule 1.75(b) which states that 'more than one claim may be presented [in an application] provided they differ substantially from each other and are not unduly multiplied'. Duplicate claims have been considered invalid on the grounds that they are 'indefinite for failing to point out and distinctly claim the subject matter which [the patent applicants] regard as the invention'.[35] If an examiner rejects a duplicate claim,[36] however, the applicant has the opportunity to amend the application to remove the duplication.

(b) Claims within Different Patents

In this scenario, the patent in which claim A is contained is different from the patent in which claim B is contained. For the sake of simplicity, it will be assumed in this scenario that claims A and B have *different priority dates*, and that the priority date of claim A is *earlier* than the priority date of claim B. It is, of course, possible that claims A and B have the same as the priority date. Such a situation is not uncommon where the patentee of both patents is the same. This will be the case where one of the patents is a "divisional" application of the other – that is, where one patent application has divided off from another application, but maintains the priority date of the original application.[37] Where the patentees of the two patents are

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[35] *Ex parte Nesbit* 25 USPQ 2.d 1817, 1818 (Bd. Pat. App. & Int'f 1992).

[36] USPTO, *Manual of Patent Examining Procedure* §706.03(k).

[37] In the United States, an example of such an application is the so-called 'continuation in part' under s. 120 of the US Code. A 'continuation application is a second application that contains the same disclosure as the original application [and is used to] introduce into the application a new set of claims and to establish a right to further examination by the primary examiner': Chisum §13.03[1]. Importantly, a continuing application is 'entitled to the benefit of the filing date of [the] earlier application [but] only as to common subject matter': *Transco*

different, the situation of claim A having the same priority date as claim B is not common, but is not impossible.

Where the priority dates of the claims A and B are the *same*, that scenario is the same, for legal purposes, as the scenario discussed in section 4.2(a), above. This is so irrespective of whether the patentee of the two patents is the same or different. This is unlikely in practice. If it were to happen, though, both sets of claims may be valid (assuming they passed the tests such as novelty and inventive step) as the claims are judged against the prior art; and the prior art includes patents published before the priority date of the claims. A patent application with the same priority date does not fall within the definition of prior art. Therefore, both sets of claims would be valid.

(i) Type I: A subsumes B

The scenario of one claim in one patent subsuming another claim within another patent granted to the same patentee is possible in practice: it is the scenario where a later claim in one patent is drafted as being 'dependent' on an earlier claim in the same patent, and that earlier claim is the same as a claim in another patent. Thus, where claim B in one patent is drafted in the form 'product/process according to claim P wherein …', and claim P is the same as claim A in another patent, then claim B is subsumed by claim A.[38] Claim B is novel compared to claim A, because claim A does not include the specific (restricted) features in claim B.

A further example of this scenario is where claim B is considered to be a "selection" claim. A selection claim is a claim within a selection patent. A selection patent is a patent that has, as its independent claim, a segment of claim that was from an earlier patent.[39] A common area for this type of claim is the chemical industry where the priority claim covers a class of chemicals and the later claim covers a particular chemical from within that class.[40] To satisfy

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Products Inc v Performance Contracting Inc 38 F.3d 551, 556 (Fed. Cir. 1994). For a discussion of continuations see M. Lemley and K. Moore, 'Ending Abuse of Patent Continuations' (2004) 84 *Boston University Law Review* 63. See also C. Quillen and O. Webster, 'Continuing Patent Applications and Performance of the US Patent and Trademark Office' (2002) 11 *Federal Circuit Bar Journal* 1.

[38] This may, however, mean that Claim A is not valid due to lack of novelty with respect to Claim P. Claim B may not infringe even though Claim A does infringe because Claim B is narrower than Claim A.

[39] The term "selection patent" is relatively well-known outside the US (the 1930 case *IG Farbeninsdustrie AG's Patents* 47 RPC 289 includes a detailed description of the category), however, it is only recently gaining recognition in that country. There is, for example, no listing for "selection patent" in the Index of Chisum. The situation is, nonetheless, known in that country.

[40] With respect to novelty, the court found that a chemical described in a selection patent could be novel as long as it had not been made.

the requirements of patentability, the later claim must still have a 'substantial advantage'[41] that demonstrates that the claim is inventive when compared to the priority claim.[42]

(ii) Type II: B subsumes A

This scenario is the same as the immediately preceding scenario, except that the subsuming claim (B) has a later priority date than the subsumed claim (A). As claim B has a priority date later than claim A, claim A forms part of the prior art for the purposes of judging the novelty of claim B. In this instance, claim B covers subject matter that is distinct from claim A; therefore, claim B is novel and, potentially, evidences an inventive step. This form of overlap, then, may be valid.

An example of this scenario is an "improvement patent". This type of patent covers the case where the subject matter of the earlier patent (the "basic patent") is improved by the subject matter of the later patent. As such, the claims of the basic patent are included in the claims for the improvement patent. The claims of the improvement patent still have to reflect the requirements of patentability. In these circumstances, neither patentee can use the embodiments of the patents without infringing the patent of the other.[43] In other words, the 'original patent owner can prevent the improver from using his patented technology, but the improver can also prevent the original patent owner from using the improvement'.[44]

An example is found in *International Manufacturing Co v Landon*.[45] In that case, the first patent was for a 'fluid recirculation system especially adapted for use in swimming pools'. The second patent, 'embodies the basic combination' of the first and 'adds additional structure and function which makes it possible to vacuum the pool'.[46] The trial court found that 'no commercially feasible device could be manufactured under one of the patents without

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[41] *Boehringer Mannheim v Genzyme* [1993] FSR 716.

[42] An example from US law can be found in *In re Baird* 16 F3d 380 (Fed Cir. 1994) where the priority patent encompassed 'more than 100 million different diphenols' of which the later claim included 20.

[43] 'Two patents may be valid when the second is an improvement on the first, in which event, if the second includes the first, neither of the patentees can lawfully use the invention of the other with the other's consent': *Cantrell v Wallick* 117 US 689, 695 (1886). This is also known as a "blocking patent". For a discussion of bargaining between patentees with blocking patents, see R. Merges, 'Intellectual Property Rights and Bargaining Breakdown: The Case of Blocking Patents' (1994) 62 *Tennessee Law Review* 75.

[44] Lemley, 'The Economics of Improvement in Intellectual Property Law', above n 6, 1010.

[45] 33 F.2d 723 (9th Cir. 1964).

[46] 33 F.2d 723, 725 (9th Cir. 1964).

infringing the other'.[47] The solution approved by the court was the collective licensing of both patents.[48]

(iii) Type III: Partial overlap

In this scenario, claim B is novel when compared to claim A as it covers different subject matter to claim A (it may be noted that the invention, the claim, as a whole is considered by the examiner, or court, when assessing validity, therefore, as a whole, claim B covers different subject matter to claim A as a whole). As it covers different subject matter, claim B may also evidence sufficient inventive step. Therefore, claim B may be valid.

If claim B is valid, then if an allegedly infringing product falls in A′ (the area of A outside the shared area), then A is infringed; if an allegedly infringing product falls in B′, then B is infringed. If it falls within the overlapping area, then, both A and B are infringed. To this extent, A and B may be understood to be overlapping claims.

(iv) Type IV: Complete overlap

This scenario of identical claims in two different patents is, perhaps, the easiest of the scenarios to consider. Where the claims are the same, then, claim B (the later claim) cannot be novel; further, if the claim is identical to claim A, then it cannot evidence any inventive step. Therefore, claim B cannot be a valid claim – this form of overlap may not, legally, exist.

4. CONCLUSION

There are two contributions that this paper makes to the debate on the quality of patents. The first is that it this is the first analysis examining what could be meant by overlapping patent claims (as opposed to the more loose discussions of overlapping patents). This provides the basis for future discussions in this area.

Secondly, this paper suggests that there are a certain number of (restricted) circumstances where overlapping claims are legally valid, such as selection patents and improvement patents. Each of these, however, reflect a monopoly founded on the requirements of patentability – novelty and inventive step. For situations outside these three sets of circumstances, it is likely that a later claim that overlapped a prior claim would be invalid. That is, it is unlikely that the claims of the overlapping patents would be upheld in court. As

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[47] 33 F.2d 723, 729 (9th Cir. 1964).

[48] 33 F.2d 723, 729 (9th Cir. 1964).

such, the claims will not be legally seen to overlap; that means, the *rights* that arise from the patents would not overlap.

It is possible that, despite the limited circumstances where overlap may exist, such overlap represents a problem for industry. If it does, and assuming there is empirical evidence to demonstrate it, then the problem would appear to be the result of the current test of inventive step. To fix any problem would require a reformulation of the test; though we are not sure how a more stringent test may be expressed in a way that can be efficiently and repeatedly applied by thousands of examiners around the world on a daily basis.

NBER WORKING PAPER SERIES

PATENTS AND THE SURVIVAL OF INTERNET-RELATED IPOS

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Working Paper 13146
http://www.nber.org/papers/w13146

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2007

Financial support from the German Academic Exchange Service DAAD is gratefully acknowledged. We thank Baruch Lev, INNO-tec, and participants in seminars at Melbourne Business School, Nanyang Technological University, Universitat Pompeu Fabra, INSEAD, ZEW, and the NBER Entrepreneurship Working Group for helpful comments and suggestions.

Patents and the Survival of Internet-related IPOs
Iain M. Cockburn and Stefan Wagner
NBER Working Paper No. 13146
June 2007
JEL No. L0,L26,L86,O34

ABSTRACT

We examine the effect of patenting on the survival prospects of 356 internet-related firms that IPO'd at the height of the stock market bubble of the late 1990s. By March 2005, nearly 2/3 of these firms had delisted from the NASDAQ exchange. Although changes in the legal environment in the US in the 1990s made it much easier to obtain patents on software and, ultimately, on business methods, less than half of the firms in this sample obtained, or attempted to obtain, patents. For those that did, we hypothesize that patents conferred competitive advantages that translate into higher probability of survival, though they may also simply be a signal of firm quality. Controlling for age, venture-capital backing, financial characteristics, and stock market conditions, patenting is positively associated with survival. Quite different processes appear to govern exit via acquisition compared to exit via delisting from the exchange due to business failure. Firms that applied for more patents were less likely to be acquired, though obtaining unusually highly cited patents may make them more attractive acquisition target. These findings do not hold for business method patents, which do not appear to confer a survival advantage.

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1 Introduction

Invention, entrepreneurship, and entry are very significant factors driving growth and competition. Patents are tightly linked to these fundamental economic processes, providing signals of quality to investors, some measure of protection from rapid imitation, and a basis for many types of commercial transactions in the market for knowledge (see Arora et al. (2001), Gans et al. (2002), or Scotchmer (2005)). This paper explores the role played by patents in shaping industry dynamics and firm survival during the rapid and unconstrained real time experiment provided by the dot-com boom of the late 1990s. During these "bubble years" new firms had unusually easy access to capital to fund their exploration of commercial opportunities opened up by the explosive growth of the internet. Entrepreneurs rapidly devised and implemented new business models and developed new products, with new firms appearing apparently from nowhere to become household names in financial services, retailing, and many other sectors. Unfortunately, it equally quickly became clear that many of these new businesses were intrinsically unprofitable and the boom years of unrestricted entry, easy access to capital, and extraordinary valuations of untested new companies were quickly followed by an equally dramatic period of collapsing stock prices, exit and bankruptcies.

This remarkable episode took place against a backdrop of a worldwide surge in filing and granting of patents, and the extension of the patent system, particularly in the United States, into new subject matter areas such as software and business methods. Patentability of software per se was firmly established in the US by the mid-1990s, and decisions in the US courts in the late 1990s such as *AT&T v. Excel Communications* and *State Street v. Signature Financial Services* were widely interpreted as opening the door to a flood of patents on methods of doing business, particularly those implemented in computers and networks.

The new dot-com companies therefore had the option of seeking patent protection for their products and business processes — and many inventors and entrepreneurs apparently took advantage of this opportunity, with thousands of "business method" patent applications filed with the USPTO between 1999 and 2002. These patents generated considerable controversy, with many industry participants, legal scholars, and economists concerned about the potential adverse consequences of allowing large numbers of low-quality patents to issue (Hall (2003), Merges (1999), Meurer (2003), Cockburn (2001), Hunt (2001) and many others). Many of these concerns parallel those expressed about the consequences of software patents for innovation and competition. Critics argued that the flood of business method patents would "choke" innovation by blocking new technological developments, making it prohibitively expensive for new firms to enter these markets, or allowing patentees to control entire markets by obtaining patents with inappropriately broad claims, and/or trivial inventive steps over the existing technology. Apparently concerned about the opportunistic assertion of patents on business methods against incumbent firms, the US Congress took the unusual step of singling out business methods for special treatment, creating a limited "earlier inventor" defense against patent infringement (or prior user right) for "a method of doing or conducting business".[1] However the impact of these patents on the profitability and growth of the companies that obtained them, or on the pace of innovation in the industries in which they compete is far from clear.

Quantitative research on patents for software and business methods is limited and often contradictory. Lerner (2002) found no clear evidence on the impact of patents on innovation in finance. Lerner & Zhu (2005) found, if anything, a positive impact of strengthened patent protection on software firms. On the other hand, Bessen & Hunt (2004) suggest that increasing numbers of software patents are associated with a decrease in R&D by large software companies. Gambardella & Giarratana (2006) find an important role for patents in the security software industry, where the commercial success of small firms appears to have been driven by their ability to license technology to established downstream competitors. Noel & Schankermann (2006) find evidence for a negative impact of strategic patenting on entry, R&D, and market value of software firms, while Cockburn & MacGarvie (2006) find that while incumbent patents deter entry in software markets, higher numbers of patents held by entrants stimulate entry. Hall & MacGarvie (2006) find mixed effects of changes in legal doctrine on the market value and stock returns of software firms, with a initially negative impact of the strengthening software patent protection on the valuation of incumbent software firms followed by an increase in the market valuation of software patents after 1995. There is, therefore, considerable uncertainty about the economic value and impact of these patents.[2]

Rather than attempt to directly assess the monetary value of these patents, or relate them to technological indicators of the pace of innovation, this paper examines the impact of patenting on a much more basic measure of economic impact — the survival of a sample of internet-based and software firms that went public during the boom phase of the dot-com bubble, and then faced high probabilities of business failure during the bust period that followed. To the extent that patents obtained by these firms improved their competitive position, through mechanisms such as excluding competitors, supporting higher margins, raising rivals' costs, or signaling quality, we hypothesize that they should have conferred a substantial survival advantage. Estimates of the size and significance of such an effect may provide useful insight into the economic impact of these types of patents.

The remainder of the paper proceeds as follows. In Section 2 of the paper we briefly summarize previous findings on firm turn-over and review existing literature scrutinizing software and business method patents. Section 3 contains a short description of the dataset used for the analysis, which combines financial data and patent data for 356 firms that made an IPO on the NASDAQ at the height of the stock market bubble between 1998 and 2001. In Section 4, results are presented from estimating multivariate hazard models relating firm survival to patenting, financing, and economic performance. Finally, Section 5 concludes and offers some implications of our findings.

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[1] 35 USC Sec. 273.

[2] It is even unclear whether claims about the poor quality of business method patents are generally true. Hunter (2003) and Allison & Tiller (2003) argue that business method patents compare well to patents in other technologies in terms of citation of prior art, etc.

2 Patents and the Turn-over of Internet Firms

In 1998 the Court of Appeals for the Federal Circuit removed the last obstacles to obtaining patents on business methods *per se* in the United States with its famous *State Street Bank and Trust Co. vs Signature Financial Group* decision involving US patent No. 5,193,056 in 1998 (Hunt 2001, Conley 2003).[3] As a consequence large numbers of applications for business method patents were filed in the USPTO, and many of the patents that subsequently issued protect inventions closely related to internet business models and software used in various e-business applications. The rapid increase in application and grant figures as well as some widely publicized patent infringement cases initiated a broad debate on the legal and economic consequences of allowing these patents.[4] Concerns expressed by many scholars about the potentially low quality of granted business method and software patents as a consequence of inadequate examination procedures of the USPTO by numerous authors (Dreyfuss 2000, Hunt 2001, Merges 1999, Wagner forthcoming 2007) were accompanied by strong objections and criticism from practitioners and policymakers. In response to this, the USPTO moved to tighten the examination procedures and standards for patents filed in USPTO Class 705, the principal classification for business method patents (USPTO 1999).[5]

Despite the debate on the consequences of granting large numbers of poor quality business method and software patents, their impact on economic outcomes — such as incentives to innovate and the pace of technical change — in affected industries has received little attention. These outcomes are very difficult to measure directly, but some insight into the economic significance of these patents may be gained from looking at whether or not they haev an impact on the economic performance of firms that obtain them.

Much of the literature on the value of patents has focused on indirect measures of their impact on profitability, such as stock market value of the firm. Relatively little systematic

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[3] "As an alternative ground for invalidating the '056 patent under Section 101, the [district] court relied on the judicially-created, so-called "business method" exception to statutory subject matter. We take this opportunity to lay this ill-conceived exception to rest." *State Street Bank & Trust Co. v. Signature Financial Group, Inc.* 149 F.3d 1368. (Fed. Cir. 1998).

[4] Outcomes of these cases have been mixed. In the *Priceline.com vs. Microsoft/Expedia* case, Priceline.com obtained an undisclosed settlement payment from Microsoft leading to a 30% increase in its stock market capitalization. But in another widely followed dispute, Amazon.com attempted to enforce a patent on "one-click" on-line purchasing against Barnesandnoble.com with only limited success: though Amazon.com succeeded in obtaining a preliminary injunction enjoining Barnesandnoble.com from using the Express Lane feature on its website during the busy Christmas buying season, this was quite quickly vacated on appeal in the face of persuasive evidence questioning the validity of Amazon.com's patent. *A*mazon.com v. Barnesandnoble.com, et al. Civ. Act. No. 00-1109, 239 F.3d 1343 (Fed. Cir., February 14, 2001).

[5] While tighter scrutiny of applications through "second pair of eyes" procedures, recruitment of appropriately qualified examiners, and improved access to relevant prior art may have raised the quality of granted patents in this class, it is not clear whether the rate at which business method patents are being issued has fallen. Applicants are likely to have reacted to this tightened scrutiny of applications in class 705 by framing the content of the application in a way that increases the likelihood of it being directed to a different part of the Patent Office.

evidence has been gathered on relationships between patenting and more basic indicators of firm performance such as growth and survival. These may be particularly useful for small or new firms, where the signal conveyed by market valuation of intangibles may be particularly difficult to identify against the noise generated by high levels of uncertainty about future growth prospects, thin trading and very volatile asset prices.

One notable exception can be found in recent paper by Mann & Sager (2005). Here the authors combine data on the venture capital financing of software start-ups with data on the patents held by those firms in order to analyze the relation between patenting and their ability to obtain venture financing, as well as and their progress through the venture cycle. They find some correlation between patenting and different proxies for success but also acknowledge that the private value of holding software patents varies greatly between firms even within the same industrial subsegment.[6]

Here we tackle a similar question — is there a private benefit from patenting business methods and software? — with a somewhat different research strategy. Analyzing a set of dot-com firms pursuing business models closely tied to internet services and software, we relate patent holdings to the survival of these firms as publicly traded companies. The survival analysis framework we employ for this purpose has been widely used in previous empirical studies of firm failure and industry dynamics. Compared to a relatively sparse theoretical literature[7], IO economics is rich in empirical evidence on entry and exit, and there is a well-established set of 'stylized facts' on firm survival. Geroski (1995), Sutton (1997) and Caves (1998) provide comprehensive surveys. Considering firm characteristics, the most common result is that survival is positively related to firm size and to firm age. Most studies find that small firms (who are more likely to operate below the minimum efficient scale) exhibit higher failure rates. Moreover, younger firms have higher failure probabilities and Audretsch (1995) argues that firm age is a proxy for the accumulation of information about technology, markets and a firm's own cost function. A greater stock of accumulated information should lead to higher survival chances. In addition to these firm characteristics, industry characteristics and the competitive environment have also been studied in depth. In particular, the point in the technology or industry life cycle at which a firm operates has been found to be an important determinant of firm survival (Agarwal & Gort 1996, 2002, Suarez & Utterback 1993, 1995). Further, failure is positively related to overall rates of entry in an industry (Mata et al. 1995, Honjo 2000) and also to average price-cost margins (Audretsch 1991, Audretsch & Mahmood 1995).

A different strand of literature, predominantly from the fields of accounting and finance, relates the occurrence of bankruptcy and M&A-activity to financial ratios based on capital

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[6] In a comment on a closely related paper by Mann, Bessen (2005) points out that some of these findings have to be interpreted with caution.

[7] Among the few theoretical treatments of firm turn-over are Jovanovic (1982) and Hopenhayn (1992) who suggest that in a theory of learning and noisy selection, firm age and size are important determinants of survival. In a recent paper, Cooley & Quadrini (2001) introduce financial markets to this model and analyze the effect of market frictions on firm survival.

market data and accounting information derived from firms' financial statements. In a comprehensive study, Fama & French (2004) document a strong increase in the number of new lists at the NASDAQ in the period between 1973 and 2001 which is accompanied by a sharp decline in survival rates over time. Fama & French (2004) find that surviving firms exhibit higher profitability and growth rates. Logit models have been used in this context to predict take-over targets (Palepu 1986) or to analyze delistings from stock markets (Seguin & Smoller 1997). Seguin & Smoller (1997) find a higher mortality rate for lower priced stocks than for higher priced issues while mortality in their sample is not influenced by market capitalization. Recently, Shumway (2001) emphasizes the advantages of hazard models compared to static models in predicting bankruptcy using financial and accounting ratios. Applying this type of model to bankruptcy data, Chava & Jarrow (2004) find that accounting variables add little predictive power when market based measures are already included in the model while Beaver et al. (2005) identify additional explanatory power of information based on financial reporting.

A number of recent papers have focused on the cohort of young high-tech firms that went public during the stock market bubble of 1998-2001. These studies seek to characterize both the extraordinary conditions of the equity markets at that time as well as the innovative activities of the new firms, relating these to firm survival after the IPO. Audretsch & Lehmann (2004), for example, analyze the survival times of a sample of 341 firms from various industries listed on the German *Neuer Markt*[8] as a function of firms' human capital and intellectual property assets. Modelling the length of time a firm was listed on the stock market before it was delisted, the authors find that the likelihood of survival is positively related to firm size, the human capital accumulated in the board of directors, and the number of German patents held by a firm. Moreover, Audretsch & Lehmann (2004) find that failure rates are negatively affected by the investment share of venture capital firms prior to IPO. In a related study, Jain & Kini (2000) find that the presence of venture capitalists prior to going public improves the survival prospects of IPO firms.

Other studies have focused on the survival of firms that are based on a business model that relies on the internet to perform transactions, distribute products or provide services, and interact with customers. For instance, Kauffman & Wang (2003) analyzed survival times of 103 such "internet firms" listed on the NASDAQ.[9] Employing a competing risks specification they found that firms which distribute physical goods via the internet (as opposed to firms provided digital services) and firms which target both consumer and business markets have longer survival times until either a merger or a delisting occurs. Botman et al. (2004) analyzed survival of 326 internet firms listed on the NASDAQ between 1996 and 2001, as a

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[8] *Neuer Markt* was launched as market segment for high-tech and internet start-ups by the German Stock Exchange on March, 10^{th}, 1997. Six years later on June, 5^{th}, 2003 *Neuer Markt* was closed in a re-segmentation of the German Stock Exchange — most likely due to dramatic losses in market capitalization and loss of investor interest.

[9] The authors are not completely clear on whether their sample consists exclusively of NASDAQ-listed firms, but given the US context this seems highly likely.

function of variables intended to characterize market conditions at the time the IPO took place, the reputation of the management and the investment bank leading the IPO as well as firm characteristics such as financial condition and age. Their results show that surviving firms are associated with lower risk indications in the IPO prospectus, higher underwriter reputation, higher investor demand for the shares issued at the IPO, lower valuation uncertainty, higher insider ownership retention, a lower NASDAQ market level, and a higher offer-to-book ratio compared to non-survivors. Comparing survivors versus acquired firms, they find that acquired firms are smaller in size and have a longer operating history.

Our study focuses on the relevance of patents for the success of dot-com companies. In particular, we examine the extent to which these firms took advantage of the changing legal landscape with regard to the patentability of business methods, and the impact of these decisions on competitive outcomes. Our study therefore combines data on firm characteristics like age, financial condition, and market environment with detailed information on their patent holdings. The patent portfolios of firms in our sample are characterized not just by counting the number of patents held, but also by measures of patent quality based on citations and international filing patterns.

3 Data and Descriptive Statistics

3.1 Data

To address these questions, we gathered data on 356 firms that made an Initial Public Offering of shares on the NASDAQ stock exchange between February 1998 and August 2001. These firms were characterized by IPO.com, a then popular but now defunct financial research service, as operating in the Internet Services, Internet Software and Computer Software Segments. We were able to obtain comprehensive data on these firms including listing information, financial information, firm age and a variety of measures with regard to their patent holdings. The data were obtained from different sources including the Delphion, USPTO, Compustat, CRSP and Venture-Xpert databases as well as firms' 10K filings and IPO prospectuses. In this subsection we briefly comment on the variables contained in our dataset before presenting descriptive statistics in the subsequent subsection.

Listing Information. For each firm we obtained detailed information on its listing on the NASDAQ stock exchange from the Center for Research on Security Prices *CRSP*-database. This data contains not only the date of the IPO ($ipodate_i$) for each firm i but also information whether or not a firm is still listed on the NASDAQ. If trading in a firm's stock was discontinued, we are able to distinguish between firms which were *delisted* due to business failure[10] and firms which *merged* with other companies. In both cases, we compute the total

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[10] This category comprises firms which were delisted due to bankruptcy and firms which have been delisted for trading persistently below the minimum price of $1 per share required

Table 1: Breakdown of firms by segment. Table includes selected examples of firms in each segment.

Segment	Firms	Examples
Internet Services	210	1-800-Flowers.com, 24/7 Real Media, Autobytel.com, Buy.com, Drugstore.com, eBay, E-loan, Freemarkets, Genuity, MP3.com, Priceline.com, Razorfish, Verticalnet
Internet Software	82	Critical Path, Entrust, Portal Software, WebMethods
Computer Software	64	Inktomi, Manhattan Associates, Onyx Software, Perot Systems, Quest Software, Red Hat
Total	356	

length of the listing period on the NASDAQ as the time between the date of delisting and the date of the IPO. This "length of listing period" is used as the duration measure in the survival analyses.

Industrial Classification. Based on the classification used by IPO.com we distinguish between three different industrial segments: Internet Services, Internet Software and Computer Software. Dummy variables for these industry segments are included in the multivariate survival analyses, with firms assigned to Computer Software used as the reference group. These categories are far from precise, assignment of firms to segments may be questionable, and some firms may in fact be operating in more than one industry segment. Table 1 shows the breakdown of firms by segment, and lists some high profile examples of firms operating in each segment.

Financial Data. We obtained financial data on a quarterly basis from the *Compustat North America* database. Compustat provides information on operating income and sales for each firm i in quarter t. The cash "burn rate" is often identified as a critical indicator of the financial health of startup firms. Unfortunately we do not directly observe cash outlays by the firms in our sample, nor do we have access to information about unused bank credit lines or other sources of liquidity. However we are able to construct a measure of the financial status or liquidity, $cashburn_{it}$, that captures some aspects of these firms' financial status. $cashburn_{it}$ is calculated as the negative of the ratio of operating income for the current quarter to the sum of cash and short term investments in the previous quarter. This variable measures the rate at which the firm is accumulating or depleting financial reserves, with positive values indicating consumption of the existing stock of cash and shortterm investments and negative values indicating further accumulation of liquid assets. op_income_{it}, $sales_{it}$ and $cashburn_{it}$ are treated as time-varying coefficients in the multivariate survival analysis of Section 4.[11]

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by NASDAQ regulations.

[11] In rare cases, these variables are not available for occasional single quarters. We interpolate missing values by averaging the preceding and subsequent quarters' value.

IPO Characteristics. Our dataset contains information on a firm's age when going public (age_ipo_i). It is measured as the difference between its $ipodate_i$ and the date of legal incorporation which was obtained from the *Venture-Xpert* database. If the date of incorporation was not available from *Venture-Xpert* it was obtained from publicly available documents such as 10K reports and IPO prospectuses filed with the SEC. Information in the *Venture-Xpert* and *SDC New Issues* databases we used to determine whether or not each firm was venture capital backed before its IPO. Further, we obtained firms' total assets reported in the quarter when going public ($assets\_tot\_ipo_i$) from the *Compustat North America*-database and include this variable as a measure of a firm's capital endowment "at birth" in our multivariate analysis. Since we are able to identify the levels of Cash & Short Term Investments as well as Property, Plant and Equipment reported in a firm's balance sheet, we further include the shares of these position when going public (as a fraction of total assets) in the regressions.

Market Environment. Capital markets in general, and the market for technology related IPOs in particular, were characterized by quite extraordinary "bubble" conditions throughout the period of this study. Investor "exuberance" during this period is widely believe to have created market conditions in which large amounts of capital could be raised at remarkably low prices, and with relatively little scrutiny. In order to control for these conditions, we include the average value of the NASDAQ Composite Index in the quarter prior to quarter in which a firm's IPO took place ($nasdaq\_ipo\_lag_i$) as a control variable in our regressions.

Patent Information. Various variables that describe a firm's patent portfolio such as number of patents, international scope of filings, and proxies for patent value were collected from USPTO and other data maintained by Delphion Inc. For each firm in the dataset, Delphion's databases on issued patents and published applications were searched by hand using the company name, along with word stems, common abbreviations, and obvious variations in spelling of companies' names. "Weak" matches were verified by inspecting the inventor names, address information, citations to other patents, and the content of abstracts. In principle, this procedure captured all patent applications and issued patents for which the firm in question was the assignee. Nonetheless is likely that some patents controlled by the firms in this sample were not captured in this search. The search process relies heavily on USPTO's coding of assignee names, and does not capture patents re-assigned to a firm after issuance, exclusively licensed from the inventor, or held in subsidiaries that we were not able to recognize. It is also possible that a significant number of pending applications have been missed in the search, either because the applicant chose to forfeit filing rights outside the US, thus avoiding publication of the application entirely, or because the 18-month period before publication was still in force at the time the search was performed.

Interestingly, notwithstanding many contemporary commentators' beliefs that business method and software patents were trivially easy to obtain during this period, no issued patents or applications could be found for more than half of the firms in this sample. Dummy variables were coded to indicate whether firms in a particular segment did apply for or hold any patents.

Various measures of the size and characteristics of each firms' patent portfolio were computed. These include the number of USPTO patent applications and grants, as well as counts of applications and grants at the European and Japanese Patent Offices, plus variables which are correlates to patent value: the average family size of a firm's USPTO patents, the average number of forward citations received per grant or application, and the number of forward citations per claim.[12]

It is well-known that the value distribution of patents is highly skewed (Harhoff et al. 1999, 2003) and value measures that average the number of cites per claim over the entire portfolio of patents held by a firm largely obscures this phenomenon. We therefore attempt to capture some aspects of the skewness of the value distribution by counting the the number of patents in a firm's patent portfolio which received 7 or more forward citations (which is approximately the upper quartile of the distribution of number of forward citations in this sample.)

3.2 Descriptive Statistics

Before advancing to our multivariate analysis of firm survival in Section 4 we briefly present major descriptive statistics of the sample. In total, our sample contains 356 firms that went public between February, 25th, 1998 and August, 6th, 2001. These 356 firms make up about 74% of the total number of IPOs reported by IPO.com in the three industry segments considered. (The remainder are firms for which reliable matches to the databases on NASDAQ trading, venture funding, or financial information could not be made.) The distribution of the IPO dates of these firms (Figure 1) shows that most of them went public in the years 1999 and 2000. Strikingly, this distribution tracks the movement of the NASDAQ composite index during this period (see Figure 2).

In total, NASDAQ trading in more than 60% of the firms in our sample had been discontinued by March 1st 2005, the end of the observational period. Table 2 clearly shows that firms from the Internet Services segment exhibit the highest exit rates with 69.5% leaving the sample before August 2005, compared to 59.7% for Internet Software and only 46.9% for Computer software firms. The average time elapsed until trading was discontinued is also presented in Table 2. Note that the average time until firms exited as a result of merger is significantly shorter than the time until delisting due to business failure. Moreover, this difference is much more pronounced for firms from the Computer Software segment compared to firms with a business model related to the internet. [13]

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[12] Lanjouw & Schankerman (2001) argue that this measure is superior to simple counts of forward citations. Note that this measure is computed using only granted patents since the number of claims is not reported for patent applications.

[13] Table 11 tracks the financial status of exiting firms for the five quarters preceeding exit.

Figure 1: Distribution of the IPO dates of the 356 firms in our sample.

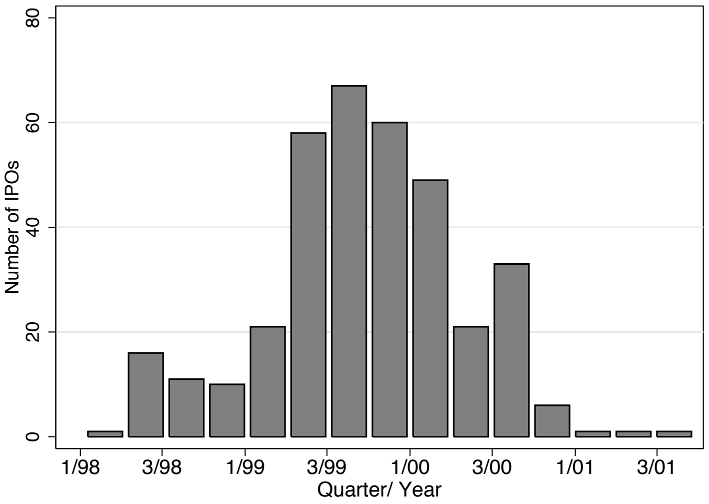


Figure 2: NASDAQ composite index for the period 1998 to 2001.

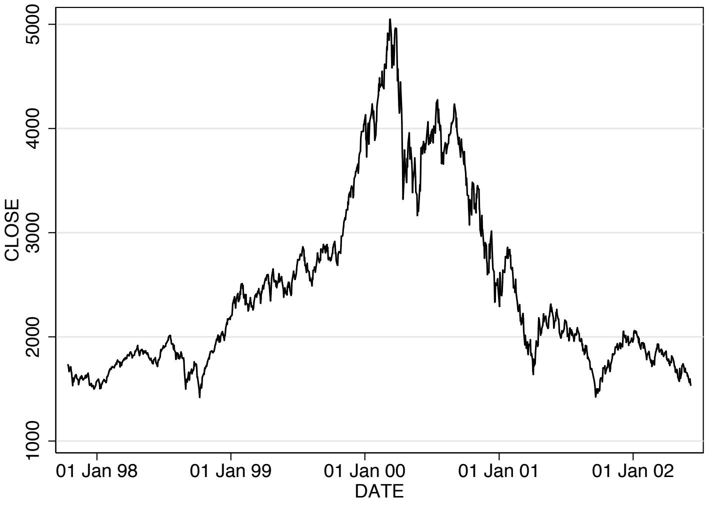
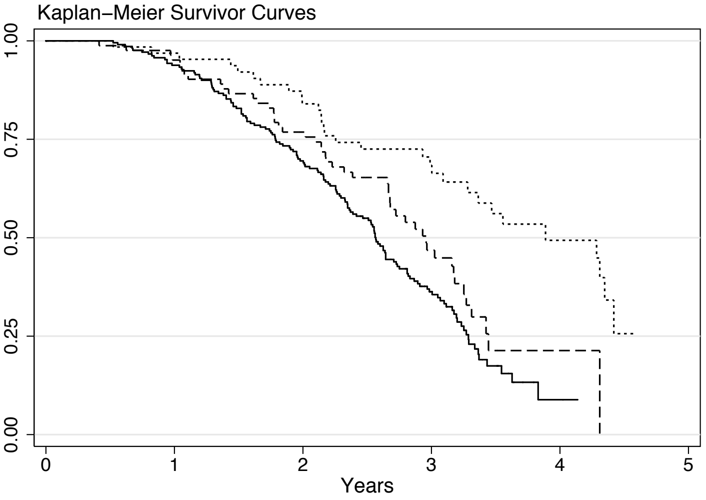


Table 2: Crosstabulation of industrial classification and the listing information for the firms contained in our sample. The second line of each row contains the average listing duration. Note: In a Pearson χ^2-test the differences between firms of different industrial classifications turned out to be significant at the 5% level ($\chi^2(4) = 11.57$).

	Listing Information						
Classification	**Still trading**		**Merged**		**Delisted**		**Total**
Internet Services	64	(30.48%)	87	(41.42%)	59	(28.10%)	210
	.		2.0 Yrs		2.3 Yrs		
Internet Software	33	(40.24%)	31	(37.81%)	18	(29.95%)	82
	.		2.1 Yrs		2.4 Yrs		
Computer Software	34	(53.13%)	18	(28.12%)	12	(18.75%)	64
	.		2.2 Yrs		3.1 Yrs		
Total	**131**	(36.8%)	**136**	(38.2%)	**89**	(25.0%)	**356**
	.		2.1 Yrs		2.4 Yrs		

Figure 3: Kaplan-Meier Survivor Curves for the firms in the sample. (—) Internet Services, (- - -) Internet Software, (· · ·) Computer Software.



Moving beyond the information in average survival times, Figure 3 presents Kaplan-Meier product-limit estimates of the survivor functions of the firms in our sample i (Kaplan & Meier 1958). The survivor curves again show that firms with internet-based business models drop out much earlier than Computer Software firms. Moreover, once past the one year mark, the survival curves for the three groups do not intersect, indicating that the proportionality assumption of Cox's Proportional Hazard model is likely to hold with regard to the different classifications of our firms (Kalbfleisch & Prentice 2002).

Table 3 summarizes some of the important observable characteristics of the firms at the time of their IPO. First, consider the age of the firm. (Recall that age is measured as time elapsed from the date of incorporation until the date of the IPO.) While the average firm is 5.91 years old when the IPO takes place, firms from the Internet Services segment have a prior firm history of only 4.72 years, while firms from the other industry segments are significantly older: firms in the Internet Software segment averaged 6.78 years since incorporation, and those in Computer Software averaged 8.69 years. There are also differences across segments in the extent to which the IPOs of these firms were backed by venture capital firms. In particular, IPOs in the Internet Software segment were more frequently venture-backed (64%) than Internet Services firms (55%) or Computer Software firms (56%). Differences across industry segments are also apparent in the sales and operating profits reported by the firms for the quarter in which their IPO took place. On average, firms in the Computer Software segment realized the highest sales (US$17.45 million) and made only minor operating losses of US$0.5. Internet Services firms achieved somewhat lower sales, averaging US$12.95 million, and Internet Software firms averaged even less, at US$7.55 million in their first quarter as

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Acquired or merging firms had relatively stable sales, improving operating income, and a moderate decline in cash and short term investments. By contrast, delisted firms had falling sales, signficantly higher losses, and a rapidly deteriorating cash position.

Table 3: Mean values of major firm characteristics for the quarter when their IPO took place.

Firm Characteristics	**Internet Services** (n=210)	**Internet Software** (n=82)	**Computer Software** (n=64)	**Total** (n=356)
Age (Years)	4.72	6.78	8.69	5.91
Venture-backed	0.55	0.64	0.56	0.58
Sales ($MM)	12.95	7.55	17.45	12.51
Operating Income ($MM)	-9.50	-5.56	-0.49	-6.97
Proceeds from IPO ($MM)	149.49	150.58	112.33	143.06
Assets ($MM)	164.09	84.49	84.89	131.52
Property, Plant and Equipment ($MM)	22.84	4.27	6.49	15.82
Cash and Short-term Investment ($MM)	88.88	64.62	51.19	76.62
Cash burn rate	0.45	0.26	0.44	0.41

a public company. Moreover, when going public these internet-related firms were highly unprofitable with operating losses averaging US$9.5 million per quarter in Internet Services and US$5.6 million per quarter in Internet software (see Table 3). These differences in profitability are also reflected by our *cashburn* measure of liquidity, defined as the negative of the ratio of operating profits divided by cash and shortterm investments in the previous period. In the quarter of their IPO, firms from the Internet Services segment had on average operating losses equalling about 45% of their cash and shortterm investments while this measure is only about 26% for Internet Software firms Computer Software firms had on average operating losses of 44% of their cash on short term investments (see Table 3).

Turning to information on the patenting activities of the firms in the sample, Table 4 reports the distribution of patent applications across technology classes, using the US Patent Classification scheme, and classifying patents based on the primary USPC code. Not surprisingly, classes that are relevant to the e-commerce and the internet (networking, databases, cryptography etc.) are well represented. Interestingly Class 705 (in which most business method patents should be classified) accounts for only 11.4% of the 1198 applications in our dataset.[14]

As noted above, a substantial fraction (53.8%) of the firms in our sample did not patent at all prior to March 2005, with significant differences across industry segments: 65.2% of the Internet Services, 51.2% of the Internet Software firms and 45.3% of the Computer Software firms had not filed a published patent application at the USPTO, the EPO, or the JPO. [15]

Table 5 gives summary statistics of the patenting activities of firms that did file at least

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[14] These patents are held by 14 firms classified to Internet Services, two firms from Internet Software and only one firm from Computer Software.

[15] Though there were (and are) significant differences in principle across USPTO, EPO, and JPO as regards patentability of software and business methods, this has not in practice prevented firms from obtaining patents on these types of inventions in all of these jurisdictions.

Table 4: Classification of the USPTO patent applications of the firms in the sample.

Class	**Description**	**Patents**	**Share**
709	Electrical computers and digital processing systems: multi-computer data transferring	188	15.69%
705	Data processing: financial, business practice, management, or cost/ price determination	137	11.44%
345	Computer graphics processing and selective visual display systems	134	11.19%
707	Data processing: database and file management or data structures	122	10.18%
713	Electrical computers and digital processing systems: support	111	9.27%
704	Data processing: speech signal processing, linguistics, language translation, and audio compression	42	3.51%
380	Cryptography	38	3.18%
370	Multiplex communications	37	3.09%
434	Education and demonstration	37	3.09%
375	Pulse or digital communications	35	2.92%
379	Telephonic communications	33	2.75%
725	Interactive video distribution systems	26	2.17%
.	Other classes with less than 20 applications (2% of total)	258	21.54%
Total		**1198**	**100%**

one published patent application. Firms from the Computer Software segment are most active patentees, averaging 12.29 USPTO applications per patenting firm, compared to 9.62 for Internet Software patenting firms, and only 4.92 USPTO applications for patenting firms in Internet Services.[16] Table 5 also reports the extent of international patenting activity by the sample firms. On average, EPO and JPO applications and grants are significantly lower than at USPTO, with smaller differences across industry segments. Curiously, despite being the least active patentees in terms of the average size of their patent portfolio, the share of international patentees is highest in the group of Internet Services firms, with the opposite effect visible for Computer Software firms.

In addition to the patent counts, Table 5 also reports measures of the value or quality of these firms' patent portfolios. The average number of claims for the patents held by the firms in our sample is 23.43 with small differences across groups. The average patent family size is 5.24. However measures which are correlates to patent value are of highest interest. Interestingly, we observe significant differences in the average number of forward citations per patent, which are highest for Computer Software firms with 7.32 compared to 5.14 for Internet Services and 4.60 for Internet Software firms. Similarly, the average proportion of firms' portfolios that is made up of highly cited patents (7 or more citations received) is highest in Computer Software, as is the average across portfolios of the number of citations received per claim. While it is tempting to interpret these as evidence of higher average quality or value of patents in the Computer Software segment compared to Internet Services or Internet Software, it is important to recognize that some of this variation may simply reflect differences across segments in the nature of technology or citation practices, and most importantly, in the size of the population of potentially citing patents.[17]

Finally, Table 6 summarizes our dependent variable in the multivariate analysis of Section 4 (the time between the IPO and the delisting of a firm) within different categorizations of important independent variables at the IPO date. Comparing the average duration for firms which filed at least one patent (opposed to firms which did not apply for a patent in the US) we find that patenting is associated with longer survival times. The same is true when distinguishing firms which obtained venture capital funding prior to their IPO with firms which did not. Having obtained venture capital financing is also positively related to the duration of the listing period on the NASDAQ. Finally, we report financial characteristics like operating income and total assets when going public. We categorize these variables in the quartiles of their respective distribution and find that both influence survival chances. The relation between operating income and survival time is straightforward: Firms generating

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[16] It is possible that these differences are a consequence of differences in firm age. However, the correlation coefficient between the number of USPTO patent applications and the firm age when going public is 0.06 and not significant.

[17] Interestingly, though, these differences do not appear to be driven by the age of firms and the age of their patents. Since older patents can be cited for a longer period of time than younger patents, they ought on average to receive more citations. However, the correlation coefficient between the number of citations received and firm age when going public is 0.03 and not significant.

Table 5: Mean values of major patent characteristics of firms who applied for at least one published patent application at the USPTO, EPO, or JPO. Firms without any patenting activities are excluded from the computation of average values. ($^{+}$ indicates that statistics are computed only for issued USPTO patents since the number of claims is not reported for published applications.)

Patent Characteristics	**Internet Services** (n=74)	**Internet Software** (n=42)	**Computer Software** (n=35)	**Total** (n=151)
Share of firms with 0 applications	0.65	0.51	0.45	0.58
USPTO applications	4.92	9.62	12.29	7.93
USPTO grants	4.28	9.14	10.91	7.17
EPO applications	2.86	3.00	2.94	2.92
EPO grants	1.79	2.19	1.23	1.79
JPO applications	0.28	0.60	0.31	0.38
JPO grants	0.23	0.30	0.23	0.25
Share of international patentees	0.64	0.57	0.54	0.60
Family size at USPTO	4.89	5.36	5.86	5.24
USPTO claims^{+}	22.42	23.91	25.00	23.43
Cites per patent	4.60	5.14	7.32	5.39
Share of patents with ≥ 7 cites	0.21	0.27	0.35	0.26
Cites per claim^{+}	0.50	0.56	0.64	0.55

income in the top quartiles tend to exhibit longer survival times than firms from lower quartiles. The relation between assets reported when going public and survival is more complex. On average, we observe a U-shaped relation with firms belonging to the top and the lowest quartiles having longer survival times than firms from the middle quartiles. However, firms which delisted their shares due to bankruptcy exhibit longer survival times if their reported assets lie in the 2nd quartile. In order to disentangle the effects of the different independent variables we conduct a multivariate survival analysis based on the Cox Proportional Hazards model in the following Section.

Table 6: Mean time until delisting. Table entries are the mean time (in years) until delisting broken down by different characteristics of firms. Categories are defined by the values of independent variables as of the IPO date. Note that the table is based only on the 225 firms which were delisted from the NASDAQ within the sample period.

Variable	**Merged Firms**		**Delisted Firms**		**Total**	
	Duration	Obs	Duration	Obs	Duration	Obs
Patents						
At least one patent application	2.14	48	2.59	33	2.32	81
No patent application	2.01	88	2.32	56	2.13	144
Venture Capital						
VC funding obtained	2.25	46	2.54	40	2.39	86
No VC funding obtained	1.95	90	2.32	49	2.08	139
Operating Income						
1st Quartile	1.74	40	2.11	29	1.89	69
2nd Quartile	1.94	36	2.31	25	2.09	61
3rd Quartile	2.27	27	2.77	28	2.52	55
4th Quartile	2.37	33	2.67	7	2.43	40
Total Assets at IPO						
1st Quartile	2.25	36	2.44	24	2.33	60
2nd Quartile	1.92	36	2.56	23	2.17	59
3rd Quartile	1.91	38	2.33	17	2.04	55
4th Quartile	2.17	26	2.33	25	2.25	51
Cash and Short-Term Investments at IPO						
1st Quartile	2.02	25	2.56	21	2.26	46
2nd Quartile	2.05	33	2.41	26	2.21	59
3rd Quartile	2.05	59	2.39	22	2.14	81
4th Quartile	2.10	19	2.32	20	2.21	39

4 Multivariate Survival Analysis

We now proceed to analyze the influence of various firm characteristics, specifically financial data and patent holdings, on firm survival.

4.1 Methodology

In order to analyze the determinants of firm survival we employ a simple hazard model where we consider survival time as a nonnegative random variable T.[18] A basic concept for the analysis of survival times is the hazard function $\lambda(t)$, which is defined as the limit

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{P(t \leq T < t + \Delta t \mid T \geq t)}{\Delta t}$$

and measures the instantaneous failure rate at time t given that the individual survives until t. In the following, different survival models are estimated where the hazard function depends on a set of covariates $x' = (x_1, \ldots, x_p)$ that influence the survival time T.

The reference model for multivariate survival analysis is Cox's proportional hazard (PH) model (Cox 1972) where the hazard rate is assumed to be the product

$$\lambda(t, x) = \lambda_0(t) \exp(x_1\beta_1 + \ldots + x_p\beta_p) = \lambda_0(t) \exp(x'\beta).$$

In this model the baseline hazard rate $\lambda_0(t)$ remains unspecified and, through the exponential link function, the covariates x act multiplicatively on the hazard rate. We use a specification which includes both time-variant regressors x_{it} like the quarterly operating income or sales and also time-invariant regressors like firm characteristics at the IPO and the patent characteristics x_j. Hence, the specification we have to estimate is of the form

$$\lambda(t, x) = \lambda_0(t) \exp(x_j\beta_j + x_{it}\beta_i).$$

As noted above, we are able to observe different modes of exit from the sample: firms can either be delisted as a result of bankruptcy or minimal market value, or cease trading as a result of a merger or takeover. We therefore report estimation results from both a pooled model that does not distinguish between different outcomes, as well as a competing risks model that explicitly takes into account the different modes of exit.[19] Schary (1991) emphasizes important economic differences between different forms of exit and argues for a

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[18] Recall that the survival time is the defined as the time between the first listing of a firm and the discontinuation of share-trading at the NASDAQ.

[19] Results from alternative parametric estimations are similar to the results from our Cox PH models. Results from log-logistic specifications of the competing risks survival models are not reported but can be obtained from the authors upon request.

separation of exit types when studying firm survival.

4.2 Results

The results of our multivariate estimations are reported in Tables 8 through 10 at the end of the paper. Table 7 gives descriptive statistics for the regressors.

In Table 8 results are reported for pooled and competing risks models for two different sets of explanatory variables. The first specification (left part of Table 8) contains only firm-specific characteristics, the level of the NASDAQ composite index in the quarter preceding the IPO, and the dummy variables indicating whether a firms from the different segments have filed at least one patent application or not. In the second specification (right part of Table 8) we control for characteristics of firms' patent portfolios using the variables described above.

Column (1) of Table 8 contains the estimation results from the pooled model, which does not distinguish between different exit modes. Large and strongly significant effects are estimated for sales, total assets, cash burn rate, the level of the NASDAQ composite index and the no-patent dummies. Unsurprisingly, firms with higher sales exhibit higher survival probabilities. An additional \$10MM per quarter in sales (sample average of \$21.96MM) increases the probability of survival by about 2%. Moreover, we find that our cash burn rate measure is a strongly significant determinant of firm survival with high cash burn rates associated with a substantially increased hazard rate. Curiously, the small but strongly significant effect of total assets at the time of IPO indicates that firms that were able to raise larger amounts of capital were somewhat more likely to exit.

Older firms have a lower risk of failure, with an additional year of pre-IPO existence increasing the probability of survival by about 3%, though the estimated coefficient is not significant. The results for level of the NASDAQ composite index are also interesting, and confirm previous findings. Firms that went public during periods of higher market valuations for high-tech firms have markedly lower survival chances. The estimated coefficient implies that an additional 1000 points on the NASDAQ at the time of IPO would reduce the probability of survival by almost 30%. Not having applied for any patents is also a strong determinant of failure. Firms that filed at least one patent application have a 34% lower probability of exit relative to baseline.

Controls for industry segment show very large (and for Internet Services firms, highly significant) differences in the hazard rates. Firms in Internet Services are twice as likely to exit via a merger as firms in Computer Software. However, we find no significant effect for firms in Internet Software compared to the reference group.

The results from our pooled model conceal some interesting differences across modes of exit from the sample. Results from the competing risks model which distinguishes between delistings due to acquisition or merger of the firm and delistings due to business failure

(Columns (2) and (3) of Table 8) are revealing.[20]

While the effect of the operating profits was — somewhat surprisingly — not statistically significant in the pooled risks specification, the competing risks specification clearly shows that this result is due to two offsetting effects. The estimated effect of operating profits is positive and significant for firms that have merged or been acquired since their IPO, but negative and significant for firms whose shares have been delisted due to business failure. Moreover, we also observe different effects for the dummy variable indicating whether firms were venture capital backed prior to their IPO. While venture-backed firms are much more likely to exit via merger/acquisition (Column 2), they exhibit lower (albeit insignificantly different from baseline) hazard rates with regard to a delisting due to business failure (Column 3). Firms that were older at the time of their IPO have a marginally significantly lower hazard rate for being delisted due to business failure, with no effect on the hazard of exiting via merger/acquisition. Turning to the effect of the total assets and the share of tangible assets of the total assets reported by a firm at the time of IPO, very substantial differences are apparent in the hazards for different modes of exit. No statistically significant effect is found on the hazard of exit via merger/acquisition, however a significant effect of small magnitude is found for the hazard of delisting due to business failure. Similarly, the cash burn rate variable has markedly different effects for different modes of exit: there is no significant impact on the hazard for exit via merger/acquisition, but a very strong effect on the hazard for exit via delisting. Puzzlingly, the effect of total assets is positive: having another $100MM at the time of IPO (compared to the sample average of $126MM *raises* the likelihood of exit through business failure by 0.1%). However, firms reporting higher shares of tangibles assets compared to the total amount of assets reported at the IPO have a significantly lower risk of failure due to bankruptcy.

The effects described above remain largely unchanged once the variables characterizing the patent portfolios held by these firms are introduced (see right part of Table 8). In the pooled risks model (Column 4) estimated hazard ratios on most of the firm characteristics are very similar in magnitude. Firms which were younger, were not venture-backed, were less profitable, had higher assets, and IPO'd when the NASDAQ was at a higher level were less likely to survive. Very similar differences between firms that exited as a result of business failure and firms that were merged/acquired are also apparent. Introducing the patent portfolio characteristics has only a small effect on the "no patents" coefficients, which become somewhat smaller in magnitude.

Among the patent portfolio variables, only the total number of patent applications filed at the USPTO is a significant determinant of firm survival. Applying for one more patent lowers the probability of exit by almost 5% in the pooled risks model. A marked difference in this effect is seen in the competing risks model: firms with more patent applications had

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[20] A formal test of whether exits to different states are behaviorally distinct is presented in the Appendix. The null hypothesis of proportionality of cause-specific hazards is strongly rejected $\chi^2(11) = 327.26$ for the models in columns (1) through (3), and $\chi^2(16) = 344.07$ for the models in columns (4) through (6).

a 10% lower hazard of exiting via merger/acquisition, but no significant effect is seen on the hazard of exiting via delisting.[21]

Disappointingly in the light of evidence on correlation between patent quality measures and patent value in other contexts, no significant effects for the variables describing characteristics of the patent portfolios beyond the number of applications were found in the pooled risks model. The same is true for the competing risks model (Columns 5 and 6 of Table 8) with one interesting exception. Having a portfolio with a higher fraction of highly cited patents had a positive and marginally significant effect on the probability of exiting via merger/acquisition. We (cautiously) interpret this as evidence that highly cited patents are a particularly valuable asset, or a signal that the exiting firm's technology/business model is high quality. (Though the inverse effect is found on the hazard of being delisted due to business failure, this effect was not significant.)

Turning to the issue of Business Method Patents (defined as patents filed in USPTO Class 705), Tables 9 and 10 present results from re-estimating the models of Table 8 columns (4) to (6) with a distinction drawn between "705" patents and "non-705" patents. Patents held or applied for by the firms in the sample were divided into two groups, those with USPC class 705 ("Data Processing: financial, business practice, management, or cost/price determination") appearing anywhere in the list of patent classes, and those where 705 appeared nowhere.[22] Panel I of Table 9 repeats the estimation, but with the patent portfolio characteristics computed only from the non-705 patents; in Panel II the patent variables are constructed only from the Class 705 patents.

The estimated hazard ratios in Panel I are almost identical to those obtained in Table 8. The new "no patents" dummy has statistically significant coefficients reflecting the findings from Table 8. In Panel II, where the non-705 patents have been removed from consideration, the "no patents" dummy loses significance, and the estimated effect of number of patent applications falls essentially to zero. We conclude, therefore, that the Class 705 patents seem to have very little effect on the survival of firms, with the possible exception of patents with a high number of citations received per claim. The coefficient on this variable implies a a large, positive, and strongly significant estimated effect on the probability of exiting via merger/acquisition: raising citations per claim by one unit (compared to a sample average of 0.23) increases the hazard of exit via merger by almost 80%. Note that there is no significant effect of this variable on the hazard of exiting via delisting.

Table 10 evaluates differences between Class 705 and non-705 patents somewhat differently. Here the specification of the model is expanded to include two sets of patent portfolio

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[21] In their analysis of 429 Finnish M&A-transactions, Hyytinen et al. (2005) find that the probability of being acquired by a domestic firm decreases with the number of European patents held by the target. However, the probability of an acquisition by a foreign firm increases with the number of patents.

[22] This is slightly more expansive definition of a Business Method Patent, capturing an additional 55 patents beyond the 137 that have 705 as their primary USPC class. It does not, however, capture any patents that have been carefully worded to avoid the extra scrutiny applied by the USPTO to business methods applications since 2000.

characteristics: those computed from the applications in the Class 705 category, and those computed from the applications outside class 705. Again, separating out the Class 705 patents has little effect on the results. Estimated hazard ratios on all the firm characteristics are very similar to those obtained previously, and as in Table 9, the only strongly significant impact of Class 705 patents is the large positive coefficient on citations per claim in the competing risks model.

5 Conclusion

Many new enterprises were created in the 1990s based on innovation in internet-enabled business models and supporting software technologies. Some of these firms took advantage of the option opened up by changing legal doctrine to protect their competitive position by filing patent applications on their inventions. The 356 newly-listed firms studied here collectively filed at least 1198 US patent applications, however these applications were generated by only 42% of the firms in the sample. Our results suggest that the firms that were unable or unwilling to seek patent protection were much less likely to survive the collapse of the dot.com bubble after 2001. After controlling for age of the enterprise, sales, assets, profitability and liquidity, as well as stock market valuations and venture capital backing prior to their IPO, we find that firms with no patent applications had a much higher hazard of exiting the sample. This is true both for the firms that exited as a result of being delisted from the NASDAQ due to apparent business failure, and for those that exited as a consequence of a merger or acquisition (which presumably reflects higher value of the firm's assets in a different corporate context.)

Of course, these estimated effects may not just represent the value of patents as a competitive asset in these markets. The estimated positive association between patenting and firm survival may also reflect a correlation between patenting and the underlying quality of the firm's products, business model, management, and other intangible assets. But it suggests a significant role for patents in driving industry dynamics in these technologies, especially within Internet Software. Puzzlingly, though applying for additional patents is associated with lower probability of exit, conventional measures of the quality or value of the patents held by a firm have little explanatory power in our regressions, though we find a hint that that highly cited patents may be an attractive asset for acquirers.

Interestingly for the debate about business method patents, we find that they have very little impact on survival compared to patents classified in other classes. There is one intriguing exception to this general result: firms which hold business method patents that attract more forward citations per claim appear to be more attractive targets for merger or acquisition.

Our estimates also point to some serious problems with adverse selection and the functioning of the US capital markets in the late 1990s. Firms that raised greater amounts of money before and during their IPO were significantly more likely to exit, particularly through delisting due to business failure. We also find a very large and significant effect of prevailing stock market valuations preceding the IPO: firms that went public at the height of the dot-com bubble faced much higher probabilities of being subsequently delisted.

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A Test of Proportionality of Competing Risk Specification

Narendranathan & Stewart (1991) provide a test of whether exits to different states are behaviorally distinct (rather than simply incidental) for continuous time proportional hazards models. This is a test of the hypothesis that the cause-specific hazards are all proportional to one another (i.e. that all parameters except the intercepts are equal across the hazards). The test statistic TS proposed by Narendranathan & Stewart (1991) is given by

$$TS = 2[\ln(L_{CR}) - \ln(L_{SR}) - \sum_{j} n_j \ln(p_j)] \tag{1}$$

where $\ln(L_{RC})$ is the maximised log-likelihood from the competing risk model (the sum of those from the component risk models), $\ln(L_{SR})$ is the maximised log-likelihood from the single-risk model, n_j is the number of exits to state j and $p_j = n_j / \sum_j n_j$, where there are $j = 1, \ldots, J$ destination states. The test-statistic is distributed Chi-squared with degrees of freedom equal to the number of restrictions.

For our basic models reported in Table 8, we can reject the null hypothesis of risk proportionality at 1% of significance both for the models not including patent characteristics ($TS = 327.27$) as well as for the model containing patent characteristics ($TS = 344.07$). Hence, we reject the hypothesis that the different forms of exit are behaviorally equal.

For our models containing only the set of no-705-patents and the set of 705-patent (as reported in Table 9), we can reject the null hypothesis of risk proportionality at 1% of significance for both specifications ($TS = 343.01$ and $TS = 342.07$). Hence, we reject that the different the hypothesis that the different forms of exit are behaviorally equal.

For our models distinguishing between no-705-patents and 705-patent (as reported in Table 10), we can reject the null hypothesis of risk proportionality at 1% of significance ($TS = 349.09$). Hence, we reject that the different the hypothesis that the different forms of exit are behaviorally equal.

Table 7: Descriptive statistics on variables used in the regressions.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Age at IPO (years)	3671	6.013	4.481	0	29.351
Dummy for Venture-backed	3671	0.615	.	0	1
Operating Income ($10MM)	3671	-0.832	3.244	-50.659	10.729
Sales ($10MM)	3671	2.196	3.841	0	36.476
Total Assets at IPO ($100MM)	3671	1.260	3.015	0.032	46.666
Share of Cash and Short-Term Investments in total assets	3671	0.641	0.280	0	0.987
Share of Property, Plant and Equipment in total assets	3671	0.073	0.090	0	0.672
Level of the NASDAQ index prior to IPO	3671	2.687	0.721	1.691	4.428
Dummy for zero patent applications	3671	0.537	.	0	1
Dummy for any international applications	3671	0.276	.	0	1
No. of applications	3671	3.984	11.438	0	152
No. of applications outside class 705	3671	3.302	10.928	0	152
No. of applications in class 705	3671	0.682	2.573	0	25
Average forward citations per claim	3671	0.234	0.736	0	7.382
Average forward citations per claim (non-705)	3671	0.205	0.741	0	8.292
Average forward citations per claim (class 705)	3671	0.086	0.351	0	5.820
No. of patents with 7 or more forward citations	3671	1.079	3.888	0	56
No. of patents with 7 or more forward citations (non-705)	3671	0.873	3.674	0	56
No. of patents with 7 or more forward citations (class 705)	3671	0.206	1.096	0	16
Average family size	3671	2.508	5.037	0	45.257
Average family size (non-705)	3671	2.048	4.407	0	45.257
Average family size (class 705)	3671	1.310	4.026	0	34.929
Internet Services	3671	0.553	.	0	1
Internet Software	3671	0.235	.	0	1
Computer Software	3671	0.213	.	0	1

Table 8: Results from Cox Proportional Hazards Regression. Estimates from pooled and Competing Risks Specification are presented. Z-Values in parentheses. ** 1%, * 5%, + 10% significant.

	Pooled	**Competing Risks**		**Pooled**	**Competing Risks**	
	(1)	(2)	(3)	(4)	(5)	(6)
Variables		Merged	Delisted		Merged	Delisted
Age at IPO	0.9735	0.9832	0.9388	0.9753	0.9867	0.9344
	(1.46)	(0.75)	(1.89)+	(1.37)	(0.60)	(1.99)*
Venture backed	1.0890	1.4421	0.7853	1.0866	1.4082	0.8042
	(0.60)	(1.93)+	(1.07)	(0.58)	(1.79)+	(0.96)
Operating income	0.9998	1.0132	0.9961	0.9994	1.0127	0.9962
	(0.08)	(1.60)	(2.44)*	(0.29)	(1.50)	(2.39)*
Sales	0.9880	0.9956	0.9563	0.9879	0.9961	0.9563
	(3.14)**	(1.20)	(4.52)**	(3.08)**	(1.04)	(4.46)**
Total assets at IPO	1.0760	0.9306	1.2673	1.0980	0.9577	1.2763
	(2.24)*	(0.67)	(4.52)**	(2.73)**	(0.41)	(4.39)**
Share of PPE in total assets	0.6211	0.1033	3.2547	0.6141	0.1139	3.3543
	(0.57)	(1.56)	(1.14)	(0.58)	(1.51)	(1.14)
Share of cash in total assets	0.9100	1.3620	0.4262	0.9901	1.5076	0.4966
	(0.29)	(0.69)	(1.80)+	(0.03)	(0.92)	(1.44)
Cash burn rate	1.0620	1.0076	1.0841	1.0587	1.0057	1.0867
	(4.86)**	(0.20)	(5.65)**	(4.43)**	(0.20)	(5.03)**
NASDAQ prior to IPO	1.3292	1.2338	1.3979	1.3474	1.2561	1.4271
	(2.56)*	(1.50)	(1.80)+	(2.65)**	(1.62)	(1.86)+
At least one patent application	0.6364	0.6098	0.6725	0.7331	0.6622	0.8706
	(2.99)**	(2.59)**	(1.58)	(1.37)	(1.41)	(0.38)
No. of US patent applications				0.9451	0.9016	0.9990
				(2.03)*	(2.37)*	(0.03)
At least one international patent application				1.0460	1.0812	1.0091
				(0.19)	(0.26)	(0.02)
Average cites per claim				0.9919	1.0807	0.7727
				(0.07)	(0.67)	(0.84)
No. of patents with >6 forward cites				1.0604	1.1718	0.9231
				(0.84)	(1.71)+	(0.64)
Average patent family size				1.0141	1.0249	0.9873
				(0.50)	(0.80)	(0.23)
Internet Services	2.1047	2.2390	2.0358	1.9616	2.1382	1.8213
	(3.18)**	(2.73)**	(1.81)+	(2.82)**	(2.52)*	(1.48)
Internet Software	1.5783	1.6478	1.5431	1.5591	1.6263	1.5569
	(1.79)+	(1.55)	(1.02)	(1.72)+	(1.50)	(1.00)
Observations	3671	3671	3671	3671	3671	3671
Firms	356	356	356	356	356	356
Exits	225	136	89	225	136	89
Log Likelihood	-1108.66	-689.47	-394.29	-1104.93	-684.55	-392.59

Table 9: Results from Cox Proportional Hazards Regression. Estimates from pooled and Competing Risks Specifications. Note: Patent characteristics used in Panels I and II are computed from different sets of patents. Z-Values in parentheses ** 1%, * 5%, + 10% significant.

	I: No 705 Patents			**II: Only 705 Patents**		
	Pooled	**Competing Risks**		**Pooled**	**Competing Risks**	
	(1)	(2)	(3)	(4)	(5)	(6)
Variables		Merged	Delisted		Merged	Delisted
Age at IPO	0.9713	0.9804	0.9362	0.9750	0.9836	0.9443
	(1.60)	(0.88)	(1.97)*	(1.38)	(0.73)	(1.76)+
Venture backed	1.1042	1.4486	0.8043	1.0962	1.4574	0.7809
	(0.69)	(1.95)+	(0.96)	(0.64)	(1.98)*	(1.08)
Operating income	0.9991	1.0111	0.9961	0.9998	1.0138	0.9962
	(0.43)	(1.30)	(2.45)*	(0.09)	(1.57)	(2.43)*
Sales	0.9883	0.9969	0.9554	0.9882	0.9964	0.9550
	(3.02)**	(0.84)	(4.46)**	(2.98)**	(0.92)	(4.56)**
Total assets at IPO	1.1015	0.9396	1.2859	1.0785	0.9246	1.2672
	(2.80)**	(0.58)	(4.54)**	(2.22)*	(0.73)	(4.44)**
Share of PPE in total assets	0.4589	0.0639	3.2051	0.4839	0.0618	3.4147
	(0.97)	(1.98)*	(1.18)	(0.91)	(1.99)*	(1.25)
Share of cash in total assets	0.8072	1.1220	0.4487	0.6950	0.9502	0.4132
	(0.81)	(0.34)	(1.94)+	(1.39)	(0.15)	(2.15)*
Cash burn rate	1.0548	1.0046	1.0793	1.0566	1.0056	1.0782
	(4.28)**	(0.21)	(5.20)**	(4.43)**	(0.21)	(5.30)**
NASDAQ prior to IPO	1.3402	1.2500	1.4099	1.3271	1.2291	1.3935
	(2.59)**	(1.57)	(1.79)+	(2.51)*	(1.45)	(1.78)+
At least one patent application	0.5843	0.4820	0.8212	0.7122	0.4968	1.4868
	(2.21)*	(2.25)*	(0.51)	(1.08)	(1.62)	(0.74)
No. of US patent applications	0.9439	0.8966	1.0007	1.0163	1.0401	0.9144
	(1.84)+	(2.11)*	(0.02)	(0.24)	(0.51)	(0.49)
At least one international	1.0208	1.0544	0.9376	0.7803	0.7943	0.7578
patent application	(0.10)	(0.21)	(0.19)	(1.36)	(1.01)	(0.89)
Average cites per claim	0.9833	1.0609	0.6510	1.6112	1.7599	0.2049
	(0.11)	(0.38)	(0.74)	(1.81)+	(2.27)*	(1.04)
No. of patents with >6 cites	1.1009	1.2750	0.8657	1.0066	1.0085	1.5860
	(0.63)	(1.22)	(0.55)	(0.03)	(0.04)	(0.81)
Average patent family size	0.9931	1.0065	0.9777	0.9519	0.9444	0.9808
	(0.24)	(0.20)	(0.42)	(1.38)	(1.29)	(0.30)
Internet Services	2.0813	2.2795	1.8954	2.3371	2.5743	2.2549
	(3.03)**	(2.70)**	(1.57)	(3.60)**	(3.18)**	(2.02)*
Internet Software	1.6407	1.7264	1.5318	1.5806	1.6637	1.6174
	(1.92)+	(1.68)+	(0.98)	(1.77)+	(1.56)	(1.09)
Observations	3671	3671	3671	3671	3671	3671
Firms	356	356	356	356	356	356
Exits	225	136	89	225	136	89
Log Likelihoood	-1102.20	-682.38	-392.05	-1106.88	-686.97	-393.03

Table 10: Results from Cox Proportional Hazards Regression. Estimates from pooled and Competing Risks Specifications. Note: Z-Values in parentheses. ** 1%, * 5%, + 10% significant.

	Pooled	**Competing Risks**	
	(1)	(2)	(3)
Variables		Merged	Delisted
Age at IPO	0.9707	0.9792	0.9389
	(1.63)	(0.92)	(1.90)+
Venture backed	1.1123	1.4460	0.7821
	(0.74)	(1.94)+	(1.06)
Operating income	0.9992	1.0115	0.9962
	(0.36)	(1.32)	(2.43)*
Sales	0.9881	0.9968	0.9544
	(3.04)**	(0.84)	(4.51)**
Total assets at IPO	1.1055	0.9393	1.2819
	(2.85)**	(0.58)	(4.40)**
Share of PPE in total assets	0.4437	0.0651	3.1755
	(1.01)	(1.96)*	(1.16)
Share of cash in total assets	0.7588	1.0679	0.4508
	(1.05)	(0.19)	(1.91)+
Cash burn rate	1.0582	1.0057	1.0808
	(4.42)**	(0.20)	(5.04)**
NASDAQ prior to IPO	1.3531	1.2716	1.4228
	(2.66)**	(1.68)+	(1.85)+
At least one non-705 patent application	0.8326	0.8564	0.8700
	(0.76)	(0.49)	(0.36)
At least one international application	1.1083	1.1533	1.0032
	(0.43)	(0.46)	(0.01)
No. of non-705 US applications	0.9356	0.8743	1.0076
	(2.06)*	(2.43)*	(0.17)
Average cites per claim (non-705)	0.9727	1.0379	0.6505
	(0.18)	(0.24)	(0.70)
No. of patents with >6 cites (non-705)	1.1448	1.3620	0.8341
	(0.90)	(1.55)	(0.68)
Average patent family size (non-705)	0.9967	1.0080	0.9849
	(0.11)	(0.23)	(0.26)
At least one 705 patent application	0.6066	0.3951	1.3610
	(1.39)	(1.84)+	(0.51)
No. of US patent applications in 705	1.0218	1.0621	0.8896
	(0.33)	(0.84)	(0.58)
Average cites per claim (705)	1.6428	1.7932	0.1814
	(1.93)+	(2.39)*	(1.14)
No. of 70 5 patents with >6 cites	0.9803	0.9911	1.6636
	(0.10)	(0.04)	(0.85)
Average family size (705)	0.9802	0.9729	1.0074
	(0.51)	(0.57)	(0.10)
Internet Services	2.0082	2.2134	1.9082
	(2.87)**	(2.59)**	(1.56)
Internet Software	1.5729	1.6710	1.5863
	(1.74)+	(1.56)	(1.02)
Observations	3671	3671	3671
Firms	356	356	356
Exits	225	136	89
Log Likelihoood	-1101.52	-680.43	-391.12

Table 11: Mean and median values for key financial variables in the five quarters prior to an observed exit.

Quarters until delisting		**4**	**3**	**2**	**1**	**0**
				Merged		
Sales (in $MM)	Mean	17.73	19.01	17.47	17.82	18.21
	Median	10.43	10.39	9.43	9.70	9.61
Operating Income (in $MM)	Mean	-5.49	-4.64	-3.69	-4.34	-4.27
	Median	-3.83	-3.77	-3.23	-3.58	-2.78
Cash & Short Term Investments (in $MM)	Mean	71.39	67.73	66.56	64.31	60.62
	Median	48.68	43.09	42.80	40.09	38.77
Working Capital (in $MM)	Mean	62.75	56.69	58.22	52.40	52.70
	Median	45.68	40.06	44.11	36.83	29.16
Quick Ratio	Mean	4.90	4.89	5.27	4.26	4.39
	Median	3.79	3.53	3.76	3.29	3.20
				Delisted		
Sales (in $MM)	Mean	17.52	17.64	16.53	15.06	14.06
	Median	6.92	6.66	6.24	5.44	5.33
Operating Income (in $MM)	Mean	-13.98	-14.87	-16.81	-10.38	-14.52
	Median	-8.26	-5.29	-5.39	-5.02	-3.64
Cash & Short Term Investments (in $MM)	Mean	75.35	62.05	48.32	39.21	41.07
	Median	21.23	14.75	9.60	2.66	2.85
Working Capital (in $MM)	Mean	63.44	43.95	32.33	-10.83	-20.67
	Median	22.69	19.33	15.30	10.75	8.83
Quick Ratio	Mean	4.16	4.49	4.26	5.89	5.88
	Median	2.71	2.20	1.56	1.24	1.22

Sequential innovations with unobservable follow-on investments[*][†]

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September 16, 2007

Abstract

We consider a cumulative innovation process in which a follow-on innovator invests in R&D activities that influence both the expected commercial value of the innovation as well as the probability of infringing on the patent of an earlier inventor. When the second innovator investments are not observable, licensing of the first innovation never occurs efficiently, and, at the equilibrium, the follow-on innovator either underinvests or overinvests. We show that a large patent breadth may be harmful for the first innovator too, and therefore Pareto-dominated; as long as the undervinvestment problem becomes more pronounced, the value generated by the follow-on innovator reduces, and so do the licensing revenues of the first inventor.

J.E.L. codes: K3, L5, O3.

Keywords: sequential innovation, patents, licensing, intellectual property.

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[*] Paper presented at the Diparmimento di ingegneria gestionale - Politecnico di Milano, and at the 34th EARIE Conference, Valencia 2007.

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1 Introduction

In several industries, technical advance does not fit the stylized representation of stand-alone inventions traditionally portrayed by Nordhaus (1969).[1] In semiconductors, biotechnology, aircraft, or computer software technical advance is cumulative and subsequent generations of innovators build on and interact with technologies provided by earlier inventors. In these instances, follow-on innovators "stand on the shoulders of giants" that laid down the foundations of the industry (Scotchmer, 1991).

When innovation is cumulative and it is carried out by subsequent innovators, the patent system has to balance two, potentially conflicting, goals: ensure sufficient rewards to the early innovators, without, at the same time, discouraging follow-on R&D efforts. The contribution to the social welfare of early discoveries is broader than in case of industries with stand-alone inventions. They are valuable not only *per se* but also because they enable or facilitate valuable derived inventions. This externality calls for broad intellectual property rights to protect early discoveries: in order to align private and social incentives to R&D, early innovators should obtain a significant stake in the revenues generated by the innovations to which they contribute. This can be accomplished by granting the original patent a broad scope so that infringing subsequent innovators will need to negotiate the permission (license) of the patent-holder in order to commercialize their discoveries.

However, rewarding early innovators with strong patent protection might undermine future R&D. Anticipating that early innovators are warranted significant claims on derived inventions, follow-on innovators may have sub-optimal incentives to perform R&D activities. This hold-up problem arises especially when subsequent inventors sunk specific investment before negotiating the terms of the license agreement with the initial patent-holder. The follow-on inventor is in a weak bargaining position in that the surplus on which parties negotiate is represented by the commercial value of the derived innovation and does not take

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[1] According to Merges and Nelson (1990) it is worth distinguishing at least four different industrial patterns of technical advance: discrete (stand-alone) invention model, cumulative technologies, chemical technologies and "science-based" technologies.

into account the costs that have already been sunk (Lemley and Shapiro, 2007; Scotchmer, 1991; Shapiro, 2001);[2] in this way, the follow-on innovator might not be able to recoup the whole R&D investment. The threat that very broad intellectual property rights may slow down the pace of future innovation is compounded in case of "patent thickets", that is, when several patents read, at the same time, on a given product or technology.[3] In these instances, the downstream innovator needs to negotiate licensing agreements with every single patent-holder. Besides exacerbating the hold-up, patent thickets may also cause the "complements problem".[4] When negotiating the licensing agreement with the downstream innovator, each patent-holder imposes a negative externality on the other patent-holders: by requiring a large licensing fee it reduces what the other holders may collect. This fact may increase the overall burden of licensing fees that the downstream innovator bears up to a point where subsequent discoveries may be threatened.

As explicitly suggested already in Scotchmer (1991), parties can curb the hold-up problem described above by employing *ex-ante* licensing contracts (or prior agreements), that is by negotiating the licensing agreement before the follow-on innovator has sunk the R&D costs. In case of an ex-ante agreement, the surplus over which parties bargain is represented by the commercial value of the derived invention net of the R&D expenditures; that is, the costs borne by the follow-on innovator are taken into account in the bargaining process.

In a seminal paper, Green and Scotchmer (1995) formalize the analysis of the optimal

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[2] According to Shapiro (2001) the hold-up problem represents a real threat to future innovation in several industries. This problem is exacerbated by the lengthy approval process of Patent Offices with the danger that new products infringe on patents issued after these products were designed. The concern about these so-called "submarine patents" is particularly relevant in the software industry, see Graham and Mowery (2004).

[3] Patent thickets are common in the IT sector where many different components of a technology are protected by one or several patents (Lemley and Shapiro, 2007; Siebert and von Graevenitz, 2006).

[4] The analysis of the classic "complements problem" goes back to Cournot, 1838, and Shapiro (2001) presents an application to the the case of cumulative innovation. Heller and Eisenberg (1998) discuss the consequences of multiple blocking patents in the context of biomedical research, and warn against a potential "tragedy of the anti-commons": in the presence of multiple patent-holders the resources may be underused.

patent policy in case of cumulative/sequential innovation using a two-stage game. In the first stage, the original innovator chooses whether to invest in order to develop her idea, and, in case she does so, in the second stage, a second innovator has the opportunity to improve upon the original discovery. In case the improvement infringes on the patent of the original discovery, in order to commercialize his invention the second innovator has to obtain a license from the original patent-holder. Assuming that parties negotiate in a context of symmetric information, the authors show that ex-ante licensing contracts, i.e. signed before the follow-on innovator has sunk its R&D costs, ensure that the improvement is realized whenever efficient. In this scenario, the main task of the patent policy is to ensure enough rewards to the original inventor, and this is accomplished by granting her a very strong patent protection; in particular, patent breadth, which determines how profits are actually shared among the two inventors, should be very large, if not infinite.

The assumption that ex-ante contracting under symmetric information is feasible has been repeatedly employed in the subsequent theoretical contributions on cumulative innovation (see O'Donoghue et al., 1998 , Scotchmer, 1996 , and Schankerman and Scotchmer, 2002).[5] In a recent paper, Bessen (2004) considers the case where the development costs of the improvement are private information of the follow-on innovator. Bessen shows that ex-ante licensing does not guarantee that all efficient follow-on innovations occur: at the equilibrium, in some cases the second innovator fails to invest efficiently.[6]

In this paper, we present a model based on Green and Scotchmer (1995) and we obtain results much sharper than those in Bessen (2004). Under the realistic assumption that when

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[5] Matutes et al. (1996) and Chang (1995) do not consider the possibility of ex-ante licenses. See Gallini and Scotchmer (2002) for a recent review on these issues

[6] Siebert and von Graevenitz (2006) formalize the choice of ex-post *vs* ex-ante licensing considering the case of n firms simultaneously involved in developing a common technology. In case of ex-post licensing, firms enter in a patent race: augmenting the number of patents that a firm possesses strengthen its bargaining position during the ensuing licensing negotiations. With ex-ante licensing, defined as agreements "to share future research results prior to R&D investments", firms avoid the patent race. The authors show that the choice between reaching an agreement ex-ante or ex-post depends on the strength of the patent portfolios that firms already have in stock, and on the nature of competition in the product market.

contracting over the licensing terms the early innovator cannot observe whether the follow-on inventor has already undertaken the R&D activity, investment to develop the derived invention is always inefficient. In particular, the mere inability of the early innovator to tell whether the follow-on inventor is "truly ex-ante" always prevents efficiency. The intuition for this result is simple. If the early innovator were sure that the follow-on inventor is approaching her ex-ante, then she would be willing to offer her technology at an efficient lump-sum licensing fee. However, in this case, the follow-on inventor benefits from asking the licensing agreement ex-post: he pays the fee only in case of infringement, and, on top of that, he can take advantage of the possibility of choosing the most favorable licensing terms by selecting between the proposal of the early innovator and the fees implemented by the courts. Given this, the early innovator is better-off conforming to the fees implemented by the courts and not proposing to license her technology at an efficient lump-sum fee.

We show that, at the equilibrium, both undervinvestment and overinvesment may occur; the level of R&D activity of the follow-on innovator has both a *commercial effect*, i.e. it increases the expected commercial value of the innovation, and an *infringement effect*, i.e. it reduces the probability of infringing the first innovator's patent. When the infringement effect prevails, the follow-on inventor invests more than the efficient level.

Interestingly, the inefficiency in the R&D investment of the second innovator has important consequences in terms of patent policy. While in Green and Scotchmer (1995) patent breadth only affects the division of profits among initial and follow-on innovators, in this paper it also affects the incentives to invest in R&D of the latter. In particular, in the paper we provide three simplified examples whereby we show that the first innovator can be harmed when the breadth of the patent protecting its invention is too broad. As a consequence, we prove that, there are circumstances where a large patent breadth is Pareto-dominated, that is both innovators are better-off with a limited breadth. This result is in clear contrast with the previous literature. Both in Green and Scotchmer (1995) and Bessen (2004) the optimal patent policy has to balance opposing interests: a larger breadth benefits the early innovator to the detriment of the follow-on firm. To the contrary, we show that the interests of the two firms do not necessarily diverge in terms of patent breadth.

Our paper contributes to the current debate about the optimal scope of patents in industries where innovation is cumulative. As Gallini and Scotchmer (2002) put it, several arguments in favor of either weak or strong standards for IPR (intellectual property rights) have been proposed, and the existing literature is inconclusive as to whether broad or narrow patents are better suited to encourage innovations. However "one lesson is clear: the optimal design of IP depends importantly on the ease with which rights holders can contract around conflicts in rights" (Gallini and Scotchmer, 2002 p. 67). In this paper we show that, under reasonable conditions, the possibility to enter into ex-ante agreements fails to ensure efficient follow-on investment. Very broad patents may result in serious underinvestment that goes to the detriment of all the industry participants.

The paper is organized as follows: in Section 2 we present the outline of the paper, we derive the main results and discuss the policy implications of our analysis. In Section 3 we check the robustness of our results to possible generalisations of the model. Finally, in Section 4 we conclude.

2 The model

We consider a cumulative innovation process in which once the first inventor, firm 1, patents its innovation, a second inventor, firm 2, gets an "idea" for an improvement. We restrict the analysis to the case in which the overall commercial value of the two innovations resides in the follow-on invention; that is, the early innovation is a research tool that has no commercial value *per se*.

The focus of the paper is on the second inventor's behavior being the first innovation already in place and protected by a patent.

The idea that the second inventor gets may be more or less promising both in terms of the commercial benefits that it can generate and in terms of the probability of infringing on firm 1's patent. Formally we represent an idea as a quadruple $\left\{F^G(v), F^B(v), \gamma(b), \beta(b)\right\}$ whose terms are described below. In order to develop the idea, firm 2 has to undertake a certain amount of R&D activity, $r \geq 0$ incurring a cost $c(r)$; once the R&D cost has been sunk, then with probability r a "good state" of the world occurs, and with probability $(1-r)$ a "bad state" of the world occurs. In the former case the innovation, *i)* has a commercial value $v \geq 0$ distributed according to $F^G(v)$ and with an expected value of V^G, and *ii)* it does not infringe the patent of the first innovation with probability $\gamma(b)$, where $b \in \Re_+$ represents the patent breadth set by Government regulations. In the bad state, v is distributed according to $F^B(v)$ with an expected value of $V^B \leq V^G$, and $\beta(b)$ is the probability that the follow-on innovation does not infringe the patent of firm 1, with $\beta(b) \leq \gamma(b)$, $\forall b$. In other words in the good state of the world both the expected commercial value and the probability of not infringing of the follow-on innovation are larger than in the bad state. It should be noted that these facts imply that: *i)* there is a positive relationship between the expected commercial value and the probability of not infringing of the second innovation;[7] *ii)* a larger r, i.e. a larger R&D activity, increases both the expected commercial value, $rV^G + (1-r)V^B$, as well as the probability that the second innovation does not infringe on the patent of the first inventor, $r\gamma(b) + (1-r)\beta(b)$.

Probabilities of not infringing decrease with the patent breadth: $\gamma'(b) \leq 0$, and $\beta'(b) \leq 0$. Moreover, we assume that $\lim_{b\to\infty} \gamma(b) = \lim_{b\to\infty} \beta(b) = x$, that is when the Government sets the breadth at its maximum level then the second invention does not infringe the patent of firm 1 with probability $x \in [0,1)$. Note that $x > 0$ implies that, even in the case of maximum patent protection, follow-on innovators still have a chance not to infringe.[8] Finally, we assume that $c(r)$ is increasing and convex.

Timing and information structure of the game

In case the follow-on innovation infringes on the patent protecting the early innovation, firm

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[7] When $\gamma(b) = \beta(b)$, $\forall b$, the probability of not infringing and the commercial value are uncorrelated.

[8] Patent breadth is set based on the current state of the art. Therefore, it is reasonable to assume that, even in the case of infinite breadth, in the future follow-on innovators still have a positive probability of not infringing.

2 needs a license from firm 1 in order to market the invention.

The timing of the game is as follows :

1. once the first inventor patents its innovation, the second inventor gets an idea, formally a quadruple $\left\{F^G(v), F^B(v), \gamma(b), \beta(b)\right\}$;
2. firm 2 faces an alternative: *i)* going to the first inventor asking for a license before having undertaken any R&D activity; or *ii)* asking for a license after having sunk the cost of R&D, thus having observed both commercial value, v, and whether the invention infringes or not. In the former case, we say that the second inventor is looking for an *ex-ante* licensing agreement while in the latter we say that it is looking for an *ex-post* licensing agreement.

The details of the contracting phase between first and second inventor are specified below when we discuss how parties bargain over the licensing agreement.

In what follows we will assume that the R&D activity is neither verifiable nor observable by the first inventor; in particular, the non-observability of the R&D activity implies that, when contracting over the licensing terms, firm 1 ignores whether firm 2 has already sunk $c(r)$ or not. Finally, we assume that both the commercial value v and the infringement of the patent are verifiable, but only once the second innovation is brought to the market; namely, the second innovator holds this information privately till the moment it markets its invention.

2.1 Licensing agreement

We assume that the bargaining stage to determine the licensing terms is as follows:

- firm 2 approaches firm 1 asking for a licensing agreement;
- firm 1 proposes a fee or a menù of fees at which it is willing to license its innovation, and firm 2 can either select one of the proposed fees or reject any proposal. In case

firm 2 rejects any offer, then, when there is infringement, the court imposes a licensing fee $L(v) \equiv (1-\rho)v$, with $\rho \in [0,1]$. ρ determines how the value of the innovation is shared across inventors and it might be related both to the bargaining power of the two firms, and to the extent to which Government and courts back a more or less pronounced "pro-patent" environment.

Firm 1 can propose a fixed fee and/or a fee that varies with the commercial value v; moreover, the payment can be contingent on infringement or it might be lump-sum, and payable independently of whether there is infringement or not. Note that, in case of infringement, firm 2 has always the option to resort (ex-post) to the court and obtain the license at the fee $L(v)$; therefore, we can assume that firm 1's proposal always includes the licensing fee $L(v)$ payable contingent on infringement.

The following proposition shows that at the equilibrium the first innovation is always licensed at the fee $L(v)$ payable contingent on infringement.

Proposition 1. *All licensing occurs at the fee $L(v) = (1-\rho)v$ payable contingent to the infringement.*

Proof. As reported above, firm 1 always proposes the licensing fee $L(v) = (1-\rho)v$ payable contingent upon infringement. In what follows, we show that at the equilibrium a lump-sum fee $\bar{L}$ is not proposed by firm 1 or, if it is, it is never accepted by firm 2.

Suppose, on the contrary, that at the equilibrium firm 1 offers $\bar{L}$ with some positive probability. We need to consider three cases:

i) when $\bar{L} > L(v)$ for every possible realization of v, then firm 2 never accepts the fee $\bar{L}$;

ii) when $\bar{L} \geq L(v)$ for some realizations of v and $\bar{L} \leq L(v)$ for other realizations of v, then firm 2 asks for a licensing agreement ex-post, once it has observed v and it knows whether there is infringement. In this way it pays the licensing fee if and only if there is infringement and, provided that $\bar{L}$ is offered, it selects the most favorable contract paying a fee equal to the min $\left\{L(v), \bar{L}\right\}$. This strategy is preferred to choosing $L(v)$ ex-ante, since firm 2 pays $\min\left\{L(v), \bar{L}\right\} \leq L(v)$, whenever $\bar{L}$ is offered. Similarly, approaching firm 1 ex-post is preferred to choosing $\bar{L}$ ex-ante since min $\left\{L(v), \bar{L}\right\} \leq \bar{L}$, and the license is payed in case of infringement only. However, if firm 2 approaches firm 1 ex-post, then firm 1 is better-off not offering $\bar{L}$: firm 2 has already made the investment (there is no investment to be incentivated through a fixed licensing fee), the variable contract $L(v)$ is acceptable by firm 2 and therefore by offering $\bar{L}$ with positive probability firm 1 only lowers its licensing revenues;

iii) when $\bar{L} < L(v)$, then again firm 2 approaches firm 1 ex-post and pays $\bar{L}$ if and only if there is infringement. Also in this case firm 1 is better off not offering $\bar{L}$.

Similar arguments apply to the other possible licensing fees that might be included in the menù that firm 1 proposes; namely they apply both to the case of *i)* a variable lincensing fee $\tilde{L}(v)$ payable both when there is infringement or not, and *ii)* a licensing fee $\hat{L}(v)$ different from $L(v)$ and payable only in case of infringement. ∎

Proposition 1 can be intuitively interpreted. Being offered a menù of contracts, firm 2 will certainly approach firm 1 ex-post, in order to exploit its informational advantage; by asking for the licensing agreement once $c(r)$ has been sunk, firm 2 enjoys a double benefit: it pays the fee if and only if there is infringement, and, whenever a menù of contracts is offered, it also selects the most favorable one. This implies that by offering a menù of contracts firm 1 certainly reduces its licensing revenues; therefore, it is better-off by proposing $L(v)$ only.

Note that Proposition 1 does not necessarily imply that all licensing agreements occur ex-post; indeed, there are two equilibria of the bargaining game. In the first equilibrium, the follow-on inventor approaches firm 1 ex-post and it is offered Ł(v). The second equilibrium is in mixed strategies: *i*) firm 2 randomizes and approaches firm 1 ex-ante and ex-post with positive probability, and *ii*) the probability according to which firm 2 goes ex-ante is small enough and such that firm 1 best response is still offering no other contracts than $L(v)$ payable contingent on the infringement.

2.2 R&D investment and licensing revenues

[9]

Having defined the equilibrium in the licensing stage, we can solve for the optimal amount of R&D activities performed by firm 2. Before that, it is useful to look at the efficient level of R&D, that is the value of r that maximizes the joint profits of the two firms.

Formally, the efficient level of r is:

$$r^{eff} = argmax_r \left\{ rV^G + (1-r)\,V^B - c\,(r) \right\}.$$

The first order condition is simply:

$$V^G - V^B = c'\left(r^{eff}\right). \tag{1}$$

Let us now consider the investment level that firm 2 actually chooses. From Proposition 1 we know that whenever the follow-on innovation infringes the patent of the first inventor then firm 2 gets only a share ρ of the commercial value generated by its innovation. Therefore, firm 2 chooses r in order to maximize the following expression:

$$\max_r \quad r\left[\gamma\,(b)\,V^G + (1-\gamma\,(b))\,\rho V^G\right] + (1-r)\left[\beta\,(b)\,V^B + (1-\beta\,(b))\,\rho V^B\right] - c\,(r).$$

Taking the derivative with respect to r, it is easy to show that the amount of R&D activity chosen by firm 2 satisfies the following:

$$\left(V^G - V^B\right)\left[\gamma\,(b) + \rho\,(1-\gamma\,(b))\right] + (\gamma\,(b) - \beta\,(b))\,V^B\,(1-\rho) = c^{'}\,(r^*). \tag{2}$$

This expression has a clear interpretation. A larger level of R&D activity increases the probability of the good state of the world, and decreases that of the bad state. This fact has two effects on firm 2's expected profits. On the one side, given the probability of infringement, the expected commercial value of the innovation is larger(*commercial effect*). On the other

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[9] In most of the arguments of this section we assume interior solutions for the R&D choice.

side, since $\gamma(b) \geq \beta(b)$, by making the good state of the world more likely, firm 2 reduces the probability of infringing upon firm 1's innovation thus benefitting from the lower expected licensing fees, $(1-\rho)V^B$ (*infringement effect*). These two effects are clearly highlighted in expression (2). The commercial effect is represented by the first term of the expression which is proportional to $V^G - V^B$. The second term is proportional to the reduction in the probability of not infringing, $\gamma(b) - \beta(b)$, and represents indeed the infringement effect.

From a simple comparison of expressions (1) and (2) it is immediate to determine under which conditions firm 2 under or overinvests .

Proposition 2. *Whenever* $(1-\gamma(b))\, V^G \geq (1-\beta(b))\, V^B$*, firm 2 underinvests and it overinvests otherwise.*

According to the above proposition there is underinvestment when V^G is large relative to V^B and when $\gamma(b)$ is not too large with respect to $\beta(b)$ (recall that $\gamma(b) \geq \beta(b)$). In other words, firm 2 tends to underinvest when the commercial effect of the R&D activity is large compared to the infringement effect; for instance, if $\gamma(b) = \beta(b)$, there is underinvestment since the infringement effect disappears and firm 2 does not obtain the full commercial value of its innovation. Conversely, when V^G and V^B are close in magnitude, the infringement effect tends to dominate and firm 2 overinvest.[10]

Note that for each idea $\left\{F^G(v), F^B(v), \gamma(b), \beta(b)\right\}$, there is a level $b > 0$ such that the commercial and the infringement effects balance each other, and firm 2 is induced to invest efficiently. Nevertheless, since the patent breadth is set by the Government before the idea is extracted, then the probability that the selected b induces the efficient R&D activity is null. Therefore, Propositions 1 and 2 imply that the inability of firm 1 to observe whether firm 2 has already undertaken its R&D activities or not always prevents that the licensing of the first innovation occurs efficiently. This is in sharp contrast to what shown in Green

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[10] A practical observation supporting this result comes from the software industry. Very often, commercial firms prefer to re-write from scratch modules or lines of codes instead of using the already existing ones just to avoid patent infringement. In this case, a clear overinvestment occurs: the duplication of the lines of code does not add value but it decreases the probability of infringement.

and Scotchmer (1995) where, in a symmetric information context, ex-ante contracts always ensure an efficient licensing agreement between subsequent inventors.

It is interesting to note that, under the mild condition that the probabilities of non-infringement decrease smoothly with b, the following corollary applies:

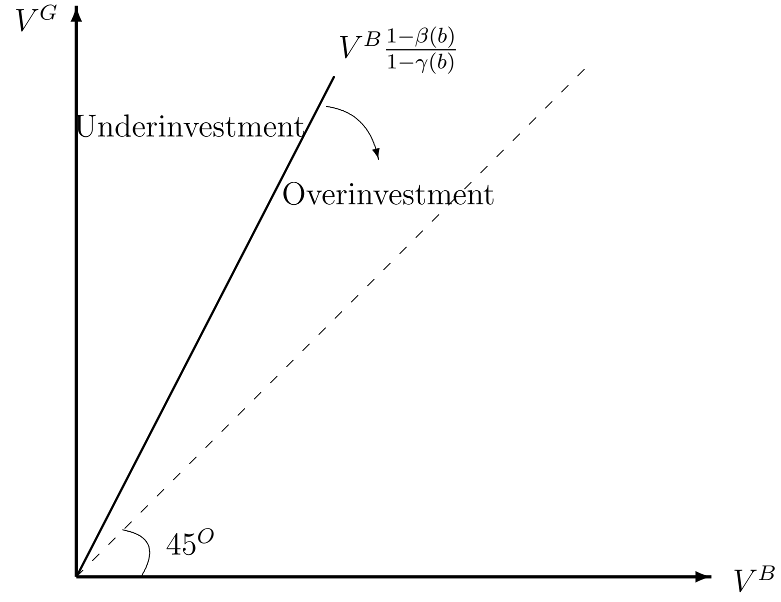

Figure 1: regions of over underinvestment as b grows above $\widetilde{b}$

Corollary 3. *Assuming that $\gamma''(b) > 0$ and $\beta''(b) > 0$, $\forall b$, then there exists a unique level of the breadth $\widetilde{b}$ such that:*

- *when $b > \widetilde{b}$, an increase in the patent breadth makes underinvestment more likely.*

Proof. In order to prove this corollary, recall that $\gamma(0) = \beta(0) = 1$, $\lim_{b\to\infty} \gamma(b) = \lim_{b\to\infty} \beta(b) = x$, and that $\gamma(b) \geq \beta(b)$, $\forall b$; therefore the assumption $\gamma''(b) > 0$ and $\beta''(b) > 0$, $\forall b$ implies that there exists a unique value of the breadth, $\widetilde{b}$, such that $\forall b < \widetilde{b}$, $\beta'(b) < \gamma'(b)$ while $\forall b > \widetilde{b}$, $\beta'(b) > \gamma'(b)$.

According to Proposition 2, firm 2 underinvests whenever $\frac{V^G}{V^B} \geq \frac{(1-\beta(b))}{(1-\gamma(b))}$. It can be easily shown that the rhs of the previous expression decreases as b grows larger than $\widetilde{b}$. Therefore, as the patent breadth gets bigger the set of combinations of V^G and V^B such that there is infringement enlarges. ∎

The explanation for this corollary relies on the strength of the infringement effect: when $b > \widetilde{b}$, the difference $\gamma(b) - \beta(b)$ reduces with the patent breadth; therefore an increase in b lessens the infringement effect and therefore reduces the investment incentives. Figure 1 provides a graphical representation of Corollary 3. All the combinations of $\{V^G, V^B\}$ that lie above the $V^B \frac{1-\beta(b)}{1-\gamma(b)}$ line represent cases in which there is underinvestment; contrarily, below the line there is overinvestment. As b grows the $V^B \frac{1-\beta(b)}{1-\gamma(b)}$ rotates clockwise and thus the region where underinvestment occurs enlarges.

2.2.1 Patent breadth and R&D investment

We are now in the position to analyse the effect of a larger breadth on the investment incentives of the follow-on innovator. Expression (2) implicitly defines the optimal investment level as a function of the patent breadth, $r^*(b)$. Using the implicit function theorem we can calculate the following expression:

$$\frac{\partial r^*}{\partial b} = \frac{(1-\rho)\left(\gamma'(b)\left(V^G - V^B\right) + \left(\gamma'(b) - \beta'(b)\right) V^B\right)}{c''(r)}. \tag{3}$$

The sign of this expression coincides with that of the numerator; more specifically, the numerator simply represents the marginal variation of the commercial and the infringement effect (the first and the second term, respectively). An increase in b always reduces the commercial value that firm 2 appropriates, and this induces the follow-on innovator to invest less in R&D activities: at the margin the commercial effect always decreases. The impact of a larger b on the infringement effect is more complicated, and in general indeterminate. When $\gamma'(b) - \beta'(b) > 0$, then as b gets larger the difference between $\gamma(b)$ and $\beta(b)$ also increases; therefore, according to the infringement effect, firm 2 is induced to invests more. When $\gamma'(b) - \beta'(b) < 0$ the opposite occurs.

Due to the indeterminacy on how a larger breadth impacts on the infringement effect, in general we are not able to give a clear sign to expression (3). Nonetheless, under the mild condition that the probabilities of non-infringement, $\gamma(b)$ and $\beta(b)$, decrease smoothly with b, then the following result holds:

Proposition 4. *Assuming that* $\gamma''(b) > 0$ *and* $\beta''(b) > 0$, $\forall b$, *then* $\frac{\partial r^*}{\partial b} < 0$ *for any* $b \geq \widetilde{b}$, *where* $\widetilde{b}$ *is defined in Corollary 3.*

Proof. From the proof of Corollary 3 we know that $\gamma'(b) - \beta'(b) < 0$, $\forall b > \widetilde{b}$. This is enough to prove the proposition. ∎

As already explained above the assumption of convexity of the probabilities $\gamma(b)$ and $\beta(b)$ implies that for $b \geq \widetilde{b}$ the infringement effect shrinks as the patent breadth gets larger. Therefore, in this case, a larger b reduces both the commercial as well as the infringement effect, and this explains Proposition 4.

2.2.2 Firm 1's licensing revenues

Under the assumption that the first innovation is a research tool, firm 1's profits coincide with the licensing revenues it gets from the follow-on innovator. It is interesting to evaluate how these revenues change with the breadth of the patent.

Firm 1 obtains a share of the commercial value of the second innovation whenever there is infringement; formally, firm 1's licensing revenues are given by:

$$\Pi_1(b) = (1-\rho)\left[r^*(b)\left(1-\gamma(b)\right)V^G + \left(1-r^*(b)\right)\left(1-\beta(b)\right)V^B\right]$$

With probability $r^*(b)$ the good state of the world occurs; in this case the follow-on innovation infringes on firm 1's patent with probability $(1-\gamma(b))$. Similarly, with probability $(1-r^*(b))$ the bad state occurs and there infringement with probability $(1-\beta(b))$. In both cases firm 1 obtains a share $(1-\rho)$ of the commercial value that is generated.

The impact of a variation in patent protection on the first innovator's profits is obtained by simple differentiation of $\Pi_1(b)$:

$$\begin{aligned}\frac{\partial \Pi_1(b)}{\partial b} &= (1-\rho)\Big(-\big(r^*(b)\gamma'(b)V^G + (1-r^*(b))\beta'(b)V^B\big) + \\ &\quad + \frac{\partial r^*}{\partial b}\big((1-\gamma(b))V^G - (1-\beta(b))V^B\big)\Big)\end{aligned}$$

The sign of this derivative is the combination of two effects, a direct and an indirect one. More specifically, as b gets larger:

1. given the investment level chosen by firm 2, the revenues of firm 1 get larger due to the increased probability of infringement. This is the direct effect which, formally, is given by $-\big(r^*(b)\gamma'(b)V^G + (1-r^*(b))\beta'(b)V^B\big)$ and it is always non-negative;
2. the indirect effect is the effect mediated by the change in $r^*(b)$; it can decomposed into two further effects since the change in the R&D activities affects both the expected commercial value of the second innovation and the probability of infringement. Formally, the indirect effect is given by $\frac{\partial r^*}{\partial b}\big((1-\gamma(b))V^G - (1-\beta(b))V^B\big)$, and it has an indeterminate sign.[11]

Clearly, the sign of $\partial \Pi_1(b)/\partial b$ depends on the sign and the magnitude of the indirect effect; although we cannot fully determinate how firm 1's licensing revenues vary with b, we can still characterise them in some specific but interesting cases.

Proposition 5. *Assuming that $\gamma''(b) > 0$ and $\beta''(b) > 0$, $\forall b$, then $\forall b \geq \widetilde{b}$:*

- *when firm 2 overinvests, then the indirect effect has a positive sign and therefore also $\partial \Pi_1(b)/\partial b$ is positive;*
- *when firm 2 underinvests, then the indirect effect is negative and therefore $\partial \Pi_1(b)/\partial b$ has an indeterminate sign,*

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[11] Note that to disentangle the double effect of the change in $\partial r^*(b)$ on the expected commercial value and on the probability of infringement, then the indirect effect should be rewritten as $\frac{\partial r^*}{\partial b}\big((1-\gamma(b))\big(V^G - V^B\big) + (\gamma(b) - \beta(b))V^B\big)$.

where $\widetilde{b}$ is defined in Corollary 3.

The first innovator tends to benefit from a larger patent breadth (the direct effect is always positive). However, as shown in the above proposition a larger b may have a negative indirect effect that moves in the opposite direction. In particular, this happens when firm 2 underinvests and the patent breadth is increased beyond $\widetilde{b}$; in this case, the reduction in firm 2's R&D activities hurts firm 1 since the decrease in the commercial value that is generated is not compensated by the increase in the probability of infringement.

It is worth noting that the presence of the indirect effect is the main consequence of the inefficiency in firm 2's investment decision and this is due to the fact that licensing contracts are not lump-sum. The inability of the first inventor to observe when the the follow-on innovator carries out its R&D activities is what drives these effects.

2.2.3 Examples

In this section we provide two extremely simplified examples whereby we show that the first innovator can indeed be harmed when the breadth of the patent protecting its invention is too broad. The key drivers of these results are the commercial effect (first example) and the infringement effect (second example) of the R&D activity of the second innovator. In both examples, we assume that $c(r) = \frac{r^2}{2} + r$, $\beta(b) = \max\{0, 1-b\}$.

Example 1

Consider the case where $V^B = 0$ and $\gamma(b) = \beta(b)$, that is the probability of non-infringement is the same in the two states of the world. In this simplified setting it is possible to show the following result:

Remark 6. *When $V^G \in \left(2, \frac{1}{\rho}\right)$, firm 1 obtains larger profits when the patent has a limited breadth, namely when b is smaller than* 1.

Proof. Firm 2 chooses $r \in [0,1]$ in order to maximize $rV^G\left(\beta(b) + (1-\beta(b))\rho\right) - c(r)$. It can be easily shown that when $V^G \in \left(2, \frac{1}{\rho}\right)$ firm 2 selects $r^* = 0$ when $b = 1$ and $r^* = 1$ for any $b \in [0, \overline{b}]$, where $\overline{b} = \frac{V^G - 2}{V^G(1-\rho)}$, that is such that $V^G\left(\beta(\overline{b} + (1 - \beta(\overline{b})))\right) = c'(1)$. Firm 1's profits are $V^G(1-\rho)(1-\beta(\overline{b}))$, when $b = \overline{b}$ and 0 when $b = 1$. Note that the set $V^G \in \left(2, \frac{1}{\rho}\right)$ is non-empty provided that $\rho < \frac{1}{2}$. ∎

When $\gamma(b) = \beta(b)$ the infringement effect is absent and $r^*(b)$ decreases with b. In particular, when the patent breadth is set at its maximum level, the second innovator does not invest in R&D, and this drives firm 1's licensing revenues to zero.

Example 2

Consider the case where $\gamma(b) = 1$, and $V^B = V^G = V$, that is the R&D carried out by the second innovator has no commercial effect but reduces the probability of infringement. In this setting the following result holds true:

Remark 7. *When $V \geq \frac{2}{1-\rho}$, firm 1 obtains larger profits when the patent has a limited breadth, namely when b is smaller than 1.*

Proof. Firm 2 chooses $r \in [0, 1]$ in order to maximize $rV + (1-r)V\left(\beta(b) + (1 - \beta(b))\rho\right) - c(r)$. It can be easily shown that when $V \geq \frac{2}{1-\rho}$ firm 2 selects $r^* = 1$ when $b = 1$ and $r^* = 0$ for any $b \in \left[0, \widehat{b}\right]$, where $\widehat{b} = \frac{1}{V(1-\rho)}$, that is such that $V(1 - \beta(\widehat{b}))(1 - \rho) = c'(0)$. Firm 1's profits are $\widehat{b}V(1 - \rho)$ when $b = \widehat{b}$ and 0 when $b = 1$. ∎

In this example firm 2's R&D does not affect the expected commercial value of the innovation and it is driven by the infringement effect only. In this case $r^*(b)$ increases with the patent breadth and firm 1 is harmed by a too large protection given that the probability of infringement is reduced without any increase in the commercial value.

2.3 Policy implications

Having examined the impact of patent breadth on the follow-on innovator's investment decision, and on the first inventor licensing revenues, we can now discuss the effects of patent breadth on the Social Welfare, here represented by the sum of the profits of the two firms.

The impact of an increase in b on firm 2 is obvious: a stronger patent protection undoubtedly reduces its profits. On the contrary, the above discussion shows that the relation between patent breadth and firm 1's licensing revenues is, in general, indeterminate. Nonetheless, a very broad patent protection can go to the detriment of the first innovator too; this may occur when the infringement effect of the R&D investment of the second innovator is very strong (example 2) or when the commercial effect is strong (example 1). In these circumstances, a large patent breadth is Pareto-dominated in that both firms would be better-off with a more limited patent protection.

In the same spirit as example 1, the results for the case of smooth probabilities of non-infringement, indicate that a large patent breadth might be socially not desirable. When b grows further above the threshold level $\widetilde{b}$:

a) according to Corollary 3, the probability that firm 2 underinvests gets large as b increases;

b) Proposition 4 shows that a larger breadth induces a lower R&D activity by the follow-on inventor; this effect combined with a) implies that the underinvestment problem becomes more severe;

c) finally, the combination of the two effects above makes more likely to have a negative indirect effect on firm 1's licensing revenues. Therefore, the indirect effect may partially or entirely compensate the direct one smoothing away the effect of a larger patent breadth on firm 1's profits.

3 Robustness

3.1 Competition between innovators

So far the analysis has been conducted by assuming that the first innovation is a research tool. In this section we show that, qualitatively, our main results hold also when the first innovation has a commercial value and the two innovations/firms compete in the same market.

A simple way to introducing competition in our model is the following. Let us assume that:

- when the bad state of the world occurs, firm 2 fails to obtain any innovation. In this case firm 2 gets a revenue equal to zero while firm 1 maintains its monopoly position, enjoying profits $\pi_1^m(q_1)$, where q_1 denotes the quality/characteristics of the first innovation;
- in the good state of the world, firm 2 obtains the innovation. We assume that in this case the two firms enjoy duopolistic profits, $\pi_1^d(q_1, q_2)$, and $\pi_2^d(q_1, q_2)$, where q_2 represents the quality/characteristics of the second innovation.

Consider first, the choice of R&D made by the follow-on innovator. Firm 2 chooses r to maximize:

$$\max_r \quad r\left(\gamma(b)\pi_2^d(q_1, q_2) + (1-\gamma(b))\rho\pi_2^d(q_1, q_2)\right) - c(r).$$

From the first order condition it follows that the optimal R&D activity, $r^*(b)$, satisfies:

$$\frac{\partial r^*}{\partial b} = \frac{(1-\rho)\,\gamma'(b)\pi_2^d(q_1, q_2)}{c''(r)} < 0.$$

The above expression is the equivalent to (3) where $V^G = \pi_2^d(q_1, q_2)$, and $V^B = 0$. Note that due the assumption that in the bad state of the world the second innovator makes no profits, the infringement effect vanishes; this implies that $r^*(b)$ always decreases with the patent breadth. Let us now focus on firm 1; its profits are given by:

$$\Pi_1(b) = r^*(b)\left[\gamma(b)\pi_1^d(q_1, q_2) + (1-\gamma(b))\left(\pi_1^d(q_1, q_2) + (1-\rho)\pi_2^d(q_1, q_2)\right)\right] + (1 - r^*(b))\pi_1^m(q_1).$$

Differentiating this expression with respect to b it is possible to investigate the impact of a change in the patent breadth on the first innovator's profits; formally:

$$\frac{\partial \Pi_1(b)}{\partial b} = -r^*(b)\gamma'(b)(1-\rho)\pi_2^d(q_1, q_2) + \frac{\partial r^*}{\partial b}\left[\pi_1^d(q_1, q_2) + (1-\gamma(b))(1-\rho)\pi_2^d(q_1, q_2) - \pi_1^m(q_1)\right].$$

This expression can still be interpreted in terms of direct and indirect effects. The first term represents the direct effect and, as usual, it is positive. Having introduced competition between the two innovators slightly changes the workings of the indirect effect. The change in the R&D activity of the follow-on innovator alters the probability that firm 1 maintains its monopoly position; this additional effect is represented by the term $-\frac{\partial r^*}{\partial b}\pi_1^m(q_1)$, which is clearly positive given that $\frac{\partial r^*}{\partial b} < 0$.

The following example shows that also in case of competition firm 1 can be harmed by a too strong patent protection.

Example 3

Consider the following extension of example 1 to the case of competing firms. As above we assume that $c(r) = \frac{r^2}{2} + r$, and $\gamma(b) = \beta(b) = \max\{0, 1-b\}$. Moreover, we assume that there is a mass 1 of consumers with utility function $U(q,p) = q - p$, where q is the quality of the product and p the price. The quality of the good produced by firm 1 is q_1 and that of firm 2 is $q_2 = V^G + q_1$ in the good state of the world and 0 in the bad state. Finally, we assume that production costs are zero and that firms compete in prices; therefore, in the bad state firm 1's product is sold in the market at price q_1, while in the good state firm 2's product is sold at price V^G.

Remark 8. *When $V^G \in \left(2 + q_1, \frac{1}{\rho}\right)$, firm 1 obtains larger profits when the patent has a limited breadth, namely when b is smaller than* 1*.*

Proof. From the proof of Remark 6 we have that firm 2 chooses $r^* = 0$ when $b = 1$ and $r^* = 1$ for any $b \in \left[0, \overline{b}\right]$, where $\overline{b} = \frac{V^G - 2}{V^G(1-\rho)}$. Firm 1's profits are $V^G(1-\rho)(1-\beta(\overline{b}))$, when $b = \overline{b}$ and q_1 when $b = 1$. Therefore, firm 1 is better-off when $b = \overline{b}$ provided that $V^G > 2 + q_1$. Finally, note that the set $V^G \in \left(2 + q_1, \frac{1}{\rho}\right)$ is non-empty provided that $\rho < \frac{1}{2+q_1}$. ∎

3.2 Different determination of the licensing fee by the court

In Section 2 we have assumed that, in case of infringement, the court determines the licensing fee in proportion to the commercial value of the innovation. One may wonder, whether our results still apply when the court follows a different rule. First of all note that, by definition, the court cannot implement a lump-sum licensing schedule, since it may impose a payment on the follow-on innovator only in case of infringement. Moreover, it is possible to show that whatever the rule used by the court, the result Proposition 1 generalises as follows: all licensing occurs at the fee implemented by the court. These facts imply that whatever the rule used by the court the investment of firm 2 is inefficient. Obviously, the kind and severity of the inefficiency depends on the specific rule actually endorsed by the court.

4 Conclusions

The definition of the optimal patent policy for industries where innovation is cumulative requires considering issues that go beyond the classic trade-off between incentives to R&D and dead-weight loss. When several inventors sequentially contribute to innovation, patents should also guarantee an appropriate division of profits among them. Early innovators should be rewarded for laying down the foundations of the industry but this should not go to the detriment of follow-on inventors who provide improvements or applications of the existing technologies to other fields. In this sense, there is the danger that a too strong patent protection, while encouraging early inventors, will hold future innovators up.

The existing theoretical contributions on the economics of cumulative innovation have stressed the merits of ex-ante arrangements; the risk that future innovations are held-up can be substantially mitigated in case the follow-on innovator negotiates the licensing agreement with the patent-holder before incurring the R&D costs. Notably, Green and Scotchmer (1995) show that, in a context of symmetric information, ex-ante licensing eliminates the risk of hold-up.

In this paper we present a model based on Green and Scotchmer (1995) and we show that when the first innovator cannot observe whether the follow-on inventor has already undertaken its R&D activities, the possibility of ex-ante licensing does not ensure efficiency. To the contrary, the investment of the follow-on innovator is always inefficient, no matter what the patent breadth is; at the equilibrium, both undervinvestment and overinvestment may occur depending on whether the commercial effect of the R&D activity prevails on the infringement effect or not.

Importantly, the inefficiency in the R&D investment of the follow-on inventor implies that a large patent breadth may be harmful for the first innovator too. In the paper we provide three very stylized examples whereby this occurs.

Contrary to the existing literature, we show that the optimal patent policy does not necessarily have to balance the opposing interests of early and follow-on inventors; a very large patent breadth, may harm both generations of innovators.

Our model rests on the assumption that both the amount of the R&D investment of the second generation inventor, and when such investment is undertaken are not observable by third parties. This assumption seems plausible, especially if one thinks to industries such as software, hardware and more broadly to high-tech sectors, where large part of R&D is made of intellectual activities aimed at knowledge creation; the very nature of these activities is clearly intangible and therefore of difficult measurement.

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Academic Licensing: a European Study

Chaire en Economie et Management de l'Innovation – CEMI
CDM Working Papers Series

Août 2007 CEMI-WORKINGPAPER-2007-001

Article publié dans… / Article à publier dans …

Keywords : Technology Transfer Offices ; Technology licensing ; University licensing

JEL classification : L3 ; O31 ; O32 ; 038

Abstract

This paper is an empirical analysis of the impact that different organisational forms of the Technology Transfer Offices (TTOs) in Europe have on their licensing activity. Given the great diversity of organization forms prevailing across European TTOs, our paper attempts to shed more light on which of those forms might be more efficient. We use as a measure of efficiency and as dependent variable of our model the number of license agreements concluded. Controlling for staff, invention disclosures, quality of the academic institution, life science orientation and demand for technology, we find evidence for the importance of personnel with a PhD in science in the TTO to facilitate communication between academics and the TTO. We find that the age of the TTO has a significant but negative effect. We do not find a positive effect for private organization of the TTO. Our data is derived from the 2004-2005 survey on TTO activities by the Association of European Science and Technology Professionals (ASTP) and information collected from TTO web sites.

1 Introduction[1]

In its recent communication "Improving knowledge transfer between research institutions and industry across Europe: embracing open innovation- implementing the Lisbon Agenda" (2007), the European Commission notes that “Europe has been less successful [than the US] at commercializing its [academic] R&D results”. It goes on to state there is a "clear need for EU-wide action to reduce the discrepancies between national knowledge transfer legal systems and practices".

The Technology Transfer Offices (TTOs) landscape in Europe is characterised by a bewildering diversity and rapid change. Germany has established patent exploitation agencies (PVAs – Patentverwertungsagenturen) in each of its states. In other countries several initiatives are underway to create national entities to assist academic institutions with technology transfer. The EC observes that "many existing European research and knowledge transfer offices suffer from a lack of critical mass". Yet in the UK, staffing levels above 20 are commonplace. In Belgium and Denmark, Technology Transfer Offices typically have only one staff member with a PhD degree or none at all while in Switzerland about half of TTO employees have a PhD degree. Several Technology Transfer Offices in the UK and Germany are organised as private entities and several French institutions appear to be moving in that direction[2].

This paper is an empirical analysis of the impact that different organisational forms of Technology Transfer Offices in Europe have on their licensing activity. Given the great diversity of organisation forms prevailing across European TTOs, our paper attempts to shed more light on which of those forms might be more efficient. Our dependent variable is the number of licences concluded which we model as a function of two inputs: staff and invention disclosures. We control for the quality of the academic institutions, their life science orientation and the demand for technology. Our variables of interest are the proportion of TTO personnel with a PhD in science, the status of the TTO (public or private) and TTO experience. We use data from the 2004-2005 survey on TTO activities by the Association of European Science and Technology Transfer Professionals (ASTP) and information collected on TTO web sites. We complement these data with certain Eurostat data series and bibliometric indicators from Thomson's ISI Web of Knowledge. Our sample consists of 51 TTOs that we observe over two years and 4 TTOs that we observe over one year.

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[1] We thank the Association of European Science and Technology Transfer Professionals (ASTP) for access to data on TTO activities in Europe. We are indebted to Dietmar Harhoff for valuable advice and to Laurent Miéville for his insights into the technology transfer process. We are grateful to Alfonso Gambardella, Patrick Llerena, Mark Schankerman, Reinhilde Veugelers and seminar participants at LMU, Bocconi and the Economics of Technology Policy conference in Monte Verita for valuable comments and suggestions. The views expressed in this paper and any errors are our own.

[2] The INSERM, a major French academic research institution with more than 6000 researchers, has just converted its technology transfer office into a private institution.

We find evidence for the influence of TTO personnel holding a PhD in science on the number of licence agreements concluded. We also find an unexpected negative effect for private organisation of the TTO. Finally, we find that the age of the TTO has a negative and significant effect. We provide some plausible explanations for these results, based on discussions with European TTO representatives.

The role of Technology Transfer Offices in commercializing academic findings has been extensively studied in the economic literature. Most of the authors focus on the activity of technology transfer offices in the US. The interest in US university technology transfer is stimulated by the "dramatic" rise in university licensing since the passing of the Bayh-Dole Act in 1980. However, it is also justified for reasons of data availability. A notable exception is represented by Chapple *et al.* (2005) who analyse the activity of Technology Transfer Offices in the UK.

Thursby, Jensen and Thursby (2001), Jensen and Thursby (2001), Thursby and Kemp (1998), Siegel, Waldman and Link (1999), Friedman and Silberman (2003), Chapple *et al.* (2005), Lach and Schankerman (2003), and Belenzon and Schankerman (2007) consider licensing as the cornerstone of the commercialisation activity of TTOs. From the survey of Technology Transfer Offices in 62 major US universities conducted by Thursby, Jensen and Thursby (2001) it emerges that 71% of US TTOs reported that the generating revenue from licences is extremely important. The number of licence agreements signed follows with 49% of the TTOs indicating that as being extremely important.

These authors have examined three main aspects of university licensing: characteristics of the knowledge transferred through licensing, evaluation of TTO productivity and the role of incentives in licensing performance. The study of Thursby, Jensen and Thursby (2001) emphasizes that the "majority of inventions are at an early stage when they are licensed". This implies that further involvement of the inventor is required for a firm to be able to commercialise a product based on a university invention. For this reason, "optimal licence contracts cannot rely on only fixed fees, but instead must involve some sort of output-based payments, such as royalties" (Jensen and Thursby (2001)). Thursby and Kemp (1998), Siegel, Waldman and Link (1999), Friedman and Silberman (2003) and Chapple *et al.* (2005) evaluate the productivity of TTOs using as metrics the number of licences and the licensing revenue generated. They find that in addition to traditional TTO inputs such as staff and invention disclosures organisational and environmental factors play an important role in explaining differences in productivity across TTOs. Lach and Schankerman (2003) and Belenzon and Schankerman (2007) analyse the role of performance pay on university technology transfer. They find that incentives for academic researchers matter and that universities adopting performance pay schemes generate more revenue per licence. This effect is more pronounced in the case of private universities. Moreover, Belenzon and Schankerman (2007) analyse how the importance attributed by TTOs to local development affects licence revenue and the number of licence agreements concluded. They find that TTOs placing more importance on local development conclude more licence agreement but generate less revenue per licence.

Although these authors tackle university licensing from different perspectives, we can identify certain common features in their studies. First, these studies take the number of licences issued and the revenue generated as the main outputs of TTOs. Second, they assume that invention disclosures and staff are the main inputs of TTOs. Typically, the greater the number of invention disclosures and the size of a TTO, the greater the number of licences issued by the TTO and the higher the licence revenue generated. Siegel, Waldman and Link (1999) find that licensing activity in the US is characterised by constant returns to scale, while Chapple *et al.* (2005) find decreasing returns to scale for TTO licensing activity in the UK. Some authors control for the quality of the universities and their biomedical orientation. Thursby, Jensen and Thursby (2001) and Belenzon and Schankerman (2007) find university quality has a positive and significant impact on licensing. In addition, they find that the presence of a medical school has a positive impact on licence revenue. Lach and Schankerman (2003) obtain a similar result; their dummy for biomedical orientation affects licence revenue positively. Friedman and Silberman (2003), Lach and Schankerman (2003) and Chapple *et al.* (2005) control for the experience of TTOs, the latter being proxied by the number of years of existence of a TTO. Friedman and Silberman (2003) and Lach and Schankerman (2003) find that older TTOs conclude more licence agreement. Conversely Chapple *et al.* (2005) find that the age of a TTO has a negative impact on the number of licences and the revenue generated. They argue that this result could reflect diseconomies of scale, given the high correlation between their "age" variable and the size of a TTO. Finally, Belenzon and Schankerman (2007), Chapple *et al.* (2005), Friedman and Silberman (2003) and Siegel, Waldman and Link (1999) analyse the impact of local demand for technology on university licensing. They typically find a positive impact of concentration of technological activities on university licensing.

Our study on technology transfer in Europe draws largely from the contributions of these authors. We provide some conclusions on the determinants of TTO performance in Europe, the latter being measured by the number of licence agreements signed. We introduce in our analysis new variables of interest relating to the TTO personnel composition and to the public/private nature of its organisation.

The remainder of this paper is organised as follows. In Section Two we introduce our hypotheses on the determinants of TTO productivity. In Section Three we describe our dataset. In Section Four we describe the model and the econometric methodology adopted. In Section five we present our results. The last section concludes.

2 The determinants of TTO productivity

2.1 TTO output

We use the number of licences negotiated as a measure of TTO output. This is consistent with the fact that TTOs themselves perceive the number of licences (together with licensing revenue) as their main output. Studies of university TTOs based on US and UK data have typically used both licensing volume and licensing revenue as dependent variables (see Belenzon & Schankerman (2007), Chapple *et al.* (2005), Friedman and Silberman (2003), Thursby and Kemp (1998), Siegel, Waldman and Link (1999), Thursby, Jensen and Thursby (2001)). Other measures of TTO productivity that have been used include number of patents, number of start-ups and amount of industry-sponsored research.

In this paper we use European data and for reasons of data availability we are unable to estimate regressions using licensing revenue. While TTOs that seek to maximise the diffusion of university technology can probably be expected to negotiate as many licences as possible, those seeking to maximise revenue may prefer to focus on a small set of promising technologies [3]. In this case, we may be underestimating the performance of revenue-maximising TTOs. Another limitation is that we do not know the nature and details of the licence, including whether or not it is exclusive.

2.2 TTO Input

In this section we examine the determinants of TTO productivity, the latter being measured by the number of licence agreements concluded.

We distinguish between four main factors affecting the licensing activity of TTOs: those relating to the organisation of TTOs, invention disclosures, quality of the academic institutions and regional demand for technology. We are careful to distinguish between the productivity of TTOs and that of their academic institutions, the latter being defined by the number of invention disclosures and their quality.

We begin by examining the factors relating to the organisation of TTOs, specifically: staff, the proportion of employees holding a PhD, the experience a TTO has, and whether a TTO is a private or a public organisation.

Staff. We expect that TTOs with a large number of employees will conclude a greater number of licensing contracts. In fact, in a large TTO employees may

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[3] Interestingly, Lita Nelsen, director of technology transfer at MIT, argues that universities should always adopt a volume strategy (Nelsen, 2006): rather than attempting to pick winners which is too difficult since university technology is at an early stage, TTOs should conclude as many licensing contracts as possible in order to maximise the probability of making a big hit.

specialise in those tasks they are most suited. This higher degree of specialization leads in turn to a higher number of licences. However, we expect that the relationship between the number of licences made and staff to be characterized by diminishing returns: beyond a certain size, any additional increase in staff yields fewer and fewer additional licences.

Proportion of employees holding a PhD in science. Among the factors affecting TTO productivity, the skill composition of TTOs plays an important role. We expect that TTOs employing staff with a PhD degree in science will conclud more licence agreements. To our knowledge, this hypothesis is new in the economic literature assessing the productivity of TTOs but it is consistent with the importance attached by several TTOs in Europe to recruting personnel with a PhD degree in science.

In a simple technology transfer model, an academic researcher makes an invention and then contacts the TTO to commercialize the invention. However, the relationship between TTO and researcher entails coordination costs that may be reduced when the TTO and the researcher have similar academic backgrounds and share common values. Thus, the importance of hiring PhDs in science lies in the reduction of the coordination costs involved in the knowledge transfer. However, while the presence of PhDs in a TTO is important, the TTO also needs personnel with experience in dealing with industry partners. Therefore, we expect the proportion of PhDs in science in a TTO to have a positive but decreasing impact on the number of licences made by a TTO. Moreover, beyond a certain level, an increase in the proportion of PhDs in science causes a reduction in the number of licences issued by a TTO.

Experience of a TTO. We expect the experience accumulated by a TTO to have a positive impact on the number of licence agreements concluded. In fact, TTOs are likely to negotiate a greate number of licensing agreements as they learn from experience. Lach and Schankerman (2003), Friedman and Silberman (2003) Chapple *et al.* (2005) adopt the age of a TTO as proxy for experience.

Economic incentives within the TTO. This is an area of particular interest as economists believe in the importance of incentives in many different settings. Although we have little information on the structure of incentives for TTO employees, we can observe whether a TTO is a private or a public organisation. Incentives may well differ according to the status of the TTOs as a private TTO may have different HR practices (salaries, bonus pay, hiring and firing). Thus we expect TTOs that are organised as private companies to offer stronger incentives to their employees resulting in more licences.

Invention disclosures. In most countries, university inventors are required by law to report new inventions to the TTO. We think of these invention disclosures as a primary input for the Technology Transfer Office. We expect that more invention disclosures will result in more licences. In addition, the technical composition of invention disclosures may matter, with academic inventions in certain fields being in greater demand than in others. Life science inventions appear to be special in this regard. Although we do not have data on the technical composition of invention disclosures, some institutions in our sample are focus exclusively on biomedical research. We control for this with the expectation that a focus on life sciences will result in more licences.

Institution quality. It is not just the volume of invention disclosures but also the quality of inventions disclosed to the TTO that matters. Invention quality cannot be observed- otherwise technology transfer would be an easier exercise! However, invention quality might be correlated with the quality of the academic institution, which can be more readily observed- for instance in terms of the bibliometric performance of its researchers. Potential licencees themselves probably take this correlation into account so that TTOs located in prestigious universities find it easier to find licencees (Sine, Shane and Di Gregorio, 2003). Therefore, we expect TTOs located in institutions whose researchers publish in top journals to generate more licences- either because inventions are of a better quality or because licencee think they are.

Demand for licences and concentration of technology firms. We expect TTOs located in regions with intensive technological activity to negotiate more licences. Firms operating in technology sectors tend to perceive academic institutions as a source of complementary assets, including licences for academic inventions. Therefore a high concentration of technology firms may constitute an incentive for academic institutions to produce the complementary assets required by firms, including a greater number of licences. Due to lack of data on concentration of technological firms, we assume a positive correlation between concentration of technological firms and regional wealth, the latter being proxied by regional GDP.

Impact on # licences	Expected
Staff	+
Staff squared	-
Proportion of employees holding a PhD	+
Proportion of employees holding a PhD squared	-
Experience of a TTO (proxied by age of a TTO)	+
Whether a TTO is a private organisation	+
Invention disclosures	+
Whether a research institution is specialised in biomedicine	+
Quality of university (proxied by # of articles in Science & Nature)	+
Demand for technology (proxied by regional GDP)	+

3 Data

3.1 The ASTP survey on European Technology Transfer Activities

Our empirical analysis is based on information provided by the ASTP 2006 Survey, integrated with additional sources of information (Eurostat, Thomson ISI Web of Knowledge and information extracted from the websites of European TTOs). The ASTP is the Association of European Science and Technology Transfer Professionals that provide technology transfer services to approximately 180 research institutions. According to the Proton Study for the European Union, ASTP, with its 209 members, represents 20% of approximately 1000 TTOs in Europe..

	AUTM Survey	UK Survey	Spanish Survey	ASTP Survey
Administered by :	Association of University Technology Managers (AUTM)	Initiated by Chapple et al. (2005) and UK Based Universities Company Association (UNICO)	RedOtri-Network of Spanish University TTOs	Association of Science and Technology Professionals (ASTP)
Since:	1996	2002	2001	2006
Coverage	Universities and research institutions in the US	Universities in the UK	Universities in Spain	Universities and research institutions in Europe (22 countries)
Number of respondents (usable answers in brackets)	190-380	~100 (40)	51 (40)	101 (~60)
Focus of the Survey	Licensing: # of contracts and revenue	Licensing: # of contracts and revenue	R&D contracts: # of contracts and revenue	Licensing: # of contracts (limited response rate for other measures of TTO output)
Used by:	See literature review	Chapple et al. (2005)	Caldera & Debande (2006)	Unused as of July 2007 (to the best of our knowledge)

Most of the studies on Technology Transfer Offices have used US data from the Association of University Technology Managers (AUTM). There have been studies of studies on technology transfer in European countries (Chapple *et al.* (2005) and Caldera and Debande (2006)). To the best of our knowledge, however, a multi-country sample of European TTOs has not yet been used

The 2006 ASTP survey was administered by the Maastricht Economic and social Research and training centre on Innovation and Technology (MERIT) on behalf of ASTP. This gathers information on technology transfer activities in 2004 and 2005. The survey response rate is 59%. We excluded from our final sample respondents who did not provide complete answers to the questions of interest[4]. Therefore, our final sample is composed of 51 academic institutions for which we have 2004 and 2005 data and 4 academic institutions for which we have 2005 only data. The institutions are based in 18 European countries (16 of which provided information for 2004): 38 are universities (34 of which provided information for 2004), 13 are research institutes and 4 are government agencies. Northern European countries account for the majority of the observations while Southern European countries are barely represented. This reflects in part the ASTP membership composition: only 19% of the 209 members belong to Southern European countries (Portugal, Spain, Greece and Italy).

	Universities	Research institutes	Government agencies	Total
Austria	2	0	0	2
Belgium	5	0	1	6
Czech Republick	1	0	0	1
Denmark	4	1	0	5
Finland	4	0	1	5
France	0	2	0	2
Germany	2	3	0	5
Hungary	1	0	0	1
Iceland	1	0	0	1
Ireland	3	0	1	4
Norway	1	0	0	1
Portugal	0	1	0	1
Spain	1	1	0	2
Sweden	2	1	0	3
Switzerland	5	0	0	5
The Netherlands	0	2	1	3
Turkey	1	0	0	1
UK	5	2	0	7

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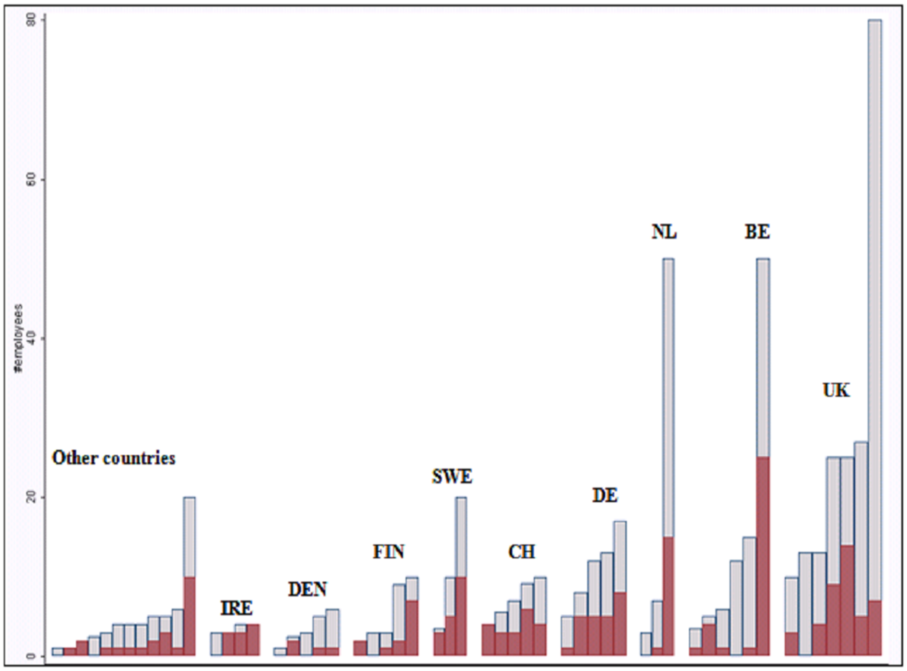
[4] Since our sample includes only institutions that were able provide to information on their technology transfer activities, it is not random.

3.2 Staffing level and composition of European TTOs

Discussions with TTO representatives in Switzerland suggested that recruting personnel with a strong scientific background might facilitate the relationship with academic researchers and increase TTO productivity. To test this hypothesis in our sample, we manually collected information on TTO staffing composition. To facilitate data collection we asked for the number of employees with a PhD without indication of the field in which the PhD was obtained. However, several checks confirmed that that TTO employees with a PhD almost always obtained it in science.

Figure 1: Staffing level and composition of European TTOs



The graph above shows the number of TTO staff with a PhD (black bar) and the number of TTO staff without a PhD (grey bar); academic institutions are grouped by country. Staffing levels and composition exhibit substantial variation across academic institutions. Certain national patterns emerge: in the UK, TTOs tend to have many employees but only a small fraction of those have a PhD degree. In Germany, Switzerland and Sweden, TTOs tend to be small but with a high proportion of PhD personnel. Irish and Danish TTOs are both very small but differ in their composition, Irish TTOs having a high proportion of PhD personnel and Danish TTOs having a low one.

3.3 Description of variables

Our empirical specification of the number of licences issued by a TTO is based on the hypothesis we made in the previous section:

$$\begin{aligned}\#licences \quad = \quad & f(staff,\ staff2,\ share\_PhD,\ share\_PhD2,\ age,\ status,\ gov\_agency, \\ & disclosures,\ biomedical,\ top\_publications, GDP\_regio)\end{aligned}$$

Where:

- *# licences*= number of licences issued by a TTO in 2004 and in 2005
- *staff*= number of employees responsible for technology transfer services
- *staff2*=number of employees responsible for technology transfer services squared
- *share_PhD*=proportion of employees holding a PhD
- *share_PhD2*=proportion of employees holding a PhD squared
- *age*= years of existence of a TTO
- *status*=dummy variable that takes the value of 1 if the TTO is a private organisation and 0 if the TTO is a public organisation
- *gov_agency*= dummy variable that takes on the value of 1 if the TTO is part of a governmental agency and 0 otherwise
- *disclosures*= number of invention disclosures reported by an academic institution to the TTO in 2004 and 2005
- *biomedical*=dummy variable that takes the value of 1 if the academic institution is specialized in biomedical research
- *top_publications*=number of articles in Science and Nature reported by an academic institution in 2004 and 2005
- *GDP_regio*=regional GDP in million EUR

Data on the number of licence agreements concluded by a TTO and the organisation of a TTO (staff, staff2, age, gov_agency) originate from the 2006 ASTP survey. Data on the proportion of employees holding a PhD, whether a

TTO is a public or private organisation and on whether an academic institution focuses on biomedical research were manually constructed by gathering information from the websites of European TTOs and academic institutions. Data on the number of articles in Science and Nature reported by an academic institution in 2004 and 2005 were extracted from the Thomson ISI Web of Knowledge. Finally, data on regional GDP at the NUTS (Nomenclature of territorial units for statistics) 2 level breakdown came from the Eurostat REGIO database.

3.4 Summary statistics

We have 106 observations from 55 distinct TTOs. The distribution of licences is skewed to the left with many institutions with a very low number of licences and a few institutions with a large number. This is reflected in the fact that the mean number of licences is 22.9 while the median is only 4.5. The top 25% observations account for almost 87% of the total number of licences. This is not so surprising, however, since TTOs vary in their main inputs (staff, disclosures) with similar (although less sharp) patterns. The median TTO size is 5.75 and the mean is 10.9 employees. 88% of our TTOs had received at least five invention disclosures but the top 25% account for 62% of total invention disclosures. It is interesting to note that the proportion of PhD personnel varies substantially: about 30% have a proportion of PhD personnel of more than half while 18% had no PhD employees. A sizeable portion of our sample consists of young institutions (25% of observations have an age of 5 or less). About a quarter of our observations come from TTOs organised as private companies while only a few (7.5%) are government agencies. As for variables related to the academic institution as a whole, 11.3 % of our observations come from institutions focused exclusively on biomedical research, 30% of institutions in our sample had no publications in Science and Nature in 2004-2005 while 40% had more than five.

			Quantiles				
	mean	sd	min	p25	p50	p75	max
licences	22.91	73.24	0	1	4.50	16	544
staff	10.89	14.05	1	3	5.75	12	80
share PhD	0.39	0.31	0	0.17	0.33	0.56	1
age	10.88	7.89	1	5	9	17	37
status	0.25	-	0	-	-	-	1
gov agency	0.08	-	0	-	-	-	1
disclosures	41.02	42.20	0	9	23.50	67	194
biomedical	0.11	-	0	-	-	-	1
top publications	14.07	32.90	0	0	3	13	179
GDP regio	182.28	329.61	7.63	51.45	84.52	164.38	1792.89

Note: 106 observations from 55 distinct TTOs
(for 51 TTOs we have data for both 2004 and 2005, for 4 TTOs we have data for 2005 only)

4 Econometric estimation

We have a panel of observation over two years. However, we did a variance decomposition and found that 99.5% of the variance was due to the cross-sectional dimension of our panel. Since the variability between cross-sectional units is so much greater than variability across time, we chose to pool observations and treat our sample as a cross-section, ignoring the time dimension of the panel. However, we take into account the fact that two observations coming from the same cross-sectional unit may have something in common by correcting the standard errors with clustering on the cross-sectional identifier.

Since our dependent variable, the number of licences made by a TTO, can take only discrete and positive values, we assume it is governed by a Poisson process. In order to take overdispersion into account, we use a negative binomial specification which generalises the Poisson distribution by introducing an individual, unobserved effect into the conditional mean. The conditional expectation of the number of licences negotiated by a TTO can then be expressed as:

$$E\left[Y|X\right] = \exp(X_i\beta + e_i) = \exp(X_i\beta)\exp(e_i) = \exp(X_i\beta)\delta_i$$

Where:

- $y = \#licences$
- $X_i =$*staff, staff2, share_PhD, share_PhD2, age, status, gov_agency, disclosures, biomedical, top_publications, GDP_Regio*
- $\delta_i \sim \Gamma(\frac{1}{\alpha})$ with $\alpha > 0$, which implies $E(\delta_i) = 1$ and $Var(\delta_i) = \alpha$

For variables where we hypothesise a quadratic relationship (staff and share_PhD), we test the significance of higher order coefficients and drop them if insignificant.

5 Results

Independent variables	(1) Dependent variable= # licences	(2) Dependent variable= # licences	(3) Dependent variable= # licences
staff	0.128***	0.135***	0.149***
	(0.034)	(0.037)	(0.048)
staff2	-0.00156***	-0.00165***	-0.00165***
	(0.00038)	(0.00040)	(0.00054)
share_PhD	3.518*	3.528*	6.864***
	(1.83)	(1.85)	(1.93)
share_PhD2	-4.035**	-4.055**	-6.652***
	(1.88)	(1.88)	(2.11)
age	-0.0978***	-0.0929***	-0.0859***
	(0.022)	(0.022)	(0.027)
status	-0.616	-0.688*	-0.480
	(0.40)	(0.37)	(0.40)
gov_agency	-1.649***	-1.636***	-0.893
	(0.45)	(0.48)	(0.61)
biomedical	2.378***	2.617***	2.664***
	(0.51)	(0.46)	(0.58)
disclosures	0.0195***	0.0196***	
	(0.0035)	(0.0036)	
top_publications	0.0201***	0.0198***	0.0188***
	(0.0042)	(0.0047)	(0.0055)
GDP_regio	0.000356		
	(0.00050)		
Constant	0.487	0.450	0.452
	(0.40)	(0.42)	(0.44)
Observations	106	106	106
Clusters	55	55	55
Log Likelihood	-316.49	-316.92	-335.84
Chi-squared	294.28	268.93	116.15
Pseudo-R2	.187	.186	.137

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Regression results are reported in the table above. The dispersion parameter alpha is significant which confirms that there is overdispersion in the model and justifies the use of a negative binomial rather than a Poisson. Our baseline model is reported in column (1). In column (2) we report the same model without regional GDP and in column (3) we exclude from the model regional GDP and disclosures. In our baseline model regional GDP is not significant, perhaps reflecting the fact that it may be a poor proxy for local demand for technology[5]. The number of invention disclosures is potentially problematic as it might be an output of the TTO and thus endogenous. Most of our results are robust to the three different specifications.

The coefficients for staff and disclosures, which are the main TTO inputs, always have the correct signs and are significant at the 1% confidence level. The staff squared coefficient is significant and negative, which is consistent with our hypothesis of diminishing returns to recruiting more TTO employees. The biomedical coefficient has the correct sign and is both very significant and large.

The relationship between the proportion of employees with a PhD degree and the number of licences made by a TTO appears to be quadratic. The coefficient for the PhD_share variable is positive and significant at the 10% significance level, while the coefficient for PhD_share2 is negative and significant at the 5% significance level. When we exclude the number of invention disclosures and regional GDP, the coefficients for PhD_share and PhD_share2 become significant at the 1% confidence level. Increasing the proportion of employees with a PhD degree seems to have a positive but decreasing impact on the number of licences issued by a TTO. Beyond a certain level, increasing the proportion of PhDs causes a reduction in the licence agreements concluded by a TTO.

Our control for the quality of the academic institutions- the number of articles published in Science and Nature- shows a positive and significant effect (at the 1% significance level) on the number of licences issued by a TTO. Our interpretation is that invention disclosed by high quality institutions are easier to commercialize.

Contrary to our expectations, age has a negative and significant effect on the number of licences issued by a TTO. We have three possible explanations for the negative coefficient.

First, when TTOs are created they may inherit a stock of invention from the past that have not yet been commercialised. Thus young TTOs having access to a larger pool of inventions to commercialise may negotiate more licences. Second, it may be that when TTOs become more mature they diversify their activities and spend less time negotiating licences. Finally, when answering to the survey question on the "creation year" some TTOs might have given the date at which an "embryonic" intellectual property office was converted into a more

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[5] We considered other proxies for local demand for technology; it is however hard to obtain complete series for the regions in our sample.

structured TTO. Discussions with European TTO representatives confirmed the plausibility of these explanations.

The status of a TTO (defined as 1 if a TTO is a private organisation and 0 otherwise) has an unexpected negative sign and is even significant at the 10% confidence level in model (2). Our prior was that TTOs organised as private companies offer stronger incentives to their employees, thus leading to more licences. However, we find that organising the TTO as a private institution does not have a positive effect on TTO productivity and may even decrease it.

An explanation for this result is that private and public TTOs may have different strategies and objectives. In particular, private TTOs may prefer to focus on a smaller set of technologies in an attempt to maximise expected licensing revenue rather than the number of licences.

Alternatively, it might be the case that private organisation of the TTO makes interactions between academic researchers and TTO staff more difficult as the two institutions are less likely to share the same values and organisational culture. Moreover, private organisation of the TTO might diminish TTO employees' identification with the university and erode their intrinsic motivation. Interestingly, private TTOs also have a lower proportion of PhD personnel than public TTOs, which could enhance these effects.

Effect on # licences	Expected	Estimated
Staff	+	+
Staff squared	-	-
Share of employees holding a PhD	+	+
Share of employees holding a PhD squared	-	-
Experience of a TTO (proxied by its age)	+	-
Whether a TTO is a private organisation	+	- (insignificant)
Invention disclosures	+	+
Whether a research institution is specialized in biomedicine	+	+
Quality of University (proxied by # of articles in Science & Nature)	+	+
Demand for technology (proxied by regional GDP)	+	+ (insignificant)

6 Concluding remarks

This paper investigated the licensing activity of Technology Transfer Offices in Europe. We undertook a quantitative analysis to derive evidence on issues of immediate policy interest such as staffing and organisation of the TTO. We used data from the 2006 ASTP survey and modelled the number of licences made by a TTO as a function of two main inputs - staff and the number of invention disclosures - and other control and policy variables.

Having controlled for the quality of academic institutions, their life science orientation and the conditions of local demand for technology, we find that the skill composition of a TTO plays an important role in determining its productivity. Employing PhDs appears to reduce the coordination costs arising from interactions between the TTO and academic researchers. Moreover, we find a negative and significant effect for age on the number of licences made by a TTO. Private organisation of the TTO seems to have a negative impact on the number of licences negotiated.

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University Inventors and University Patenting Patterns at Lund University:
Conceptual- Methodological & Empirical Insights

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2007-08-20

Abstract

One of the most interesting indicators to show the change in the socio-economic role of universities in the last several decades has been the use of university patenting. However except some individual studies for European countries (e.g. Finland, Norway, Belgium, Italy, Germany and France) there has been no such a comprehensive data available for Sweden and most other European countries. The main motivation of this paper is therefore to obtain a systematic database on university patenting activities in Sweden. The main method of this research is data-matching between the EPO-patents and Lund University Faculty registers, and manual controls. The methodology of this research underlines the importance of searching for university-patents by the name of university inventors rather their affiliated university. The main findings of this research includes among others, the rate of patenting activity showed a positive trend between the years 1990 and 2004. 458 patents have been filed by Lund University researchers. The total number of inventors is 250. Although the number of large firms is lesser than the SMEs, the former group (e.g. Ericsson, Astra-Zeneca) has applied for a larger number of patents than the total number of patents of SMEs.

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[1] The earlier versions of this paper has been presented in DRUID winter (2006) Conference and Technology Transfer Society (2005) Conference. Many thanks go to participants in those conferences. I acknowledge the comments of Martin Meyer, Henry Etzkowitz, Don Siegel, Ed Steinmueller, Maryann Feldman, Jesper Christensen and Elad Harison.

1. Introduction

In today's global world, knowledge, learning and innovation have become strategically important factors that foster competitiveness and economic growth of countries. Globalization, international knowledge exchange and an increasing global competition require a rapid transfer of scientific knowledge and understanding into everyday life. Technological change, the accumulation of knowledge and its spill-over into the production process is considered as the primary engine of economic development in the new growth theories (Romer, 1990, 2002; Grossman and Helpman, 1991). This trend has resulted in the full recognition of the role of knowledge and technology in economic growth. The roles of universities have changed. Universities are not only important organizations for basic research, but they are also expected to contribute to the industrially relevant technologies in modern knowledge-based economies. Consequently, governments throughout the OECD have launched different policy-programs to link universities more closely to industrial innovation and to increase technology transfer from universities to companies (Mowery and Sampat, 2004).

As a consequence of globalization in the most developed countries, there has been a shift from traditional manufacturing industries towards new-knowledge based economic activity. The question where the knowledge comes from and how it is generated remained uncertain despite the fact that universities emerged perhaps as the most crucial component to generate this new knowledge among others like private sector, research institutes etc. (Audretsch et al. 2005:59). In the past few decades, universities have therefore witnessed substantial changes in terms of research objectives and funding sources. They have become more proactive in their efforts to commercialize scientific discoveries (e.g., Jaffe and Lerner, 2001; Jensen and Thursby, 2001; Thursby and Thursby, 2002; Di Gregorio and Shane, 2003).

While universities have for long served as sources of knowledge, it has been argued that their relations with industry have intensified in the recent years. Stylized facts behind this intensification are: *(i) the development of new, high-opportunity technology platforms e.g. computer science, molecular biology, and material science; (ii) the more general growing scientific and technical content of all types of industrial production; (iii) the need for new sources of academic research funding created by budgetary stringency;* (Bercovitz and Feldman, 2005:175) *(iv) and the prominence of government policies aimed at raising the economic returns of publicly funded research by stimulating university industry technology transfer* (Geuna, 2001:10).

The general decline in public funding was partly compensated for by an increase in funding from non-profit organizations and by tighter relationships between university and industry. Overall, university researchers and university research centres are now clearly being encouraged to embark upon collaborations with private companies (Geuna, 2001:10). Universities are further suggested to get involved in technology transfer (patenting, licensing and spin-off company formation) in order to continue their missions and to retain their autonomy as a way of controlling their own destiny (Clark, 1998).

University Industry Technology Transfer (UITT hereafter) results from interactions between various actors and organizations. Key actors include: universities, researchers, private or public companies, technology transfer agencies, venture capitalists, financers, and governments. The process of university patenting includes initiation of research projects, achievement of research results (e.g. inventions and invention disclosures to TTO) evaluation for patentability, patent applications and attempts to transfer to industry (i.e. license patent or initiate a new venture based on patent). In this understanding of the UITT process, each actor i.e. faculty, research groups, TTO staff and firms play different and ever changing roles (Markman et al. 2005, Feldman and Bercovitz 2005, Lundqvist 2003, Large et al. 1995-2000).

There is a growing literature on university industry relations in general. The field has been explored from different theoretical and conceptual angles (i.e. systems of innovation, triple helix, innovation networks, academic entrepreneurship, firm formation and so forth). However there are not enough theoretical and empirical studies on the roles of university scientists per se. This is in fact due to the novelty, complexity and difficulties in capturing the roles of individuals in social sciences in general. In spite of the large amount of research on university industry relations, university scientists have been relatively neglected in the university industry relations research. The aim of this study is to understand *who* are involved in patenting and *what is the rate and patterns of university* patenting activities among scientists at a large research intensive university in Sweden. Rather than focusing on what universities do, it instead focuses on what university scientists do. Thus the main findings are about the commercialization of university research results are based on the actual activities of university inventors.

Interaction between researchers working in private firms and those working in publicly financed institutes such as universities is seen as particularly important because it may provide unique competitive advantages (e.g., associated with specific competencies of high-quality universities). The European Commission (2003) lists this as one of the six priorities for European universities in the immediate future, and concludes that it is vital that knowledge flows from universities into business and society. Subsequently, the two main technology transfer mechanisms i.e. patenting, licensing, and start-up company formation have been articulated as the most popular policy tool in the last two decades. This policy tool increased the debates over the role of intellectual property rights in the process of public-private knowledge transfer.

It is generally argued that with the introduction of the so-called Bayh-Dole act, U.S. universities got the right to patent discoveries resulting from federally funded research. Partly due to the passage of Bayh-Dole Act, university patenting in the US has increased substantially (Mowery et al. 2005). In addition, some success stories from US universities have induced European policy makers to also consider a Bayh-Dole-like legislation (OECD, 2003). This argument is made against a background of, often anecdotal, empirical evidence that European universities are not very active in patenting and far behind in the commercialization of university research results compared to the US. The US is believed to outperform Europe on the commercialization of university research results. This phenomenon is even named the *European Paradox*.

The aim of paper is not to provide a final answer to the question whether Europe needs a patent legislation similar to the Bayh-Dole Act or not. The aim is rather to present alternative definitions and methodological tools that may better suited to the European context. In this way this study provides the background information for further theoretical, empirical research.

The first objective of this paper is to construct a database by exploring the university research results in the forms of patents at Lund University.[2] In order to be very specific and sufficiently detailed for a meaningful analysis patenting activities at the Engineering Faculty (LTH), Natural Sciences (NS) and Medical Faculty (MF) are complied into a database called Lund University Patent Database. This database makes the investigation of the main argument, i.e. lack of micro

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[2] In Sweden, the law of University Teacher's Privilege (UTP, Lärarundantaget/ individual ownership of patents) exists since 1949. UTP is a common practice at Swedish Universities. This law implies that university employees own one hundred percent of his/her research results conducted at the university where s/he is employed. Therefore in Sweden while non-university public organizations retain the ownership of intellectual property, in the case of colleges and universities employees have the right of ownership in the absence of another contract. (*Goktepe, 2004:37-38*)

level research on university inventors, possible. It provides the basic information and profiles of university inventors.

This Chapter is organized as follows. After this introduction, a brief overview of the use of patents in university industry technology transfer is discussed under three themes. Section 3 reviews the methodology and the findings of the previous empirical work on university patents for some European universities. Section 4 describes the data collection and the construction of the Lund University Patent Database (LUP database hereafter). Section 5 presents the empirical findings. The empirical analyses are organized under three questions. First, it describes the basic characteristics of patenting patterns at LU. Second, it discusses the characteristics of inventors and finally it presents the applicants of patents. Section 6 summarizes the main findings and sketches the future work.[3]

2. Patents & University Industry Technology Transfer

2.1 Academic Side of the Coin: "who are the inventors?"

Most of the studies have focused on the organizational and institutional aspects or the outcomes of patenting. Such focuses preclude the identification of factors related to inventors.[4] The literature is full of examples where the individuals are forgotten. For instance after the initial discovery of the basic technique for recombinant DNA, from Stanford University and University of California, San Francisco, or the discovery of enhanced vitamin-D in food from University of Wisconsin; and Tethalin from University of California etc, there have been an increasing amount of research and interest about commercialization of research, Most studies thus far have focussed on the role of institutions and organizations on the patenting, licensing and spin-off company formation rates of universities, TTO, Bayh-Dole etc. Inventors, or in general individuals, have not received the same amount of attention and interest as much as institutions and organizations did. Scholars have hardly asked the questions: *who were the inventors behind all the university inventions, what were their motivations to patent, how did they patent, did they have special skills, knowledge to patent, what were the problems that those inventors faced?*

In this research I assume inventors are one of the principal actors of the invention process. Still they are one of the most neglected units of analysis compared to organizations and institutions. Despite the importance of inventors, there is little knowledge on who at universities are patenting and how their work could be influenced by individual characteristics of scientists. For instance, at the initial stages the UITT depends highly on the decision of faculty to patent or not to. In Sweden due to the Law of University Teacher's Exemption (UTE hereafter), the individual decision of faculty to patent or not is very critical. While in the US model, faculty are expected do invention disclosures to the university Technology Transfer Offices (TTOs hereafter), there is no such requirement for faculty employed at Swedish Universities. However up to date, we have not had any systematic data about university patents and university inventors in Sweden and even for most countries except the U.S.

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[3] This paper is a quantitative prelude for a better understanding of university patenting in terms of methodological empirical and theoretical dimensions.

[4] A detailed literature review on university industry technology transfer (UITT specifically patenting, licensing and spin-off company formation) from both macro and micro approaches can be found in the following Chapter-2.

2.2 Policy side of the coin: "European Paradox"

The boom of university patents in the USA made policy makers and scholars in Sweden more and more interested in university patents. A better and faster utilization of university research results has become one of the most important issues in the policy agenda in Sweden. Among others, the intensification of interactions between universities and industry is related to the political interest as well. Governments have initiated policies aiming at raising the economic returns of public financed research by stimulating interaction between university and industry with the goal of increasing the technology transfer from universities (Geuna, 1999:4). In particular, the governmental push for more university patents and or industrially relevant research at the universities is of main concern.

Patenting, licensing and spin-off company formation has become one of the main political and economic objectives for many governments. The dominant myopic theoretical focus on the institutions and organizations of university patenting is also common to the political beliefs. There have been several attempts to show that utilization of university research results for economic and industrial needs is not at the desired level. It is claimed that there is a gap between high levels of scientific performance on one hand, and their minimal contributions to industrial competitiveness, licensing or new venture creation. This gap is also known as the *European [academic] paradox.* This perception is partly exacerbated by the impression that universities in the USA have higher performance in commercializing their research results. Subsequently, several European countries have started to implement the organizational ownership of intellectual property (patents) at their universities. These policy developments are mainly inspired by the Bayh-Dole legislation in the USA model. This policy emulation is purely reflecting how governments initiate top-down plans without considering the needs and expectations of the bottom. Against these top-down policy implementations, a group of researchers have warned about the risks of emulating the so-called USA model (Valentin and Jensen, 2006; Mowery et al. 2004).

The European Commission (2003) lists this as one of the six priorities for European universities in the immediate future, and concludes that "it is vital that knowledge flows from universities into business and society. Subsequently, the two main technology transfer mechanisms i.e. patenting, licensing, and start-up company formation have been articulated as the most popular policy tool in the last two decades. This policy tool increased the debates over the role of intellectual property rights in the process of public-private knowledge transfer.

With the introduction in 1980 of the so-called Bayh-Dole act, which gave U.S. universities the right to patent discoveries resulting from federally funded research, this debate was decided in favour of those supporting active patenting by universities. The rise in university patenting observed in the U.S., and the success stories of some university discoveries that yielded high-income streams from licensing have induced European policy makers to also consider Bayh-Dole-like legislation (OECD, 2003). This argument is made against a background of, often anecdotal, empirical evidence that European universities are not very active in patenting and far behind commercialization of university research results.

2.3 Invention, Innovation and Patent

This research mainly focuses on the university knowledge that can be patentable. A focus on university patents might seem to be a strange route to better understanding of the university industry technology transfer (Henderson et al., 1995:1). Since university patents are a small fraction of all patents (Henderson et al., 1995) and only a small fraction of university knowledge can be patentable. As a result one cannot learn about the full spectrum of university research and knowledge from patent data. This research focuses on a sub-set of university knowledge that is patentable. Yet university patents are informative, they reflect research that the university [or academic inventor e.g. in Sweden] believes has direct commercial application (Henderson, et al., 1995). University patents are also interesting in their own right since they are a unique and highly visible method of “technology transfer” (Archibugi, 1992; Basberg, 1987; Boitani and Ciciotti, 1990; Trajtenberg, 1990). Similarly understanding the university patenting patterns over time is an important dimension to understand the relationship between university and industry (Blumenthal, 1986; Caballero and Jaffe, 1993; Dasguspta and David, 1987; David, Mowery and Steinmueller, 1992; Jaffe, Trajtenberg and Henderson, 1993; Mansfield, 1991; Pavitt, 1991).

A patent is an exclusive right granted for an invention. Patents are perhaps the most important legal instruments for protecting intellectual property rights. A patent confers to a patentee the sole right to exclude others from economically exploiting the innovation for a limited period of time (e.g. 20 years from the date of filing). In return for a government-enforced monopoly franchise on the commercial exploitation of an invention, the patentee must disclose and explain the invention, in principal with sufficient detail that a knowledgeable practitioner of the relevant technology could reproduce the invention using the patent document. When a patent is issued, a large amount of information is publicly recorded, and most of this information is now available in computerized form. The information that is available includes the following information: 1) the name(s) /or and postal address(es) of the inventor(s); 2) the organization, (applicant) if any, to which the patent property right was assigned or transferred when the patent was issued, and its legal address; 3) a detailed technological classification of the invention; 4) the patentee’s specific claims regarding what the invention can do that could not be done before; and 5) citations that indicate previously existing knowledge, embodied in prior patents or other publications, upon which the patent builds (Jaffe, 1998). Patents provide information on the temporal, geographical, technological and sectoral distribution of inventions. They are generally considered to be important indicators of technological activities (Archibugi 1992:358). The availability of data in electronic format has also increased the size of the datasets being used in the literature (Pavitt, 1998).

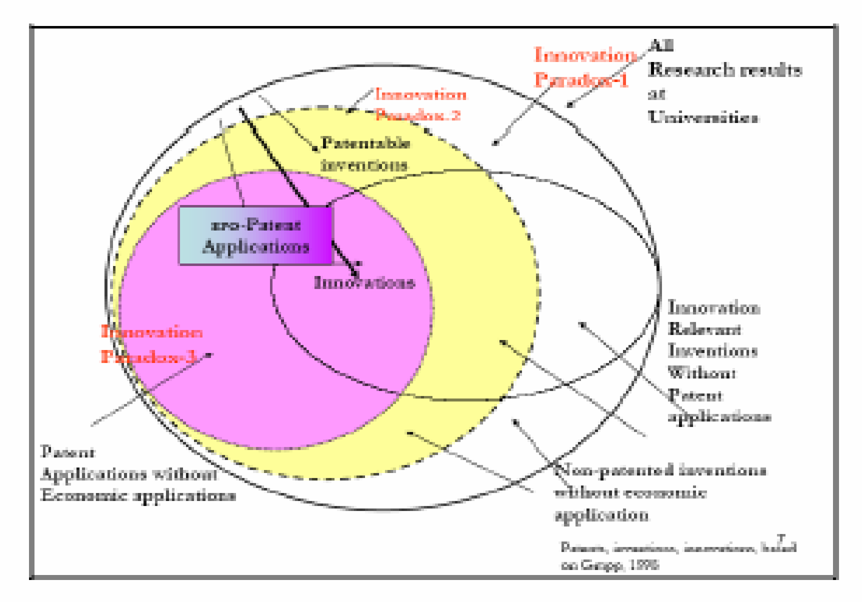
The large and growing literature studies the patterns of technological evolution, knowledge creation and diffusion, and firm technology strategy by using patent data. Key areas of research include: the geographic localization of knowledge flows (Almeida and Kogut, 1999; Jaffe, Trajtenberg, and Henderson 1993); knowledge diffusion across and within firm boundaries (Rosenkopf and Nerkar, 2002; Song, Almeida and Wu, 2003); technological positioning of firms (Podolny, Stuart, and Hannan, 1996); factors associated with the production of important innovations (Cockburn and Henderson, 1998; Gittelman and Kogut, 2003); the impact of the structure of knowledge on knowledge diffusion and firm strategy and (Sorenson, Rivkin and Fleming, 2002, Ziedonis, 2003) and university-firm technology transfer and universities as a source of important innovations (Henderson, Jaffe, Trajtenberg, 1998; Mowery, Sampat, and Ziedonis, 2003: Meyer, 2003; Saragossi and van Pottelsberghe de la Potterie, 2003; Azagra-Caro et al. 2003; Schmoch, 2000; Gulbrandsen et al., 2005; Balconi et al., 2003; Leydesdorff, 2003).

Regarding the university industry relations, Jaffe’s (1989) research relies upon the number of patented inventions registered at the U.S. patent office, which he argues is a ‘proxy for new economically useful knowledge’ (p.958). Jaffe’s (1989) Model provides statistical evidence that corporate patent activity responds positively to commercial spill-overs from university patents. However, despite its widespread use, patent data has its own drawbacks such as: the propensity to patent differs across country and industry, differences in patent regulations across countries, and changes in patent laws (difficult to analyze trends over the time), value distribution of patents is skewed, finally many inventions are not patented (Pavitt, 1998). Although patents are good indicators of new technology creation, they do not measure the economic value of these technologies (Hall et al., 2001). More specifically, to be able to give a fair image of the impact of university knowledge on technological development, patent data should not to be confused with data on innovations.

Patents are a rather partial indicator of technological inventive activity. For instance while Jaffe's (1989) Model provides explanations to the role of university research to generate 'new economically useful knowledge', Scherer, 1983; Mansfield, 1984; and Griliches, 1990 have warned that measuring the number of patented inventions is not the equivalent of a direct measure of innovative output (Acs et al., 1992). According to Griliches (1979) and Pakes and Griliches (1980, p. 378), patents are a flawed measure of innovative output particularly since not all new innovations are patented and since patents differ greatly in their economic impact. Similar to these arguments, Pavitt (1998) also had a sceptical view of university patents as an indicator of useful university research. Pavitt (1998) further argued that patents granted to universities give a partial and distorted picture of the contributions of university research to technical change. Patenting by universities is not a potentially useful measure of university research performance. He further argued that citations in patents to published papers provide a better picture of the academic research contribution to technical change (Pavitt, 1998). However patent citations also have several drawbacks. The patent citations are done by patent attorney and patent examiners who do not represent knowledge spill-overs between the sources and users of knowledge.

Measures of technological change have typically involved one of the three major aspects of the innovative process: (1) a measure of the inputs into the innovation process, such as R&D expenditures; and R&D personnel, (2) an intermediate output, such as the number of inventions which have been patented; or (3) a direct measure of innovative output. During the 1950s and 1960s, our understanding of the economy was advanced by developing measures of research and development (R&D), an input measurement, as a proxy for innovative output. R&D suffer from measuring only the budgeted resources allocated towards trying to produce innovative activity (Acs et al. 2000:2) university and industry [i.e. contribution of university publications to technological development] (see Jaffe et al., 1993; Alcacer and Gittelman; 2004, Wong, 2005). The reasons behind this critical view on the use of patents in university industry relations could also be explained by Arrow's (1962) distinctions between general knowledge and economically relevant knowledge. Based on Arrow's distinction, knowledge is only partly economically useful and also to some extent utilized. Endogenous growth model assumes that there is no barrier to the diffusion of knowledge within countries [e.g. from university to industry or among firms] to commercializing knowledge, i.e., spill-overs are automatic and there is no distinction between knowledge and commercialized knowledge (Romer, 1990 and Grossman and Helpman, 1991). On the other hand, not all inventions are utilized and commercialized, and lead to innovations. In the same way Invention refers to an idea, a sketch, or a model for a new or improved device, product, process or system. Such inventions do not necessarily have to be patented and they do not necessarily lead to technical innovations.

Fig.1.Relations between Knowledge & Patents



Patents, inventions, innovations, based on Grupp, 1998

This Fig.1 shows that knowledge -defined as codified R&D- is believed to be automatically transformed into commercial activities, or what Arrow (1962) classifies as economic knowledge. However the imposition of this assumption lacks intuitive as well as empirical backing. It is one thing for technological opportunities to exist but an entirely different matter for them to be discovered, exploited and commercialized (Acz et al. 2003).

An innovation is accomplished only with the first commercial transaction involving the new product, process system or device, although the word is also after used to describe the whole process (Freeman & Soete 1997:6). Thus not all innovations are patented and some innovations are not necessarily need to be patented. The relation between inventions, innovations and patents is summarized by Grupp (1998), based on a similar argument already made by Arrow (1962). Similar theoretical grounds could be also found according to Narin's and his colleagues (1976) typology of research. Narin el al. (1976) classified research into four: Applied technology; engineering science-technological science; applied research and targeted basic research and basic scientific research. It is difficult to assume which of these research groups yield more patents or no patents at all.

Universities are therefore expected to produce general knowledge (e.g. in the forms of publications, books, conference papers, lectures and so forth), educate students and generate knowledge that can also be patentable. While the former type of knowledge will contribute and increase the public knowledge, it is difficult to measure the direct contribution of e.g. publications and students in any specific industrial innovation per se. It is certainly plausible that the pool of talented graduates, the ideas generated by faculty, and the high quality libraries and other services of universities facilitate the process of commercial innovation in their regions [e.g. Silicon Valley, Route 128 etc.], but there has been very little systematic empirical evidence for this phenomenon (Jaffe, 1989:957) due to difficulties in measurements. Keeping all these limitations in mind, within the scope of this research I cover only a sub-set of university knowledge, which is codified in the forms of patents.

While patenting can be considered as the tips of the iceberg, other more generic mechanisms can be seen as the deeps of this iceberg. Therefore even though a substantial amount of technology transfer may also take place through more general mechanisms (Goktepe 2004, OECD, 2002a), it is difficult to generalize, identify and measure these mechanisms in terms of technology transfer (Audretsch et al 2005). However in the case of most European Countries, e.g. in Sweden even the university patenting is taking place beneath the surface which needs further research to identify inventors and the extent of patenting. Thus the choice of patenting to study UITT is not at all due to practical choices i.e. availability of databases etc. Second the focus on patenting would not undermine the importance of other mechanisms. Thus, although patent indicators reflect an important part of the overall innovation process, they should not be used in isolation. They show only one aspect of innovation, thus a consistent picture of technological change can only be achieved by combining several indicators and other qualitative works (Sirili 1992, and Grupp 1990 in OECD 1994).

3. Selected Studies on University Patenting under non-Bayh-Dole Systems

A number of scholars have shown that the number of USPTO patents applied for by U.S. universities has increased dramatically over the last 20 years coinciding with the so-called American Bayh-Dole Act. Over the same years the number of science-based university spin-offs has also grown (*among others see Henderson et al. 1998, Etzkowitz, 2002, Mowery et al. 2004*). Although the effects of the Act on the increase of patenting is far from definite and conclusive, universities increased their share of patenting from less than 0.3% in 1963 to nearly 4% by 1999 (Mowery and Sampat, 2005). As a result, it seemed that there is a positive relation between the numbers of university patents the Bayh-Dole Act.

On the other side of the Atlantic, the propensity of university patenting, licensing, spin-off company formation in Europe has been claimed to be low especially relative to the investments in higher education institutes in Europe. This phenomenon has been labelled as the “European Paradox”, according to which European countries have strong science base, but are not good at transferring research results into commercially viable new technologies (EC, 1995, 1993). University patenting seems to be limited in Europe. Although there *has been no* a systematic attempt of measuring it, it is well-known fact that no European university holds as large patent portfolio as MIT or Stanford, it is believed that many European Universities do not have patents at all (OECD, 2003).

This belief put the institutions and organizations behind university industry technology transfer into question. Given the impression of the “higher number of university patents, spin-offs and higher licensing revenues of the U.S. universities”, the emulation of the U.S. Bayh-Dole model has been considered as the main solution by many European policy makers. *Countries such as Germany, Denmark, Austria, and Norway adopted the Bayh-Dole model, while it is an ongoing debate in Sweden, (see Goktepe, 2007)*

Some concerns have been raised that policy suggestion are based to a large extent unrealistic and wrong assumptions. First of all, most information on university patenting, licensing, and spin-off company formation came from surveys submitted to university-TTOs, from newly established TTOs, or from searching for university names as the applicants. Remedies to the lack of systematic data on patents for European universities and further investigations of the “European Paradox” have been suggested by the European scholars.

In order to create comparable patent data sets with the USA system, almost coinciding with this research timeframe, a number of scholars *e.g. Belgium (Saragossi and van Pottelsberghe de la Potterie, 2003), Finland and Flemish Region (Meyer et al., 2003), France (Azagra-Caro et al.,* *2003), Germany, (Schmoch, 2000) Norway, (Iversen et al., 2005) and Italy (Balconi et al., 2003).*[5] *Italy, Sweden, France (Lissoni et al. 2006)* has recently identified university patenting in Europe by pursuing a different methodological suggestion. These scholars have departed from the argument that lack of the so-called Bayh-Dole system at universities in Europe should require a new methodology in order to find how many university scientists are actually listed as inventors of patents instead of searching for university names or university-TTOs as applicants of patents.[6] The starting point for this study is similar to the aforementioned studies. Due to different institutional and organizational set-ups of the Swedish universities, who is patenting and the propensity of university patenting should be investigated through the finding the names of the university scientists who are also registered as inventors in the patent databases. *(The methodological and empirical investigation and the construction of the Lund University Patent and Inventor database as a case for Sweden are presented in Section 4).*

The scholars of the previous studies on university patenting for European universities departed from the distinction between inventors and an applicants of patents.

Inventor: The inventor(s) developed the idea (knowledge) represented in the patent. The inventor of a patent can be collective (co-inventorship). Inventors can be affiliated with universities, research institutes, or public and private firms.

Applicant: The patent applicant is normally the individual(s), the firm or another organization responsible for the patent costs, and who/which may assume ownership, if the patent is granted. Applicants can be different from the inventor(s) who developed the idea represented in the patent.[7]

Depending on the ownership of IPRs at universities (i.e. individual ownership or organizational ownership), university inventors can apply for patents by themselves (individually), by university technology transfer offices (hereafter TTOs) or through other actors (e.g. patent attorneys, firms, and technology transfer organizations). The inventor(s) may assign his/her rights to another party to apply for a patent. Therefore, a distinction between inventor and applicant of a patent needs to be highlighted.

The aforementioned scholars *(Saragossi and van Pottelsberghe de la Potterie, 2003; Meyer et al., 2003; Azagra-Caro et al., 2003; Schmoch, 2000; Iversen et al., 2005 Balconi et al., 2003 and Lissoni et al. 2006).* These scholars have distinguished the university-owned patents and university-invented patents from as follows:

University-Owned Patent: University-owned patents are the patents in which universities or their technology transfer offices (TTOs) are listed as applicants, owners (assignees) of these patents.

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[5] In some cases I made personal communications with other researchers, Eric Iversen, Magnus Gulbrandsen, Manuel Trajtenberg, Stefano Breschi and Martin Meyer in order to learn from their methodological experiences. Each scholar has developed their own database management techniques. All comments are highly acknowledged.

[6] Chapter 5 is mainly based on the methodologies used in these studies, yet the how the name matching techniques are achieved for these studies have not been published. Authors just summarized the whole name matching procedure and university patent database construction in their publicly available publications. I therefore can not give the technical details of their name matching procedure.

[7] In the United States Patent & Trademark Office (hereafter USPTO), the patent applicant is called the *patent assignee.*

University-Invented Patent: University-invented patents are defined through the affiliation of their inventors with a university rather than university ownership of patents. University-invented patents have a member of a university faculty among the inventors whether or not the university is the patent applicant.

The main principle of the methodology of these different studies is to match two different databases. The database of patent applications (e.g. national patent office, EPO, USPTO) is matched with the so-called University Researcher Personnel Registers which has information on all scientific and administrative personnel at the universities, university colleges, state colleges and research institutes. Most of these studies have used surveys (emails, telephone calls to the inventors) to assure the matching of inventor and faculty member, and sometimes additional interviews as case studies. The main findings of the previous empirical work are presented below and in Table 2.3.

Balconi et al. (2003) found that out of 1,475 university-invented patents in Italy between 1978 and 1999, only 40 EPO patents had universities as applicants, whereas Italian university inventor patents account for 3.8% of EPO patents by Italian inventors. Meyer et al. (2003a) reported that Finnish universities own 36 USPTO patents, but that there were 530 Finnish university inventor patents between 1986 and 2000. In another research, Meyer et al. (2003b) showed that university-invented patents are 379, while the number of university-owned patents is 100 at the Flemish Universities.

In Germany, university assignee patents are relatively rare, but university invented patents have increased continuously from less than 200 in the early 1970s to around 1,800 in 2000 (Meyer-Krahmer and Schmoch, 1998 and Schmoch in Geuna and Nesta, 2004:8). Rapmund et al. (2005) investigated the university patent holders at Norwegian Universities and research institutes between 1998 and 2000. Preliminarily they have concluded that 8-12% of all Norwegian domestic patents are invented by university and PROs researchers.[8]

At an individual university level, Saragossi and van Pottelsberghe de la Potterie's (2003) study points out that the number of university invented EPO patents for Université Libre de Bruxelles (ULB) is more than double the number of university owned patents for the whole period 1985-1999. Azagra-Caro et al. (2003) point out that although French universities are legally entitled to own patents based on faculty research results, in practice the 'university invented, but not university owned' patent has been and remains the most common form of 'university' patent. These authors offer statistical evidence for the University Louis Pasteur (ULP) in Strasbourg, which, in 1993 to 2000 had 463 patents (from the French patent office, the EPO and other patent offices). 62 patents were owned by the university (ULP).

On a more narrow level, Schild (1999) examined the university patent holders at Linköping University who has patents within the Swedish-PCT filings from the East Gothia region. She found that a total of 88 (approximately 14 %) of the East Gothia patents have at least one inventor from Linköping University. She identified 82 inventors affiliated to Linköping University out of 656 inventors in the East Gothia region.

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[8] On the other side, the impacts of institutional changes (i.e. from individual to organizational ownership of IPR) on university patenting in Germany, Norway and Denmark have not been clearly measured yet. (see Valentin and Jensen 2005.)

Table 1: Selected Studies on Patenting versus Publishing

Author /Country	***Data***		***Findings***		
	Time Period Database	**Type of University investigated**	**#of University-invented Patents**	**# of University-owned Patents**	**Main Technological Category of Patents**
Finland (Meyer et al.2003a)	1986-2000 USPTO	All universities except Social Science & Arts etc.	530 patent 285 inventors	36	Telecom Instruments Pharmaceuticals
Flanders (Meyer et al.2003b)	1986-2000 USPTO	Technical Universities	379 x	100 (TTOs)	Organic chem. Life Science
France (Azagra-Cara & Llerena 2003) (Univ.of Strasbourg)	1993-2000 French National Patent Office	Univ.of Strasbourg 82 Research Laboratories	463	62	Genetics Biology Physics
Germany (Schmoch 2000)	1970-2000 EPO	All University Professors. Title of Professor is searched	1800 (2000) and 200 (1970)	NA	Biotech, Medical Engineering, Organic Chemistry
Italy (Balcani et al.2004)	1978-1999 EPO	All Professors registered to Ministry of Education and Research	1,475 919 inventors	40	Biotechnology Drugs, organic chemistry
Norway (Iversen et al. 2005)	1998-200 Norwegian Domestic Patents)	All researchers at universities - colleges	307 (8-12% of all Norwegian Domestic Patents)	NA	Life sciences Instruments
Sweden-Chalmers (Wallmark-Survey)	1943-1994 Swedish Patents or EPO	Chalmers University of Technology	417 68	NA	Chemical Engineering Electrical Engineering
Sweden-East Gothia (Schild) Linkoping University (LiU)	1980-1996 (Swedish-PCT filings from East Gothia)	Linköping University Technical Faculties	88 (Swedish-PCT filings from East Gothia) 82 Inventor	NA	Instruments Electricity Health & amusement
Sweden Lund (Goktepe 2005)	1990-2004 EPO	Lund University Except Social Science	458 EPO-patent 250 inventor	1	ICT, biotech, pharmaceuticals

University-invented patents can also be analyzed by looking at the distribution across science and technology areas. Cesaroni and Piccaluga's data point to a clear preponderance of patenting in the broadly defined area of Chemistry and Human Necessities (which includes biotechnology). Studies for Belgium, France, Finland, Germany and Italy show that the technological areas where patenting is most frequent are those relating to biotechnology and pharmaceuticals (in Geuna and Nesta 2004:8).

The strongest technological sectors in each country also tend to be those where university patents are heavily concentrated. For instance, telecommunications in Finland account for 12% of university-invented patents while pharmaceuticals and biotechnology only account for about 9% each (Meyer, 2003). The broadly defined research area of biotechnology and pharmaceuticals tends to be an area of extremely high university patenting activity across many countries.[9]

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[9] These studies have found almost the similar tendencies as in the US. In the US, 41% of academic USPTO patents in 1998 were in three areas of biomedicine indicating a strong focus on developments in the life sciences and biotechnology fields. In terms of revenues, about half of the total royalties were related to life sciences, including biotechnology (NSF, 2002). Whether a corresponding degree of concentration in this

In their three countries study, Lissoni et al. (2006) found that the university professors that are active in 2004 for Sweden and Italy and 2005 for France are responsible for a substantial number of patent applications during 1978-2002. There are 2800 patent applications in France, 2200 in Italy, and 1400 in Sweden. They compared the propensity of patenting in these three countries (for the years between 1994 and 2001) with the U.S. university patent data (for the years between 1993 and 2000) in order to make the U.S.-Europe comparison possible. They found French, Italian and Swedish university-owned patents are less than 1% of total domestic patents, while, in the same countries university-invented patents are respectively around 3%, 4% and over 6%. U.S. estimates for university-invented patents move are 6%. This shows that the gap between the U.S. and Europe in terms of patents, turn out to be a limited gap between U.S. and France and Italy on the one side, and no gap at all between U.S. and Sweden (Lissoni et al. 2006:18)

These empirical investigations support the view that university patenting is not a new phenomenon to the European universities. They show that the more inclusive approach of tracing patents made by academics allows the analysts to identify a much broader impact of and propensity of university patents. They provide clear empirical evidence that the number of university-invented patents is much higher than the number of patents owned by universities. Thus although university-owned patents do not fully show the wealth of contributions university and researchers make to technological development, university-invented patents can be used as a more stronger indicator of the role of universities (Meyer, 2003).

Although the number of university-owned patents are limited, these universities or countries do not necessarily lag behind the U.S. universities. The difference in the numbers can be explained by different institution and organizations. There are no straightforward answers to existence of patenting activities in Europe. However, we still do not know if patenting activities in European universities can be explained because of the individual ownership of patent legislations, entrepreneurial academics or it has been due to the changes in the technology transfer infrastructures or in the academic culture. The previous studies on university patenting have not investigated those issues in a systematic way, except case studies of Gulbrandsen (2005) and Meyer (2005) to date.

4. University Inventors & University Patents in Sweden

The empirical investigation is based on Lund University which was founded in 1666 in the south of Sweden. It is the largest unit for research and higher education in Sweden (and in Scandinavia) with eight faculties and a multitude of research centres and specialized institutes. It has faculties in three cities: Lund, Helsingborg and Malmö. The University has 42,500 students and 6 000 employees. More than 3 000 post-graduates work at LU, 45% of them women. Most doctorates are awarded in medical sciences, followed closely by technology and natural sciences. In 2004 the University had 554 professors, of which 14% were women. 435 new research students were accepted in 2004, half of them were women. 458 doctorates were awarded the same year. Towards the establishment of technology transfer infrastructure LU has taken important steps. For instance, The LU-Innovation unit (former industrial liaison office), LUAB, LU-Development Company, provide business advice to university researchers. Additionally, regional actors (Innovation Bridging Company, Forskarpatent, Teknopol and so forth) have been established in the last decade to guide and help university researchers for commercializing their research results.

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area exists for university patents in Europe is less than clear-cut, but the available evidence is not at odds with this assumption (Geuna & Nesta 2004:8)

Lund University Patents (LUP): are defined as the patents for which at least one of the inventors is affiliated with Lund University. In order to be counted as a university person, the inventor has to be included in the official university personnel registers and has to be employed at the time of invention.

This research has used a novel quantitative methodological approach which has now become a standard method to identify university inventors where individual ownership is the common practice (Trajtenberg, 2004; Meyer et al. 2003; Balconi et al. 2004; Iversen et al. 2005). The methodology is based on a procedure which matches names and addresses between two databases i.e. university personnel registers and the patent data.

4.1 Selection of the Databases

The two databases that were used for identifying the university inventors are: European Patent Database (EPO) and Lund University Faculty Registers (LUF).[10] Based on an initial comparison between EPO, PRV and USPTO, EPO database has been chosen. EPO-database provides the most reliable first page information of the patents (i.e. full names and addresses of inventors and applicants, while the other office databases give only the city names but do not have address information for inventors. The EPO database made it possible to find patents and patent applications that have at least one Swedish inventor.

First, EPO-database is selected over Swedish national-PRV database. According to the previous studies, USPTO and EPO patents can be seen as an indicator of commercially more promising inventions than national applications. For instance sometimes national offices (e.g. Italy, France and Norway) may appear to adopt a looser interpretation of the criteria for technical novelty and inventiveness than other patent offices (e.g. EPO, Germany, and USPTO). (Meyer 2004:5).

EPO-database is chosen over USPTO for practical reasons. The USPTO database does not include the full-addresses of inventors, it would have been almost impossible to find whether the inventor and university researcher is the same person. Moreover since most of the Swedish applicants (e.g. firms) work within the European market, they may more likely to care for protection in the European market.

This study counted *patent applications* rather than *granted patents*. This is the standard practice among studies using EPO database (see Balconi et al. 2004; Schild 1999; Breschi, 2004). There are two main reasons: First, a large proportion of patent applications to EPO are eventually granted (80%). Thus the distinction between patent applications and granted patents is relatively insignificant (Schild 1999:38). Second there is a time-lag between the applications and granting. This would preclude an up-to-date database if granted patents were to be used (Schild 1999:39). By the same token, Meyer et al. (2003:33) mentioned that in certain areas such as biotechnology, examination times may take five years. The use of granted patents limits the scope of the research and prevents us from identifying potential inventors. For the sake of simplicity in this research, the term patent is used instead of patent applications.

The EPO-Swedish patent is defined as a patent where at least one of the inventors has a residing address in Sweden, i.e. having SE in the address field. In the EPO- database I found 35,073 patents that have at least one inventor from Sweden from 1978 till February 2005.

Patents that have application dates earlier than 1990 have been excluded because of research objectives. (The choice of time-frame is a trade-off between taking stock of patenting activity

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[10] On the other hand, Wallmark (1997) for Chalmers University of Technology-Sweden and Chang et al. (2001) for Taiwan conducted surveys to find out academic patent holders instead of patent searching which was they considered costly and time-consuming.

over longer period of time on the other hand, and lowering the correct matches inventors and university scientists) As a result I have 22,824 patents from 1990 to 2004 that have at least one inventor with a Swedish residence regardless of the nationality of the inventor.

The second database used in this research is Lund University Faculty (LUF) registers. LUF Registers for three main faculties i.e. Lund Institute of Technology (LTH), Faculty of Medicine (MF), and Faculty of Science and Technology (NS) for the years 1999-2004 have been requested from Lund University Personnel Office. This file contains 4214 university employees (LUF).

4.2 Construction of the LU-patent Database

For this research I have developed a new method through the combination of Excel, Access and Visual Basic. The matching of the two databases follows a logical step-by-step procedure, often involving the repetition of the same basic steps.

Step 1: Name-matching between EPO-SE-inv- and LUF
First the procedure is based on matching first two letters in the first name, and full surnames of inventors in the EPO-SE-inv and LUF databases. This type of matching gives all possible combinations (e.g. Anders Andersson---Anders Andersson but also Andrea Andersson, Andrias Andersson etc.).[11] All these matches are controlled manually and only exact matches are taken.)

Step1.a: The same matching procedure is repeated for the different combinations of first names, middle names and surnames. (E.g. Anders Andersson → A. Sven Andersson, →Sven Andersson)

However homonyms are controlled by address match. (Homonyms: They have the same names they are not the same person. I do not know if they are the correct match of inventor and university employee). I made a manual address, zip-code and city control and then conclude that university scientist and the inventor is the same person. Moreover some names are abbreviated (e.g. Daniel→Danny) or sometimes mid-names are not registered at all or initials are used (e.g. Anders Sven→ A.Sven, or only Sven). All these different name combinations are checked. Moreover I thoroughly went through every match and checked each name one-by-one) due to possible spelling mistakes such as use of double *ss* or single *s (e.g. Andersson might be spelled as Anderson or the other way round).*

Step 2: Name, Address and zip-code matching [12]
The second stage of matching is based on name, zip-code and address and name matching. This matching provides the perfect matches since it confirms both names and the addresses of inventors.

Step-3: Address and zip-code matching
In this step, only the addresses and zip-codes are matched. As a result of the address matching some of the names that are missed are found. (E.g. some names were misspelled, changed, abbreviated names, use of middle names, divorced, married, different transliteration of foreign names- Chinese, Russian etc., different uses of Å, Ö, Ä etc.)

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[11] All names used for methodological explanations are arbitrary and created by the author. They do not reflect the real inventor-researchers.

[12] This kind of methodology has not been used or suggested by the other researchers in the field. This method is especially important to find the misspelled names. The address-matching confirms also our choice of EPO database, but the others (USPTO, PRV etc.)

The same procedure is repeated for all the inventors from INAD1 to INAD27, and zip-code matching for INzip1 to INzip-27. All possible abbreviations of addresses e.g. Gatan-G, Vägen-V, Södra, Östra, Västra, Norra, abbreviations etc., different spellings of ä-å-ö are checked manually. As a result name and address matching and subsequent manual controls, two sets-of name matches were found.

Perfect matches: The first-name, mid-names and surnames, address, zip-code and city of the inventors in EPO-SE-inv and researchers in the LUF registers are matching).
Name-matches: The first-name, mid-names and surnames of the inventors in EPO-SE-inv and researchers in the LUF registers are matching but their addresses can not be controlled due to lack of information.

Step 4: Controlling Scientific field of the Inventor-researcher Pairs and Patent Area
For further assurances, the possible relevance between the scientific fields of the researchers and the patents are manually controlled.

Step 5: Co-inventors and Colleagues
I manually checked the co-inventors. I have checked the LU Publications, and research projects list, staff homepages and CVs of inventors to find out if any of the co-inventors is also from LU. 10 more inventor-researcher pair is identified. Their names are different and who could not be identified due to missing address (e.g. inventors who have different name orders e.g. Arabic and Chinese names and who did not have the same addresses in databases. They were mostly foreign PhD students.).

Step 6: Identification of Academic title and Age at the time of Patent Application
The date of patent application is used as proxy to identify the link between the inventor and LU. In order to identify the academic title of the inventor, I consider the academic title and age which is the closest to the application date of the patent.

Step 7: Identification of Academic Affiliation at the time of Patent Application:
The identification of academic affiliation has been complicated due to the ongoing changes (re-organization) at LU, especially at the Medical Faculty. Another problem is the miscoding of academic affiliations in the LUF database. Moreover, some of the employees have been affiliated with several divisions and it was very difficult to determine which division should be the inventors' milieu. I consider the academic affiliation which is closest to the application date of the patent.

Step 8: Identification of Patent Applicants
In order to get the most accurate information about the size, sector, location, type and linkages of applicants to the inventors, the applicants of each patent are identified in the EPO-SE-Inv database. These features of all applicants & proprietors are investigated by using search engines, homepages and business websites. Use of different names for applicants (e.g. Astra or Astra Zeneca, Ericsson or Telekombolaget Ericsson, etc.) are controlled manually

To sum-up, name and address matching is more accurate than the methods used in previous researches which have mainly relied on name-matching and surveying the name-matches. This research has on the other hand decreased the risks of including non-patent holders due to same names. As a result of matching and manual controls I found around 273 inventors, 23 of which had only name matches, but they do not have address information. These 23 inventor-researcher pairs are put into a gray zone for further controls.

Step 9: Validation of the names in the gray zone

This thorough methodology has decreased the number of researcher-inventor pairs into 23, which needed to be further re-checked personally (by phone and emails for confirmation). 10 inventors confirmed that they were the inventors and employed at LU. 3 inventors stated that they were inventors but they patented at another organization, and eventually asked not to be included in the LUP-database. 10 inventors could not be reached due to missing addresses. These inventors were not included in the final database. I checked their EPO-addresses in Eniro Swedish (online yellow pages) in order to contact them. However this effort did not lead to any conclusion. This step-by-step, quite tedious and manual procedure has provided a methodological efficiency by eliminating the risks of excluding or including wrong inventor-researcher pair. Finally 260 inventor-researchers from LU are identified.

4.3 Limitations

First, the use of EPO limits the scope of the analysis. By doing so, I might have excluded inventors who have patents registered only in other offices (e.g. USPTO, Japan Patent Office, and Swedish Patent & Registry Office-PRV, etc.). Second, the university researchers are covering Lund University employees. A broader researcher register (covering all Swedish universities) could have been used. However given the time and resources allocated, it is far beyond the scope of this research. Yet Lund University can be taken as an exemplary of other research and industrial activity intensive universities in Europe. Third, names (of inventors and researchers) were matched across the periods. Although it is found to be a perfectly legitimate choice; it has certain limitations whether the inventor was employed at the university at the time of invention. This is especially important for pre-1999 patent applications in this study. This problematic side is encountered when the inventors' survey was sent to 260 inventors. Approximately 10 inventors responded to the survey and claimed that they were not employed at Lund University at the time of patenting. They are excluded from the LUP-database and the surveyed sample.

5. Empirical Findings

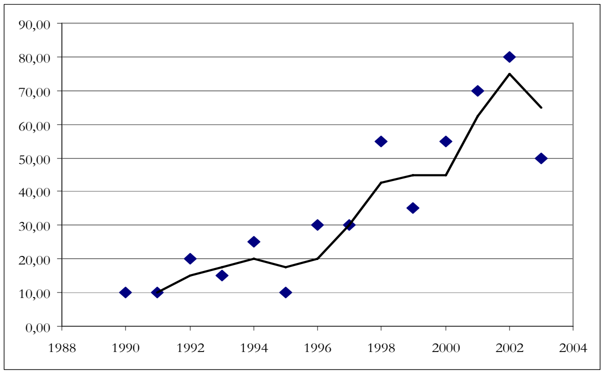
As a result of these matching and validation processes with a survey and telephone calls, a total of 458 patents with 250 university-researchers as inventors were identified at Lund University. This means that Lund University-related patents (LU-patents) account for at least 2% of the total amount of national patents (1990-2004). The following section describes these findings in detail. Empirical findings are analyzed in the lights of the three research questions that are posed in the introduction. First, it reflects on the patterns of LU-patents over time. Second, it presents the basic information about inventors and sets the background for further in-depth studies on inventors. Third, it presents the findings related to applicants, and proposes tentative insights where university patents are utilized.

5.1 Basic Characteristics of Patenting Activity at LU

Distribution of the patents at LU yearly and over 5-years periods

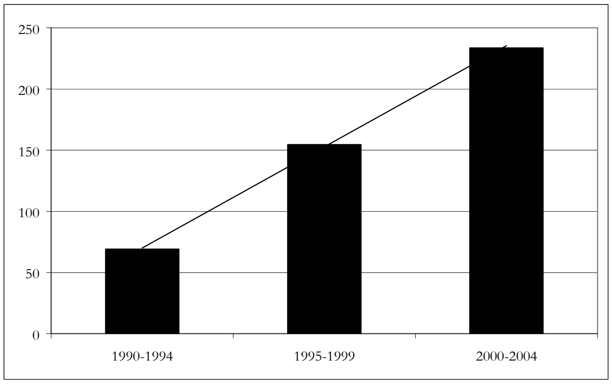
The extents of patenting at LU yearly and over selected periods are examined. As shown in Fig. 2, there has been a positive trend in the number of patents over the years 1990-2004. Although it is difficult at this point, to conclude the reasons behind this positive trend, the literature suggest several factors such as the development of new, high-opportunity technology platforms e.g. computer science, molecular biology, and material science; the more general growing scientific and technical content of all types of industrial production; the need for new sources of academic research funding created, and the so-called "third mission activities".

Fig. 2 Distribution of Patents Yearly (1990-2004)



Even though many scholars have argued that university patenting has not been exceptional before 1990s, patenting has become much more common within the last 2 decades. Fig.3 shows this positive trend in a more definite way by grouping the patents into 5-years periods. Between 1990 and 1994; the total number of patents was 69, between 1995 and 1999. The number of patents increased to 155, more than double of the previous period. Finally, the number of patents reached around 250 between 2000 till 2004.

Fig. 3 Distribution of Patents on 5-Year Basis (1990-2004)



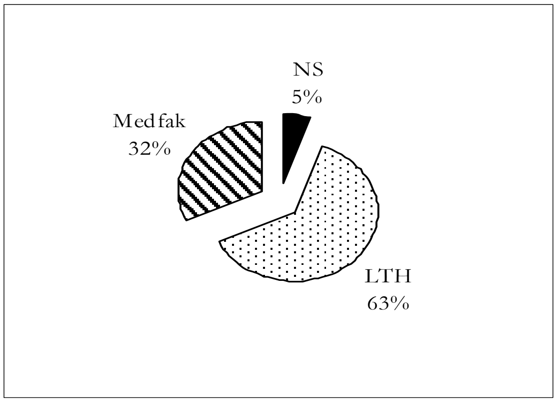
It has been argued that the relations with industry have intensified in the recent years. Stylized facts behind this intensification are: (i) the development of new, high-opportunity technology platforms e.g. computer science, molecular biology, and material science; (ii) the more general growing scientific and technical content of all types of industrial production; (iii) the need for new sources of academic research funding created by budgetary stringency; (Bercovitz and Feldman, 2005:175) (iv) and the prominence of government policies aimed at raising the economic returns of publicly funded research by stimulating university industry technology transfer (Geuna, 2001:10), (v) institutionalization of university patenting e.g. the Bayh-Dole Act of the USA and active roles of TTO. Although these factors are not exhaustive and conclusive, it is not feasible yet within the scope of this paper to go further in depth to find further explanations behind this positive trend.

Distribution of Patents by Scientific Fields

Patenting activities can also be related to the field of scientific specialization. Fig.4 shows the more patent intensive research milieus at LU. 63% of the patents have emerged from LTH-based scientific fields e.g. electronics, chemistry etc. 32% of the patents are related to Medical Faculty, and 5% of the patents have originated from Natural Sciences.

The basic explanation behind the scientific distribution could be that, in certain fields (basic-theoretical physics, geology etc.) patenting is not the preferred route for the protection and utilization of research results (Stephan, 2005). On the other hand, it has become more common to patent in fields like biotechnology, chemistry or engineering fields in general. The NS has 36 patents (out of 458). The lower rates of patenting at NS, can partly be explained by the nature of the research at NS, which is more theory oriented, compared to engineering fields at LTH or Medical Faculty. Second, LTH and MF have more connections with the surrounding industry. Third, due to the relatively higher research funds and research stuff at LTH and MF, these faculties have produced more patents.

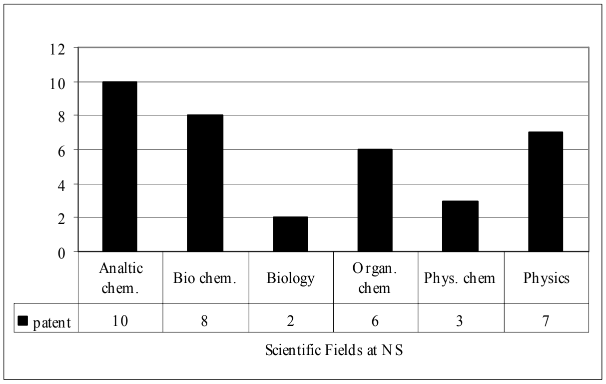
Fig. 4 Distribution of Patents by Faculties of (1990-2004)



The intensity of patenting activities differs not only among these three faculties, but to a considerable extent, the departments within the same faculty differ in their patenting activities as well. Each university patent in this study was allocated to a university department by the identification of the departmental affiliation of the inventor.[13] The differences within the same faculty can not be explained by the "stylized facts behind the university patenting" or "reasons behind differences of the patenting intensity of different faculties".

The following three figures show the distribution of patents at departments within the same faculty. Fig.5 shows that the most patent intensive department is the Analytical Chemistry at the Faculty of Natural Sciences (NS). It is followed by bio-chemistry, physics and organic chemistry.

Fig. 5 Distribution of Patents at the Natural Science Departments (1990-2004)



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[13] In cases where a single patent is invented with several inventors from LU, the patent was allocated to each of the relevant inventor's department. This resulted in a small amount of double-counting. Yet, as shown in Fig.1.2 this also implies the intensity of patenting among LU. The single counting of patents is 458.

According to the Table.2 the Departments of Chemical Engineering (79), Information Communication Technologies (45), Physics (44) and Mathematics (41) Biotechnology (27), Industrial Electronic and Automation (28), have the highest numbers of patents at the LTH.

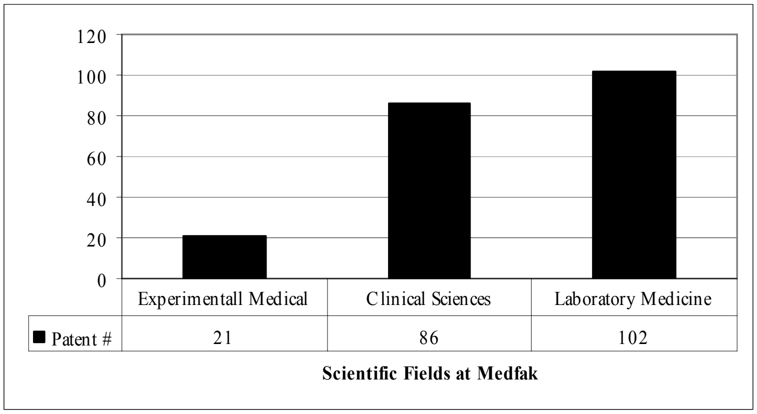
Table:2 Distribution of Patents at LTH Departments (1990-2004)

Automatic Control	17
Biotechnology	27
Chemical Engineering	79
Communication	10
Computer Science	5
Electrical Measurements	30
Electro-science	26
Food Engineering	19
Industrial Electronics	28
Information Technology	45
Mathematics	41
Energy-Building Sciences	20
Mechanics-Design	10
Physics eng.	44
other	9

The possible explanations behind difference among department within the LTH; can be "difference in the size and resources of departments, role and motivations of chairperson, the inherent culture of the department, external funding and so on." Participation of departments in projects with industrial partners or in Vinnova Competence Centres, such as Nanotechnology Forum, Electro-science Forum, Bio-separation Centre and so on are expected to be important reasons for the intensity of patenting in these fields.

Fig.6 shows the distribution of patenting at the departments of Medical Faculty. [14] The patenting activities in the Medical Faculty are concentrated to three departments: Laboratory Medicine (102) and Clinical Sciences (86), and Experimental Medical Sciences have (21) patents.

Fig. 1 Distribution of Patents at Medical Faculty Departments (1990-2004)



At the Medical Faculty, inventive activity is concentrated to the divisions of cell and molecular biology, Medical Sciences and clinical chemistry, cardiology and orthopaedics. Differences

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[14] From 01.01.2005, Medical Faculty has been re-organized under 6 main departments (located either at University Hospital Lund, or Malmo General Hospital-MAS).

within the Medical Faculty can also be explained by the culture of the department, closer relations to industry and participation in competence centre such as Swegene Center for Integrative Biology, Biocatalysis (BIOCAT), and Vinn excellence centre for Drug Development (VIDD).

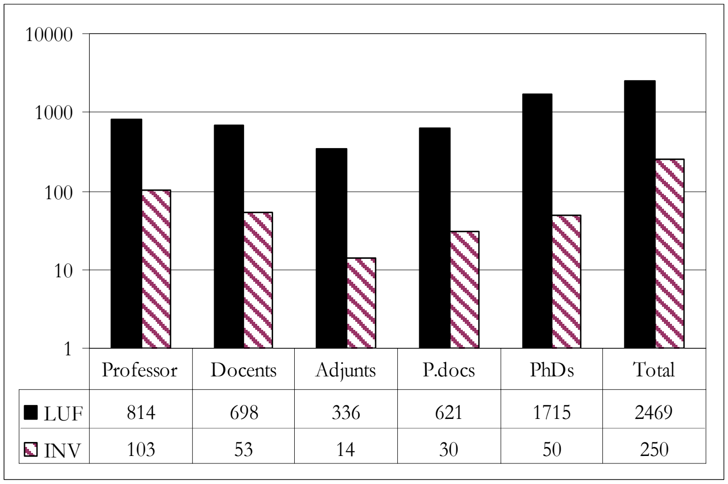
However, when comparing departments & faculties in terms of patenting, it should be noted that departments and faculties vary in size (number of faculty, research expenditure, types of research etc.). The different budgets and research personnel allocated to different departments may affect the research profile and capacity of the departments. For instance, the number of faculty at LTH is 1802, at the Medical Faculty 1610, and at the Natural Sciences 802. The industrial funding that LTH-faculty receives and the industrial networks they have may be higher than has the NS-faculty.

5.2 Basic Characteristics of Inventors

"Academic rank, scientific field, employment status, gender, age and even residence of inventors" are investigated. The basic descriptions of the inventors by these aforementioned features would imply what sort of faculty members are involved in patenting. This analysis may help us to distinguish what might be the main the motivations and incentives of each group of inventors. This analysis would also indicate if there is any specific group of faculty who was not involved in patenting.

Fig.7 shows the distribution of inventors by academic ranks. Most of the patenting activity is concentrated among professors (103), it is followed by associate professors (Docents, 53), PhD students (50), and Post-doctoral fellows (including assistant professors). A special group is the university employees who are adjuncts (working part-time at LU). Out of 366 adjunct-employees, 14 of them are inventors. The reasons behind the higher number of professors can be explained by life-cycle theories. Scientists start patenting when they are established in their careers. It is also expected that professors can identify the patentability of research results and they are in most cases the principal investigators of projects. They hence become listed as inventors in most cases. Third, they may have more contacts and networks with industry or TTOs which can help them to patent more.

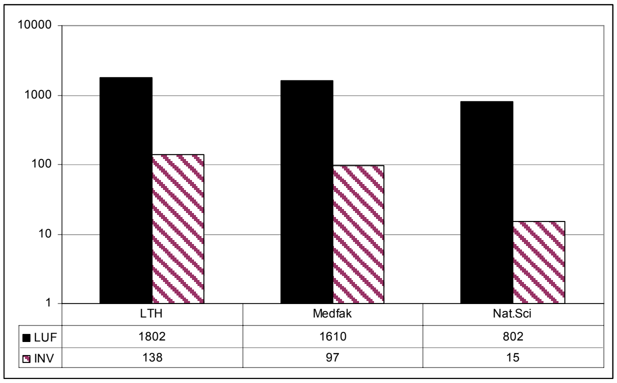
Fig. 2 Distribution of Inventors by Academic Rank



	Professor	Docents	Adjunts	P.docs	PhDs	Total
■ LUF	814	698	336	621	1715	2469
▨ INV	103	53	14	30	50	250

Classification of inventors according to their scientific fields are reflects which faculties are patent intensive. Accordingly the inventors are classified by their scientific fields at the time of the patent application.

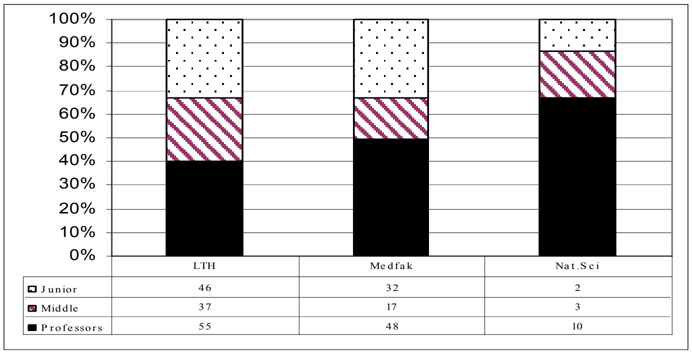
Fig. 3 Distribution of Inventors by Faculties



According to Fig.8 LTH has the highest number of inventors (138 out of 250), it is followed by the Medical Faculty and finally there are 15 inventor-researchers affiliated with Faculty of Natural Sciences.

One step further, the inventors are grouped into three main levels: seniors (full professors, professor adjuncts), middle-level (associate professors), and juniors (post-docs, assistant professors and PhD students). After this classification, the inventors are distributed by their scientific fields. Fig.9 shows the distribution of inventors by academic ranks and scientific fields.

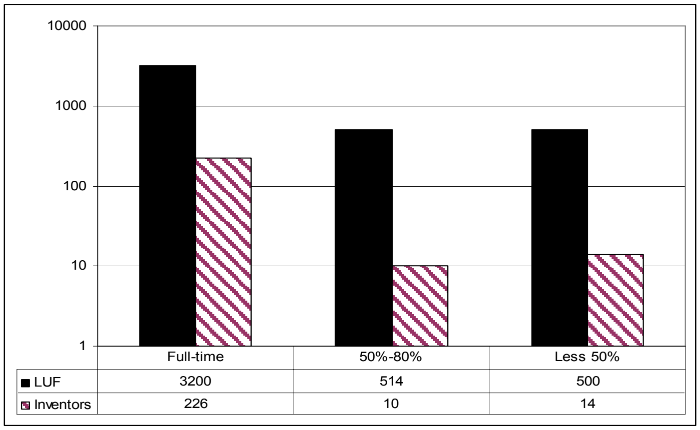
Fig. 4 Distribution of Inventors by Academic Ranks & Scientific Fields



At the Natural Sciences, 10 of the inventors are full professors as compared to 5 inventors who are either at their middle or early levels of their careers. At the Medical Faculty, the number of professor-inventors is 48, and the number of inventors from other ranks is 49. At LTH out of 142 inventors, professor-inventors are 55, while the total of other groups is 83.

Fig.10 shows the distribution of inventors by employment status. Most of the LU-inventors are employed full time. The inventors who have less than half-time employment are mostly adjunct professors. Their patents need further identification if those patents were the direct results of their activities at their industrial jobs, or a result of interaction with their university colleagues. However even these patents are mainly resulting from their activities at their industrial jobs, it is most likely that their tasks in both places are mostly overlapping and complementing each other.

Fig. 5 Distribution of Inventors by Employment Status



Another implication is on the ownership of such patents. Should the patents resulting from the collaborative works with industry belong to the firm directly or it should be co-ownership with university or with the inventor? It is expected that a legal involvement of university, e.g. in the form of a TTO, would most likely yield to tensions between the inventor and the firm.

Fig.11 shows the distribution of inventors by gender. The number of women inventors is quite low, compared to their total employment at LU.

Fig. 6 Inventors by Gender

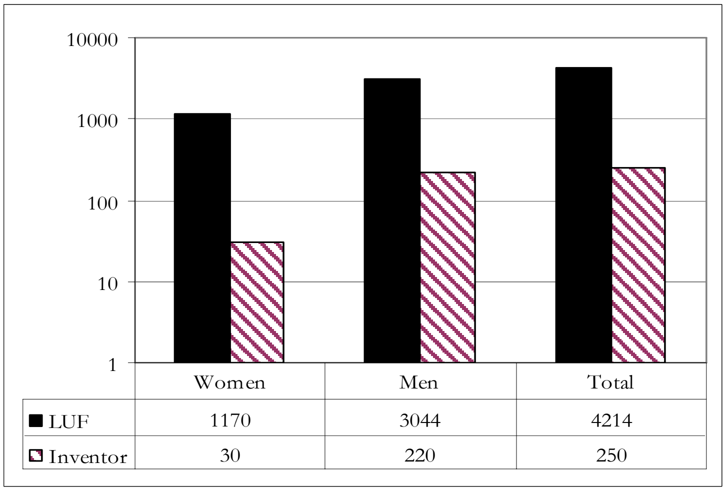


Fig.12 shows the distribution of inventors by gender & age. Similar to the academic ranking discussions, it is problematic to determine the impact of age on the productivity of the scientists.

Fig. 7 Distribution of Women Inventors by Age

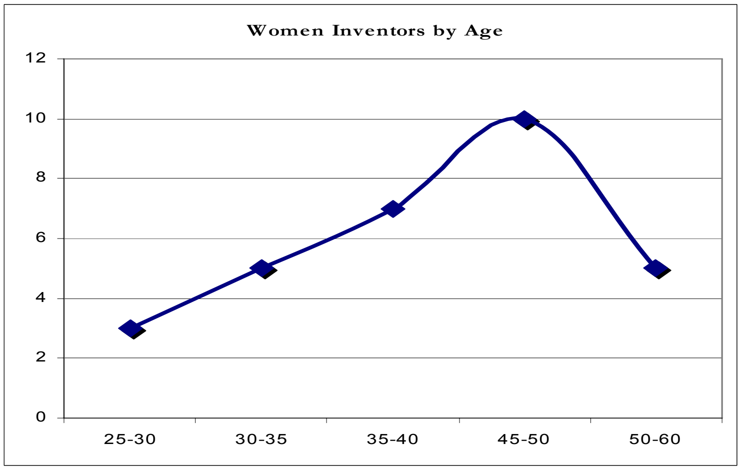
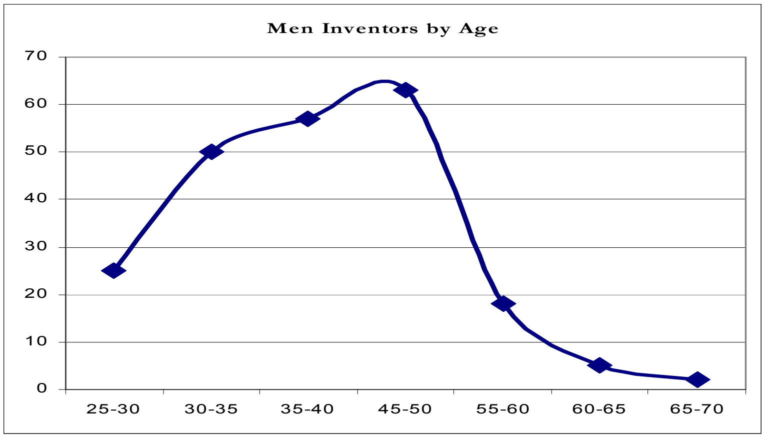


Fig. 8 Distribution of Men-Inventors by Age

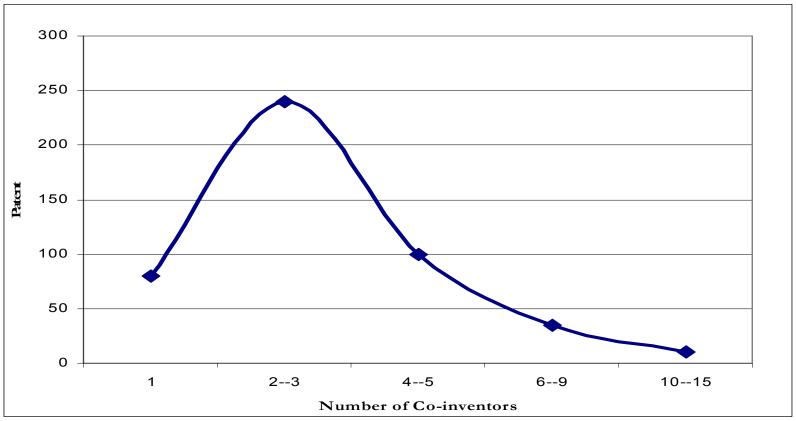


The findings show that the numbers of men and women inventors are highest between the ages 45-50. The oldest man inventor at LU is around 60, while it is 50 for woman. The age of the youngest inventor for both men and women is around 26 to 30 which may be during their doctoral education. Yet women inventors have started to do patenting later than the men.

Number of inventors per patent

Fig.14 shows the number of co-inventors per patent. Around 80 patents have single inventors, while patents invented by groups of two to three inventors reach a peak of around 200 patents out of 458. The number of patents decreases to 100 as the number of inventors increased to four to five. The number falls below 50 for patents with more than six inventors.

Fig. 9 Number of Co-inventors per Patent



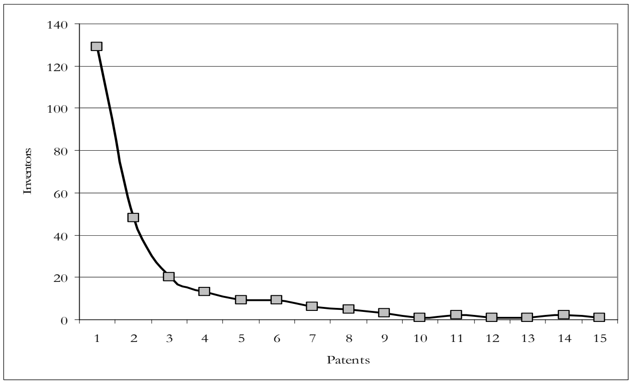
The breaking-down of the number of co-inventing over time (year by year, and over three and five years) do not yield any noteworthy differences. In different time periods, patents with two to three inventors are found the most common.

With regard to clustering based on technological fields, while chemistry related patents slightly higher co-inventors, traditional engineering sectors (machine tools, controls) have lesser co-inventors. However differences are not very significant. (The number of the co-inventors and the size of research groups (e.g. co-authorship, role or researchers who were not listed as inventors) are investigated further in Göktepe, 2007.

Skewed distribution of patenting activities

It was found that out of 250 inventors, 130 of them only have one patent. After the fifth patent, the number of inventors is decreasing sharply. The Fig.15 shows a skewed distribution of patenting activity. Five times of patenting could be considered as a threshold level for becoming a more patent productive inventor. The number of inventors who have five or more patents is 40. These 40 inventors are named serial inventors. This implies that university patents are concentrated on some serial inventors.

Fig. 10 Skewed Distribution of Patenting



Basic explanations behind this skewed distribution of patenting goes back to Lotka's Law. I assume ability to recognize the patentability of research result, having resources to apply for patent, learning to patent are some of the factors that may enable and motivate scientists to patent further. The more they do patenting, the more they learn what is patentable and how to apply for a patent, and even they might have established their networks to get their research results patented.

Hence the process becomes less burdensome. The details of the skewed distribution of patenting, role of serial inventors and their research group (members) are analyzed in Goktepe, 2007.

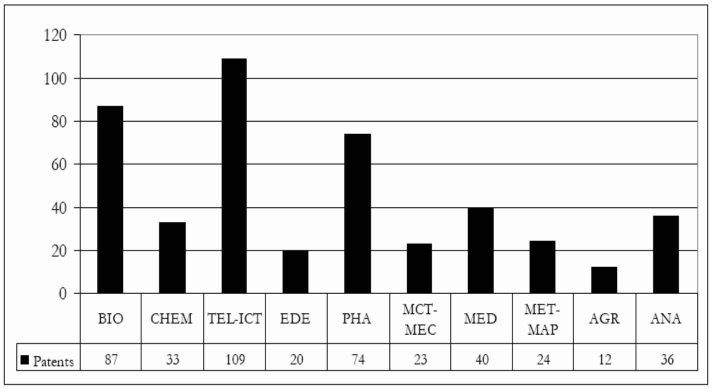
5.3 Basic Characteristics of the Applicants of LU-Patents

This part focuses on the applicants of the LU-patents. There is a burgeoning amount of literature examining when, why, how and which types of firms that collaborate with university and faculty (e.g. Community Innovation Survey etc.). This Section investigates the applicants of patents as a proxy to investigate the nature of relations between LU and industrial partners according to type, sector and location of firms.

Distribution of patents by technological classification

LU-patents are classified according to technological and industrial sectors.[15] According to Fig.16 Pharmaceuticals, biotech, and ICT (including telecom) are the largest sectors. The number of patens in Telecom-ICT is 109. It is followed by biotechnology (87) and pharmaceutical sectors, 74. Most of the Telecom-ICT patents are reflecting the dominance of telecommunications sector in the Swedish Economy and presence of Ericsson close to Lund University. Dominance of bio-technology and pharmaceutical patents are closely related to the strong Medical Faculty, Department of Chemistry, university-industry consortia, e.g. Swegene, Bio-seperation etc. Importance of strong patent protection as well as recognition of this field as an important sector and thus availability of investors and industrial demand for these fields triggered higher number of patents.

Fig. 11 Distribution of Patents by Technological Field (1990-2004)



The region Skåne is traditionally strong in agriculture sector in Sweden; however there are relatively less patents in the agriculture field. This is partly due to the lower needs for patent protection in agriculture and lack of connections between agriculture sector and university researchers. This has changed recently, due to needs for functional foods, alternative production methods, better preservations, etc. A number patents in agriculture have been taken. They are resulting from the Divisions of Food Engineering and Food Technologies at the Departments of Chemistry at Lund University together with industrial participants from Food Innovation Network.

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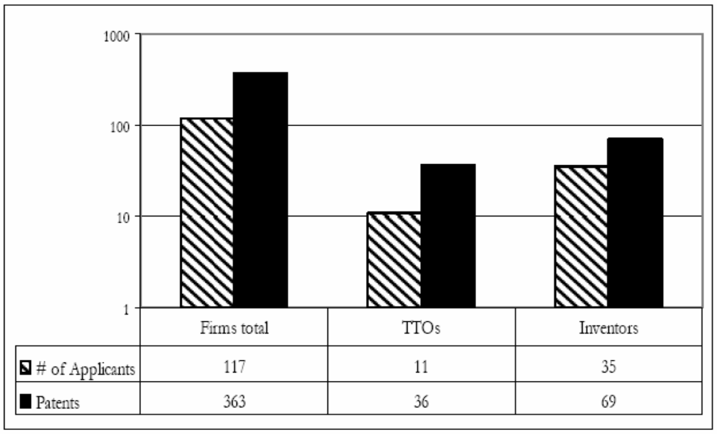
[15] The classification scheme was originally developed by the Fraunhofer Institute in collaboration with the French Science and Technology Observatory-OST and IP agency INPI (Meyer et al., 2003). The scheme is based on the International Patent Classification and provides a more aggregated view of patenting by distinguishing thirty technological sectors. Full list and the abbreviations can be found the in the Appendix.

Applicants of LU-patents

Fig.17 shows how LU-Patents are distributed by different types of applicants. Firms are the main applicants of patents; in total (116) firms applied for 353 patents. 69 patents were applied for by the inventors themselves. Those 69 patents are unassigned to any company at the time of application. Inventors most probably assign (license-sell or give) the patents to firms after the application.

Fig. 12 Distribution of Patents by type of applicants (1990-2004)



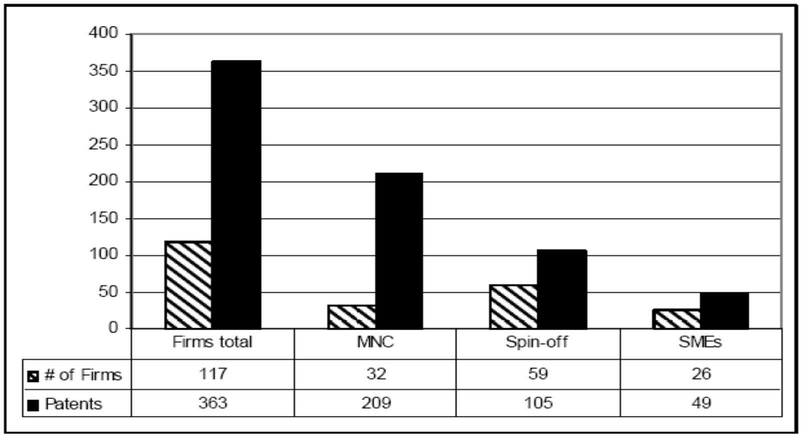
	Firms total	TTOs	Inventors
▨ # of Applicants	117	11	35
■ Patents	363	36	69

In total 11 technology transfer organizations (3^{rd} agents e.g. Forskarpatent i Syd AB, BTG international) or public research institutes (e.g. Lund University and several other research centres) applied for 36 patents.

Types of industrial firms

Fig.18 shows the distribution of patents by type of applicant firms. The number of large firms (32) is less than the number of spin-offs (58) as applicants of LU-patents. However, the number of patents applied for by large firms (209) is higher than the total number of patents applied for by SMEs (48) and Spin-offs (95). This reflects the dominance of large firms in the Swedish economy and in access to university knowledge.

Fig. 13 Distribution of Patents by type of applicants firms (1990-2004)



	Firms total	MNC	Spin-off	SMEs
▨ # of Firms	117	32	59	26
■ Patents	363	209	105	49

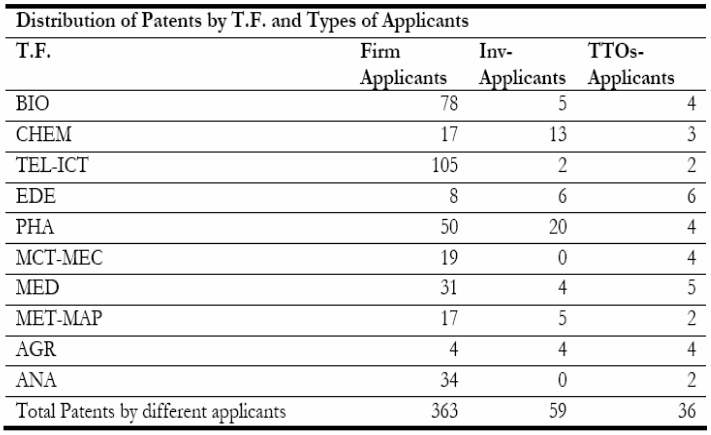
These findings have different implications to understand whether university research results are absorbed by the existing companies (incumbents). On the other hand, despite dominance of big companies, e.g. Ericsson, there has been substantial amount of spin-off companies. There is no evidence that Swedish universities are not generating spin-offs at all or all of their research results are taken by existing (incumbent) firms.

Distribution of the applicant firms by technological field and size

Table 3 shows the distribution of different types of applicants (i.e. firms, inventors and TTOs) by technological fields of patents. In Pharmaceuticals and Chemistry individual applications are the most common. Higher levels of individual applications could be explained by the fact that inventors aim to show the value of their research results by applying for patents to the firms. Especially these sectors are dominated by traditional large firms and some of these firms may be reluctant to undertake the "newer university research results", yet an existing patent application may increase the interest of the firms while it increases the bargaining power of university inventors vis-à-vis firms.

Particularly after changes in the firms' structure (loss of the contact person at the firms, closure of relevant programs, or closure of firms e.g. Pharmacia, Kabi AB etc.); inventors may find it difficult to convince the industrial firms to apply for a patent. Therefore they may be inclined to patent themselves and then to find a company to sell or license the patent.

Table:3 Distribution of Applicants by Technological Fields (1990-2004)



Distribution of Patents by T.F. and Types of Applicants

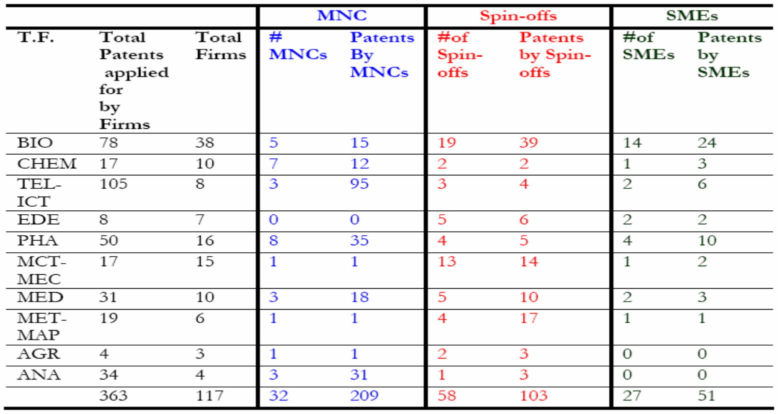
T.F.	Firm Applicants	Inv-Applicants	TTOs-Applicants
BIO	78	5	4
CHEM	17	13	3
TEL-ICT	105	2	2
EDE	8	6	6
PHA	50	20	4
MCT-MEC	19	0	4
MED	31	4	5
MET-MAP	17	5	2
AGR	4	4	4
ANA	34	0	2
Total Patents by different applicants	363	59	36

On the other hand, firms may take the advantage of inventors when they actually disclose their research results to the firms. For instance due to the weaknesses of non-disclosure agreements and the possibilities of being cheated by the firms; inventors could again be motivated to patent in advance as to protect themselves against firms.

Distribution of applicant firms by technological field and types

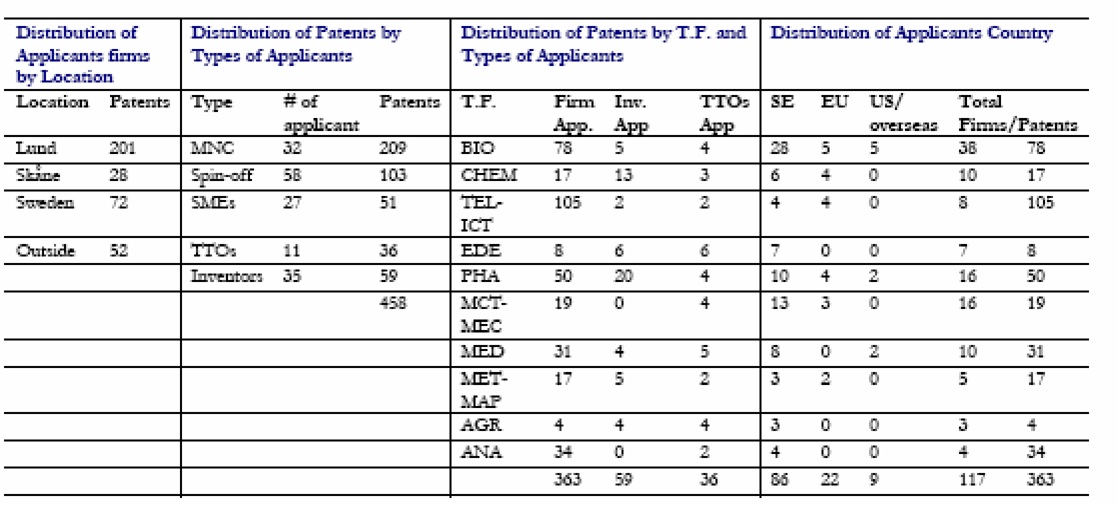
Table 4 shows the distribution of the applicant firms by the technological field and types. There are 105 patents in ICT sector, but there are only 8 companies, in which 80 of the patents are applied for by one large company (i.e. Ericsson). To some extent the majority of large firms are in the pharmaceuticals, chemistry and electronics. In mechanics and biotech, there are more SMEs and spin-off firms.

Table:4 Distribution of Applicant Firms by Technological Field and Types (1990-2004)



			MNC		Spin-offs		SMEs	
T.F.	Total Patents applied for by Firms	Total Firms	# MNCs	Patents By MNCs	#of Spin-offs	Patents by Spin-offs	#of SMEs	Patents by SMEs
BIO	78	38	5	15	19	39	14	24
CHEM	17	10	7	12	2	2	1	3
TEL-ICT	105	8	3	95	3	4	2	6
EDE	8	7	0	0	5	6	2	2
PHA	50	16	8	35	4	5	4	10
MCT-MEC	17	15	1	1	13	14	1	2
MED	31	10	3	18	5	10	2	3
MET-MAP	19	6	1	1	4	17	1	1
AGR	4	3	1	1	2	3	0	0
ANA	34	4	3	31	1	3	0	0
	363	117	32	209	58	103	27	51

Mapping of LU-patents' Applicants

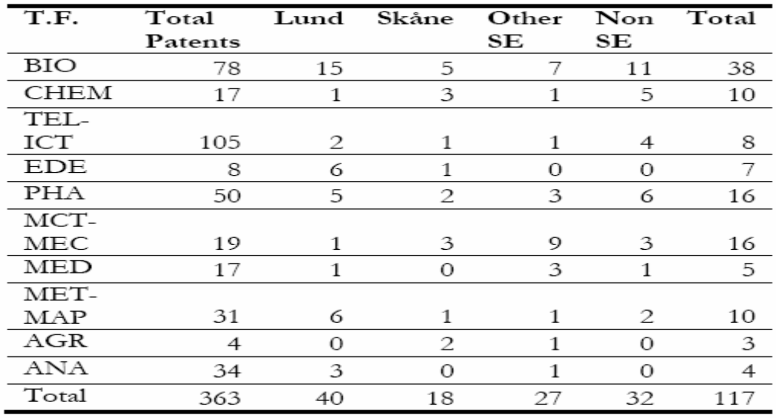


Distribution of Applicants firms by Location		Distribution of Patents by Types of Applicants			Distribution of Patents by T.F. and Types of Applicants				Distribution of Applicants Country				
Location	Patents	Type	# of applicant	Patents	T.F.	Firm App.	Inv. App	TTOs App	SE	EU	US/ overseas	Total Firms/Patents	
Lund	201	MNC	32	209	BIO	78	5	4	28	5	5	38	78
Skåne	28	Spin-off	58	103	CHEM	17	13	3	6	4	0	10	17
Sweden	72	SMEs	27	51	TEL-ICT	105	2	2	4	4	0	8	105
Outside	52	TTOs	11	36	EDE	8	6	6	7	0	0	7	8
		Inventors	35	59	PHA	50	20	4	10	4	2	16	50
				458	MCT-MEC	19	0	4	13	3	0	16	19
					MED	31	4	5	8	0	2	10	31
					MET-MAP	17	5	2	3	2	0	5	17
					AGR	4	4	4	3	0	0	3	4
					ANA	34	0	2	4	0	0	4	34
						363	59	36	86	22	9	117	363

Distribution of applicant firms by technological field & geographic location

Table 5 shows that university patents are mostly utilized by firms located in Lund (53). Around 30 of them are located in the Ideon Science Park, which also implies the importance of science parks around universities. After Lund Malmö, Stockholm, Uppsala, Gothenburg and Västerås are the main cities where companies that applied for LU-Patents are located. Few (32) companies that applied for LU-patents are located outside Sweden.

Table:5 Distribution of Applicant Firms by Technological Field & Geographic Location (1990-2004)

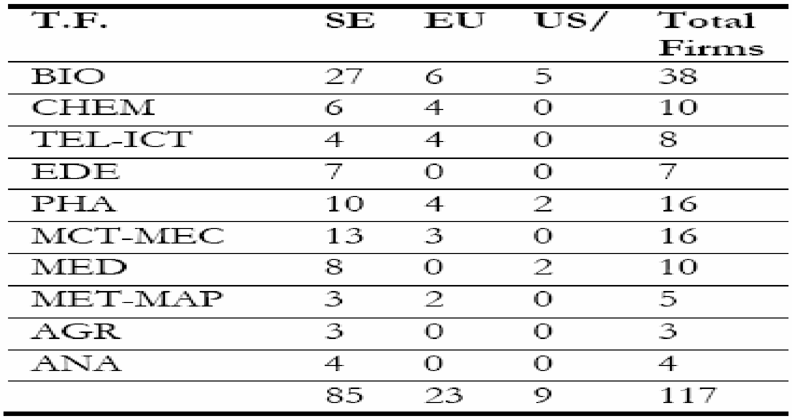


T.F.	Total Patents	Lund	Skåne	Other SE	Non SE	Total
BIO	78	15	5	7	11	38
CHEM	17	1	3	1	5	10
TEL-ICT	105	2	1	1	4	8
EDE	8	6	1	0	0	7
PHA	50	5	2	3	6	16
MCT-MEC	19	1	3	9	3	16
MED	17	1	0	3	1	5
MET-MAP	31	6	1	1	2	10
AGR	4	0	2	1	0	3
ANA	34	3	0	1	0	4
Total	363	40	18	27	32	117

Distribution of applicant firms by countries

Table 6 shows that the applicant firms' countries. Sweden is the main country of the applicants. This implies that most of the LU-Patents are applied for by firms located in Sweden. These findings underline the fact that there is not strong evidence that Swedish research result are flowing out of Sweden and causing lower levels of the utilization of research results.

Table:6 Distribution of Applicant Firms by Technological Field and Country (1990-2004)

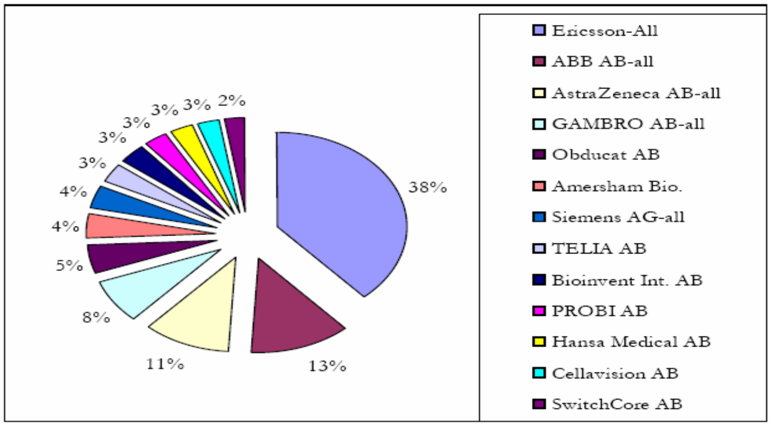


T.F.	SE	EU	US/	Total Firms
BIO	27	6	5	38
CHEM	6	4	0	10
TEL-ICT	4	4	0	8
EDE	7	0	0	7
PHA	10	4	2	16
MCT-MEC	13	3	0	16
MED	8	0	2	10
MET-MAP	3	2	0	5
AGR	3	0	0	3
ANA	4	0	0	4
	85	23	9	117

Distribution of patents by key applicants

Fig.19 shows that LU-Patents are concentrated to small number of key applicants. Ericsson, Astra-Zeneca, ABB, and Gambro are the key applicants of the LU-patents. Obducat AB, Amersham AB, Bioinvent and Probi AB are small sized firms that spun-off from Lund University and they still have links with the respective researchers at Lund University.

Fig. 14 Distribution of Patents Key Applicant Firms (1990-2004)



6. Concluding Remarks

This study has acknowledged the main findings of the previous studies. I pursued that that in countries where individual ownership is the common practice, the share of contributions of universities to technology transfer in terms of patenting can be best determined by tracking university patents by the names of university inventors, rather than by the names of universities or TTOs. This approach gives a more appropriate picture of the role of universities in technology transfer, especially for a European context (e.g. Sweden, where university technology transfer infrastructure-TTOs- are not only inexperienced, but also quite uncommon to the scientists). The tracking of university inventors illustrates a more inclusive notion of university-related or academic patents and it captures more comprehensively the contributions of academic science to a technological base. Naturally, also academic patents are only one of several indicators of useful research. Due to the individual ownership practices in Sweden, the number of Lund University-owned patents is only 1 out of 458 patents which have at least one inventor affiliated with LU. While they seem to capture the inventive activity of researchers more comprehensively, they still remain a partial measure of scientific contributions to technological change Meyer (2003).

Even though this research has departed from the similar point as the studies for *the identification of university patents and inventors it* aims to go well beyond these studies. The common conclusion of the studies on university patenting in Europe is that European Universities are actually patenting and they are as entrepreneurial as their American counter-partners even without the Bayh-Dole Act. This conclusion has few implications. Different technology transfer infrastructure and patent legislations at European universities require a different methodological approach. Finding the names of university scientists by matching with the inventors of patents rather than cursory investigation of the names of universities or TTOs as applicants for patents gives a better picture of the propensity of university patenting. In countries where universities don't own the patents researchers still make a substantial contribution to technological development. European universities do not necessarily need to emulate the Bayh-Dole Act in order to increase university patenting. European university scientists may be as inventive and /or entrepreneurial as their U.S. counterparties.

I found that researchers are not islands and research (patenting) is a collective, interactive process which involves more than one actor. Involvement of an industrial researcher or a researcher with some industrial background has become quite common. University scientists who were involved in competence centres, like Bioseperation, Swegene, Functional Food Centre, or in joint centres of different faculties were listed as inventors more often than non-participating scientists. These platforms also provide a substantial number of patents and spin-off companies. Triple Helix dynamics seemed to be achieved through top-down initiations of the governmental actors. On the other hand since a substantial amount of the patents resulted from the individually initiated relations with industry, I found bottom-up motivations. This model of triple helix relations is resulting from the synthesis of bottom-up (individual) and top-down (government) initiations, instead of following a single mode. Thus e.g. abolishment of university teachers' privilege law, and adoption of Bayh-Dole model will not increase relations between these actors.

In this study, a total of 458 patents with 250 university-researchers as inventors were identified at Lund University. This means that Lund University-related patents (LU-patents) account for at least 2% of the total amount of national patents (1990-2004). One must bear in mind that this is a conservative measure since only four /five years of personnel register were available for the analysis, compared to 15 years of EPO database. As there are long examination times, especially for life science related applications, not all inventive activity in these areas could be investigated here.

Inventive activity is shown to be concentrated in terms of both inventors and faculties. I have identified 40 serial inventors who are quite prolific in patenting. This study showed that some departments (i.e. electronics, telecommunications, physics, mathematics, chemistry, biotechnology, laboratory medicine) account for the highest number of LU-patents.

Similarly to the inventor concentrations, there is also a concentration on key assignees. Mostly large firms are applicants (e.g. Ericsson or Astra Zeneca) of LU-patents. In total 11 technology transfer organizations applied for a 36 patents. The chief technological contributions of Lund University-based inventors are in biotechnology, pharmaceuticals and telecommunications sectors. Foreign-owned LU-patents patents invented in Sweden but owned by overseas organizations are limited. Although most of the patents are owned by big companies (i.e. Ericsson, AstraZeneca Gambro etc.); there are around 40 spin-off companies, and several SMEs which are related to LU employees or had been started by former LU-employees. Finally, only a limited number of foreign companies are applicants of LU-patents.

This Chapter argues that the relation between knowledge, invention, innovation and patents is not linear. It suggests that it is unrealistic to expect that all investments to R&D (universities) will lead to knowledge that is patentable and/or commercialized. Only a sub-set of knowledge can be commercialized. Second, by adopting an extensive research strategy, this Chapter constructs the university patent and inventor data base to analyze the extent of patenting at a Swedish University for further qualitative and quantitative studies on the factors that motivate, enable scientists to patent or factors that influence the scientists' decision to patent.

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International cooperation for Swedish inventors – an exploratory study

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Abstract

In this paper we report from a research project exploring the reasons behind why Swedish domestically invented patents end up being owned a foreign company. Based on survey data, we find that the majority of inventors behind these foreign-owned patents are professional inventors who have a relatively high amount of patent experience. They are also highly educated with about one third of the respondents having doctoral training. They are primarily motivated to invent because it is meriting and good for their career and as it gives them higher influence in the milieu where they are working. Only about 11% of the inventors had any influence on the decision to collaborate with a foreign firm. In most of the cases the inventors were either employed by a private firm who controlled the patent, or the invention behind the patent was ordered by the foreign firm already from the beginning. In the case where inventors had any influence on the decision, the most common reasons for seeking international collaboration was that the foreign firm provided better opportunities to commercialize the patent compared to Swedish firms and that the foreign firm could offer more money for financing development costs compared to Swedish firms.

Key words: domestic inventions, foreign ownership, international cooperation, inventors

Acknowledgements: We wish to express our appreciation for the financial support received from Sparbankstiftelsen Skåne.

This is a preliminary first draft. Please do not cite without permission of the authors.

1. Introduction and aim of study

Technological progress is today well recognised as a major driver of long term economic growth. This recognition has among other things led technological advanced economies to implement national policies to support the generation and commercial exploitation of domestic inventions. As a result, many European countries spend large sums of government money on research in the public sector, especially in science and technology fields. In addition, many countries have publicly sponsored financial support for private R&D efforts. These include programmes for boosting the innovative performance of small firms, support for R&D partnerships between large and small firms, and special tax concessions which allow private companies to deduct qualifying expenditure incurred on R&D activities. These efforts are all expected to have a positive effect on national competitiveness and the overall innovation performance of the country.

An important indicator of the innovation performance of countries is their total number of patent applications[1]. Patenting activities is in this respect following the general trend towards globalization of the economy (OECD, 2006). This means that patents, as well as the inventors behind the patents and the ownership of these patents, are increasingly crossing international borders (Guellec and van Pottelsberghe, 2001). However, this general trend also suggest that public efforts to support domestic innovation through direct funding or through tax concessions may risk having a more uncertain impact as the resulting inventions may end up being controlled and commercially exploited by firms in foreign countries. In the case where the increasing internationalization affects all countries to a similar extent this may be no problem. But, in the case of an uneven balance between countries, which have been indicated in recent reports (Guellec and van Pottelsberghe, 2001; OECD, 2006), this may be a sign that the area deserves further scholarly attention to better understand the causes and effects of this potential unbalance.

One issue that we find relevant to examine is to what extent the decision to collaborate with a foreign firm as the applicant for the patent is a deliberate choice, which means that domestic investors actively pursues the opportunity to collaborate with a foreign applicant for their

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[1] A patent is a set of exclusive rights to an invention for a fixed period of time in exchange for a disclosure of the invention. This means that the owner of the patent has the right to prevent or exclude others from making, using, selling, offering to sell or importing the invention. For a discussion of the strength and weaknesses of using patents as indicator of innovative output, see Griliches (1990).

patent. There is often an implicit assumption that the lion share of domestic inventions that end up in foreign hands is due to cross-border ownership of companies and where inventors is corporate employees and thus has no influence on patent decisions. However, international studies of patent inventors (e.g., Sirilli, 1987) have suggested that the share of independent inventors with no formal affiliations is larger than what is often expected. Comarov (2002), for example, estimated that the number of patents awarded to independent inventors in the USPTO increased by 30% between 1990 and 2000. Also, in recent years we have in Europe seen an increasing amount of patents originating from the public research sector (Geuna and Nesta, 2006). In both of these scenarios, patent inventors have larger degrees of freedom in choosing what to do with and where to place the patent. Therefore, against this background we are interested in finding out the proportion of domestic patent inventors that actively pursues the opportunity to find a foreign firm as the applicant.

In the case where the decision to collaborate with a foreign firm as the applicant for the patent is a deliberate choice, a relevant question is also to examine the motives behind this choice. For example, is it issues related to taxation, lack of competence or other problems in the innovation system that made inventors turn to foreign firms? Or, do personal considerations such as career motives and informal network linkages play an important role in this process? Surprisingly, this is an issue that so far have received very little attention despite its relevance for both theory building and policy making in the area of international cooperation in patenting.

In this paper we are focusing on the Swedish context. To examine the reasons for why Swedish domestically invented patents end up being owned a foreign company we ask the following research questions:

- How common is it that Swedish domestically invented patents have a foreign firm as applicant?
- Who are the inventors behind these patents?
- What are the main reasons for their collaboration with a foreign (non-Swedish) firm as applicant for the patent?

By addressing these questions we believe our paper will contribute to the accumulation of knowledge about why international knowledge transfer takes place and why this is a rising phenomena.

The rest of the paper is structured as follows. In the next section we present a literature review which serves as our point of departure for the following empirical study. Thereafter we describe the overall research design and the data collection process. We continue with a section where we present data for how common is it that patents with a Swedish inventor have a foreign firm as the applicant. Then we present an overview of the profiles for these patent inventors. This section is followed by an overview of the inventors' main reasons for collaborating with a foreign firm as applicant for the patent. Lastly, we conclude with a summary of the main findings.

2. Literature review

International cooperation in patenting is becoming increasingly common. Guellec and van Pottelsberghe (2001) in their study of patent data for example show that there is an increasing trend towards globalisation of technology in the OECD area. Moreover, they observe large cross-country differences where the degree of technological internationalisation is higher in small open economies such as Sweden. In a recent report from the OECD, it is furthermore pointed out that the pattern of technological internationalisation is increasing and that it continues to be uneven between countries (OECD, 2006). Among other things, this increasing trend towards globalisation of technology consequently opens up questions about the profiles and motives of domestic inventors who have a foreign applicant on their patent. By doing so, we can better understand why they collaborate with a foreign applicant and to what extent these inventors actually have an influence on this decision.

However, most academic studies on the issue of international cooperation in patenting have largely focused on the perspective of companies who are exploting and commercializing patents (i.e., Hagedoorn & Schakenraad, 1990; Suarez-Villa & Walrod, 2003; Edler, 2004), while the perspective of the inventors behind the patents has been left largely unexplored. Neglecting this issue has led to that there is very little contemporary knowledge in the scholarly community about the reasons for why inventors located in one country end up cooperating with foreign companies and to what extent these inventors have any influence on this decision. By doing so, we can better understand why domestic inventors collaborate with a foreign applicant and to what extent they actually have an influence on this decision.

The role of inventors in the patent process has generally been overlooked in literature and research on innovation. A review of published articles reporting results from empirical studies of inventors identified only a handful articles dealing with the topic. An overview of the articles can be found in table 1 below.

Table 1: Overview of articles dealing with the role of inventors in the patent process

Authors	**Topic and context**	**Method**
Schmookler (1957)	A study of independent inventors in the US.	Mail survey to a selected number of 122 inventors that applied for a US patent in 1953. 87 usable questionnaires was received (71 % response rate).
MacDonald (1986)	A study of the characteristics and work of Australian independent inventors	Mail survey to independent inventors who had applied for patent protection in 1978. Responses from 601 respondents were analyzed.
Sirilli (1987)	A study of Italian inventors and their inventions.	Mail survey to 7014 Italian inventors who applied for a patent in 1981. 555 usable questionnaires was received (7.9% response rate).
Amesse et al (1991)	A study of the nature of the inventive process among individual inventors in Canada.	Mail survey to 887 inventors to whom Canada had issued patents in 1978 and 1983. 374 usable questionnaires was received (42.2 % response rate).
Dagenais, Séguin-Dulude & Desranleau (1991)	A study of individual Canadian inventor behavior.	Mail survey to Canadian inventors. No information about initial sample. 265 cases are analyzed.
Kassiciieh, Radosevich & Umbarger (1996)	A comparative study of the entrepreneurial environment and the incidence of entrepreneurial spin offs in three large US national laboratories	Mail survey to 213 inventor-employees (49.4%) and 24 entrepreneurs (55.8%) who have previously been inventors at the national laboratories.
Livesay, Lux & Brown (1996)	A study of different types of US inventors and their motivations to invent.	Data collected from small business and independent inventors who participated in the Energy Related Inventions Program (ERIP). Qualitative case studies were conducted on 101 participants. The economic impact of the program was assessed at five points in time by mail and/or telephone surveys. The progress of 442 ERIP technologies was tracked.

Authors	**Topic and context**	**Method**
Markman, Balkin & Baron (2002)	A study of patent inventors and the incidence of new venture formation in the US.	Mail survey to random selection of 586 patent inventors. Sample was obtained from USPTO. 217 questionnaires was received (37% response rate).
Tijseen (2002)	A study of science dependence of technologies in the Netherlands.	Nation-wide mail survey amongst inventors working in the corporate sector and the public research sector. Study is based on a stratified sample of 171 inventors from all Dutch-invented patents on technological inventions filed through international patent offices (EPO, PCT, USPTO) in 1998 and 1999. A total of 93 usable questionnaires was received (55 % response rate).
Meyer (2004)	A study of independent inventors and the public efforts supporting them in protecting and capitalizing on their inventors in Finland.	Multi-case study methodology. 33 cases were selected out a databank of 682 inventors and 967 patent records. Interviews were semi-structured aided by an interview guideline.
Ibrahim & Fallah (2005)	A study of the various sources and forms of knowledge that have influence on the innovation process in the US.	Mail survey to a random sample of 250 inventors in the telecommunications industry who had filed for patents in the past three years. 122 usable questionnaires was received (48.8% response rate).
Giuri et al (2005)	A study of European patent inventors.	Large scale survey to 27531 inventors of European patents granted by EPO between 1993 and 1997, located in France, Germany, Italy, the Netherlands, Spain and the United Kingdom. 9017 responses were returned (32.8% response rate).
Weick & Eakin (2005)	A study of the role of independent inventors in the innovation process in the US.	Electronic survey to independent inventors using “snowball” technique. Two major US inventor organizations mailed their members and encouraged independent inventors to answer the survey. Data from 352 usable questionnaires was received.
Weick & James (2006)	A study of part time and full time US inventors	Mail survey to independent inventors. Interviews were also conducted with successful inventors.

Schmookler (1957) in his classical study of independent inventors in the US challenged the prevailing assumptions of the diminishing role of these inventors. The background of his study was that the inventive activity had gone from being overwhelmingly dominated by independent individuals in the beginning of the 20th century towards more and more taking part in business enterprise. In his study he showed that about 40 % of inventions were not made by technologists or employed inventors, and a respectable part came from non-college graduates. He concluded that the process of transfer of the inventive function from independent to employed corporate inventors was slowing down.

Macdonald (1986) in a study of Australian independent inventors examined their characteristics and whether their work is different from that of formal research units. He report that most inventors were middle-aged, middle-class males with a fairly high level of education. He moreover report that individual inventors work in different areas from corporate research units. Their work is moreover regarded as less professional compared to formal research. However, even if research units have little contact with independent inventors and generally do not consider their work as valuable, they show an interest in their patents and occasionally license from them.

Sirilli (1987) investigated Italian inventors and their inventions. He found that the vast majority of inventors were males. Their average age was 46.5 years and as high as 40% of them were independent inventors not working for a company. The level of formal educational training was fairly high with more than 75% had a diploma or university degree. Moreover, only one third of respondents claimed invention to be their main activity. For the others it represented either one of several activities, or a sporadic or minor activity. About 80% of the inventions relate to products and the rest to processes. The major sectors to which the patent application was related were (in descending order): mechanical engineering, chemicals, electrical-electronic and vehicles.

Amesse et al (1991) studied the characteristics of individual inventors and the fate of their inventions. They report that individual inventors were highly experienced both in terms of technical and commercial knowledge, with educational and income level above average. Educational training was mostly in engineering or applied science and in 46.3% of the cases they were self-employed. The invention process varied widely in its length and cost. Half of inventions were made within a short time and at low cost. About 25% of the inventions require a good deal of time and substantial expenditures. They also reported that about 43% of all inventions were commercialized.

In a study of individual Canadian inventor behavior Dagenais, Séguin-Dulude and Desranleau (1991) found that almost half of all individual inventors did nothing with their invention. Individuals who were self-employed had much higher probability of commercializing their invention. Inventions with more schooling moreover tended to be less innovative, and if it was more innovative the probability of obtaining financial success were much lower. Prior patent experience was moreover positive for the likelihood of commercializing the patent, succeeding financially and making patent agreements or licensing. Non-native Canadians have a much higher financial success rate and were more likely to be involved in successful transactions. Probabilities of financial success are lower for inventions of processes than products. Inventors using patent agents are more likely to commercialize their invention.

Kassiciieh, Radosevich and Umbarger (1996) examined laboratory inventors in three large US national laboratories by measuring their personal characteristics, attitudes, and perceptions of situational variables commonly associated with entrepreneurship. They report that inventor-employees are reluctant to leave their laboratory and start up entrepreneurial spin offs based on their research. Attributes of inventors who have started up spin-offs moreover differ significantly from non-entrepreneurial inventors on the bases of personal characteristics, perceptions of the supportive situation, and attitudes towards entrepreneurship. They conclude that the level of actual support at national laboratories seems to be a key factor in explaining the low incidence of entrepreneurship rather than inventors' own perception of their situation or their attitudes towards entrepreneurship.

Livesay, Lux and Brown (1996) present a study of different types of US inventors and their motivations to invent. They identify five categories of inventors based on their view of success and their corresponding attitudes toward technology, reaching the market and creating a business. Their likely commercial success is in diminishing order as follows: i) entrepreneurs with technology, ii) industry-specific inventors, iii) professional inventors, iv) grantsmen and v) inveterate inventors. In addition, they categorize thirteen different motives underlying the choice to develop technology, which form the basis for a motivational taxonomy.

Markman, Balkin and Baron (2002) report a study of patent inventors and the incidence of new venture formation in the US. Using concepts and theories from cognitive psychology they find that self-efficacy and regretful thinking distinguish inventors who start up their own firms (technological entrepreneurs) from non-entrepreneurial inventors. Technological entrepreneurs have higher self-efficacy (belief in one's own capability). Also, technological entrepreneurs have stronger regrets about business opportunities, while technological non-entrepreneurs have stronger regrets about career and education decisions. However, there was no difference in quantity of regrets.

Tijseen (2002) examine inventors' perspectives of the role of scientific and engineering research in the development process leading to patented inventions. He report several more or less equally influential factors influence knowledge creation and transfer processes leading to successful technical innovations. These include inventors' own capabilities and previous R&D achievements, external information sources, and the general R&D environment. He also finds that citations in patents refereeing to basic research literature were invalid indicators of a technology's science dependence. Moreover, about 20% of private sector innovations were based on public sector research.

Meyer (2004) reported from a study where he examined the experiences of independent inventors in Finland trying to protect, patent and utilize their inventions, with a focus on the extent to which the inventors received public support. He shows that independent inventors are a heterogeneous group of inventors encompassing a variety of types. Different types of inventors and their patents concur with different levels of access to and use of support measures. Access to innovation support does not necessarily coincide with commercialization success. Inventor categories with some success in utilizing patented inventions coincided with little support and advice from public organizations.

Ibrahim and Fallah (2005) in their study of US inventors examine the individual knowledge creation process and explore sources of knowledge that them in coming up with their inventions. They report that the company environment and interaction with co-workers in terms of their tacit knowledge and non-codified explicit knowledge. The influence of collective and individual tacit knowledge was rated higher than the influence of explicit knowledge. Inventors who commercialized their inventions generally rate the influence of knowledge from their organizations as higher than those who did not.

Giuri et al (2005) in their large scale study of inventors in France, Germany, Italy, the Netherlands, Spain and the United Kingdom examine their characteristics, the sources of their patents, the importance of formal and informal collaborations, the motivations to invent, and the actual use and economic value of the patents. They report that 75% of the surveyed inventors have a university degree, while 25% have a PhD degree. Personal and social rewards (like personal satisfaction, prestige, reputation and contribution to the performance of the organization) were more important motives for patenting compared to monetary rewards and career advances. Most patents are the outcome of team activity - only 1/3 of the patents were developed by individual inventors and the vast majority of co-inventors belong to the same organization. Customers were the most important source of knowledge for the patents, followed by other patents and scientific literature. University and research laboratories were ranked as the least important sources. Geographical proximity does not influence probability of collaboration if researchers belong to different organizations. About one third of the patents were not used for specific economic or commercial activities. Half of these were dormant and the rest were blocking patents. The distribution of patent values was moreover skewed and only a few patents yielded any large returns.

Weick and Eakin (2005) examined the role of independent inventors in the innovation process in the US. They report that the inventions of these independent inventors tended towards hardware/tool, household products, industrial/commercial products, novelty items and toys/games/hobbies. About 39% of the respondents generated sales from their inventions and about 20 % profited from them. Inventors who started up a firm to exploit a patent were more likely to achieve higher sales compared to only licensing. However, inventors with a firm who licensed the invention were more likely to achieve higher sales, compared to only commercializing through their own firm or only through licensing.

Weick and James (2006) examined differences between part time and full time inventors. They report that part time and full time inventors are similar in terms of age, gender, educational level and the types of invention they pursue. Sales levels are significantly related to the combination of a full time commitment to inventing and a willingness to invest in patent protection. The transition from part time to full time inventing was driven by unexpected events, a desire to change careers, or preference for working in a more creative atmosphere.

In sum, the identified studies reviewed above have all great merit in contribution to our understanding of the role of inventors in the patent process. However, although giving some reference points for comparisons most of them deal with inventors operating in their national contexts. Hence, much is still unknown about the issue of international collaboration in patenting and the reasons for why domestically invented patents end up being owned a foreign company from the perspective of inventors. It thus seems fair to argue that there is a need for more research that addresses these questions.

3. Data collection

To meet our addressed research questions we collected our data in two major steps. First, we investigated patent data in the European Patent Office (EPO) database. At this stage we identified Swedish domestically invented patents[2] with foreign ownership over the period 1978 to 2005. We also identified its mirror image, i.e., the number of foreign inventions with Swedish ownership. We counted patent applications rather than granted studies as we were interested in the reasons for why Swedish patent inventors' patents seek collaboration with foreign companies. Whether or not they become granted was hence a minor issue for us.

We identified the names and addresses of 553 Swedish inventors who in 2003[3] were reported as inventors where there was a foreign firm reported as applicant. The EPO database provides full names and addresses of inventors and applicants, which made it possible to track both inventors and applicants. This information about names and addresses of the inventors was cross-checked against the official Swedish population register (SPAR) where all people living in Sweden are registered. By using SPAR we were able to check the address was correct, if he or she has moved to a new address, and whether the person was still living in Sweden - thus giving us the opportunity to update the addresses. This effort consequently led to that we could identify the names and addresses of 528 inventors.

The second major step in our data collection was the construction of a questionnaire survey sent to the 528 inventors who were identified in the previous step. The questions were derived from a careful review of previous theoretical and empirical work surveying patent inventors. Before sending out the questionnaire it was pilot tested both on a group of practioners (inventors and people working with patents) and scholars working in the field of innovation studies. Based on this feedback, the questions were honed and clarified for the final research instrument.

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[2] Swedish inventions are in this study treated as inventions made by inventors who in the patent database report a Swedish postal address.

[3] Due to a time lag in the update of the EPO-database this is the last year from where we have reliable data.

The questionnaire was sent out in February 2007, and was addressed to the inventors. After the first send-out we received 37 returned envelopes due to problems of finding the inventor (unknown address). This reduced the total number to 491 inventors. Following the initial mail survey and one postal follow up, 229 usable responses were returned. This corresponds to an effective response rate of approximately 46.6%, which compares favorably to previously published studies of patent inventors reported in international journals (e.g., Sirilli, 1987; Weick and Eakin, 2005).

4. Results

In this section we present the results from our study with respect to the initial research questions that were addressed in the introduction.

4.1 Patents domestically invented in Sweden with a foreign firm as applicant

Our first question was how common it is that patents that are domestically invented in Sweden have a foreign firm as applicant. In Table 1 we present data over the number of EPO-patents where Swedish inventors have been involved between 1978 and 2003. Here we can see that the number of EPO-patents with at least one Swedish inventor have increase steadily during the time period. Similarly, there is an increase in the number of EPO-patents where a foreign firm is listed as the applicant (owner) and where there is at least one Swedish inventor. In 2003 there were in total 2 104 patents with at least one Swedish inventor, and there were 413 patents[4] where a foreign firm was listed as the applicant and where there was at least one Swedish inventor. A list of the sectors to which these 413 patents belong is presented in the appendix, following the classification of Breschi, Lissoni, and Malerba (2002).

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[4] In some cases there were more than one person listed as the inventor, hence giving slightly more inventors than patents.

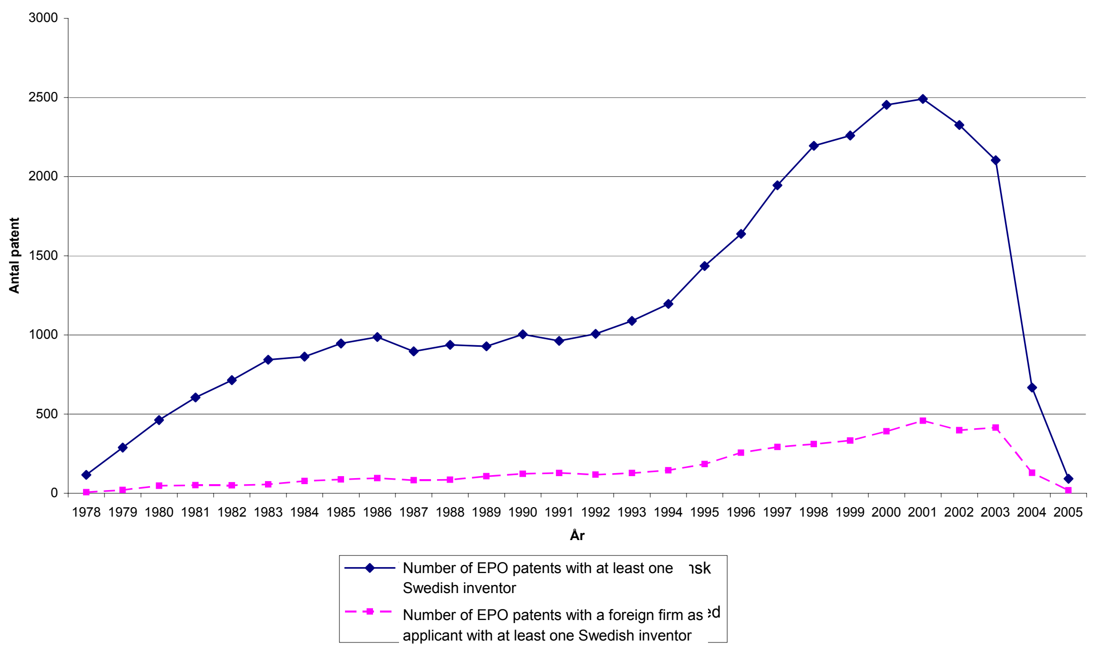

Table 1: EPO data 1978 - 2003

In Table 2 below we present a comparison of international cooperation in patenting activity in Sweden between 1978 and 2003. Here we can see that there since 1997 on average have been more patents with at least one Swedish applicant (owner) and only foreign inventors compared to patents with foreign applicants and with at least one Swedish inventor. In 2003 there were in total 422 patents where there were at least one Swedish applicant and with only foreign inventors, and there were 413 patents with at least one Swedish applicant and only foreign inventors. In sum, in Sweden there seems to be about an equal balance between foreign ownership of domestic inventions and domestic ownership of inventions made abroad.

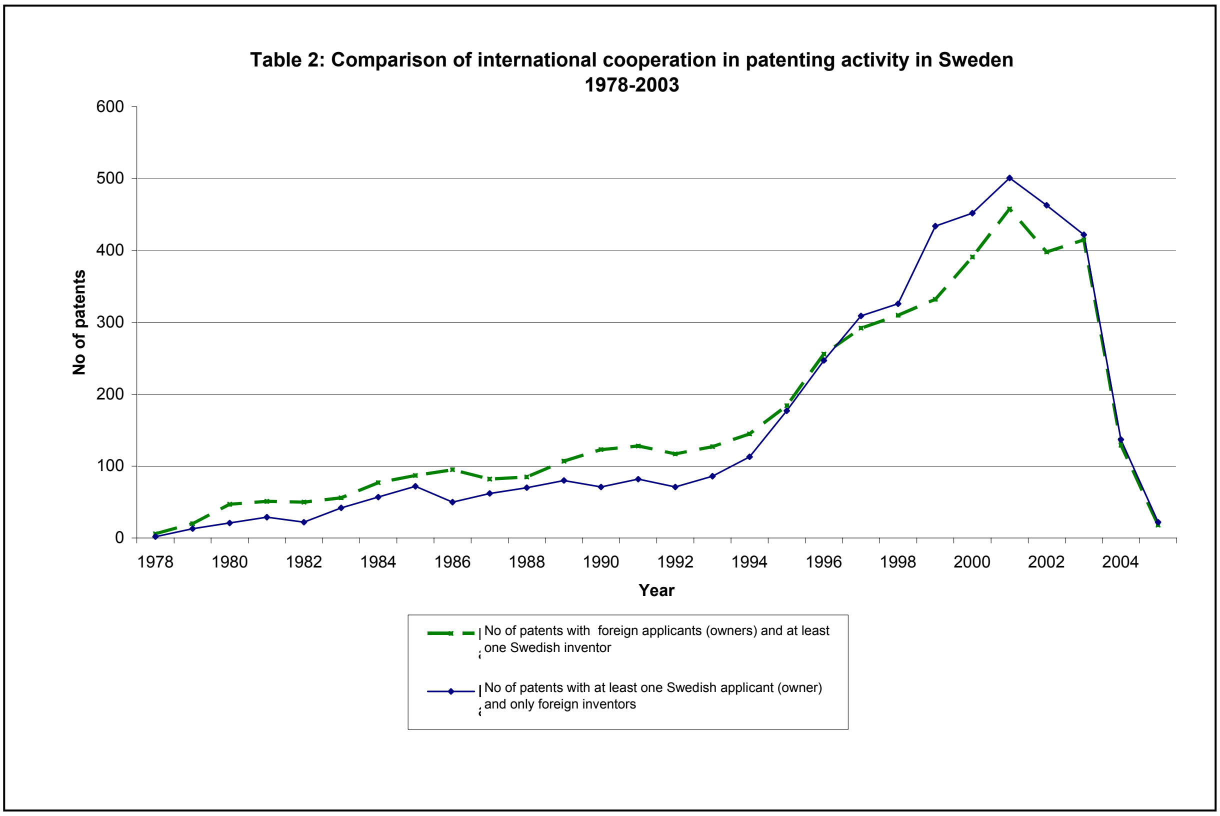

Table 2: Comparison of international cooperation in patenting activity in Sweden 1978-2003

4.2 The inventors behind the patents

Our second research question addressed the issue of who the inventors behind these patents are. This data is based on responses from the 229 inventors who responded to the survey[5]. Table 3 below provides information about their age and patent experience. The data show that most of the respondents are middle aged. Despite different samples and time periods, this corroborates findings in previous studies of inventors which have reported that the typical inventor is in the range between 40-55 years old (MacDonald, 1986; Sirilli, 1987; Amesse, 1991). Many of the inventors are moreover quite experienced inventors with several EPO-patents in their portfolio. Many of them also have also multiple experiences from applying for EPO-patents with foreign firm as applicants.

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[5] We have information about age, geographic location and gender for the total population. This will be used to test for possible non-response biases in the sample.

Table 3: Age and patent experience

	Mean	Min	Max	Std.dev.
Age of respondent	47.8	25	82	10.5
Total number of EPO-patents	5.61	1	75	8.89
Total number of EPO-patents with foreign firm as applicant	3.91	0	40	5.09

Table 4 provides data about the educational level of the respondents. The table shows that the surveyed inventors have a fairly high level of education, with about 85% having experience of university studies and about 1/3 of them having doctoral training. The patent inventors are clearly better educated than the average adult Swedish citizen. The percentage of inventors with university degrees in this study is also fairly high compared to previous studies of patent inventors. Weick and Eikin (2005) in their study of independent patent inventors in the US for example report that about 56% of their respondents having experience of university studies and only 1% having PhDs. Other studies presenting data about the proportion of inventors with university degrees have reported 24.9% (Sirilli, 1987) and 46% (Amesse et al 1991).

Table 4: Educational level

	%
Compulsory school education (7 or 9 years)	0
Gymnasium/senior high school	15.6
University studies, less than 3 years	11.1
University studies, more than 3 years	39.6
Doctoral training	33.8

Moreover, we collected data about the inventors' motivation to invent. Here, inventors were asked to rate to what extent four different reasons were motivating them to be involved in patenting along a five point Likert-like scales (1=low extent, 5=high extent). As can be seen in table 5 below, most inventors state that they are motivated to invent because it is meriting and good for the career and that it gives higher influence in the milieu where they are working. This result is fairly similar to the results reported in Giuri et al. (2005). Possibilities for extra income besides ordinary salary were rated somewhat lower, and the possibility for an increase in their research budget was the least likely motive and rated considerably lower than the other alternatives. This is interesting as it suggest that monetary reasons are seen as fairly low motivators to invent.

Table 5: Motivation to invent

	Mean	Min	Max	Std.dev.
It is meriting and good for the career	3.09	1	5	1.25
It gives possibilities for extra income besides ordinary salary	2.46	1	5	1.35
It gives possibilities for an increase in research budget	1.91	1	5	1.18
It gives influence in the milieu where the inventor is working	3.09	1	5	1.35

With respect to the research questions motivating this study it is of interest to see where the patent inventors were employed when the EPO patent was applied for, as their affiliation has an impact on their ability to influence what to do with the patent[6]. In table 5 below, we can see that the major part of all patent inventors (90.1%) was affiliated with a private firm. Of these was about 6 % reported to collaborate with a university for the specific EPO patent in question, while 84.6% were operating alone. Only about 8.3% were affiliated with a university. The miscellaneous category “other” included inventors who were unemployed or had retired people and thus having no formal affiliation. Please note that the total percentage can be above 100% due to the possibility of cross-affiliations (for example inventors being employed both by a university and a private firm).

Table 6: Employment when EPO patent was applied for

	Percentage
University	8.26%
Private firm	90.1%
Civil service department/public authority	0%
Other	4.1%

4.3 Main reasons for collaboration with a foreign firm

Our third research question addressed the issue of the main reasons for collaboration with a foreign firm as the applicant for the patent. In table 7 below, we can see that about 52% of the respondents were employed inventors where the ownership of the invention belongs to the

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[6] For example, in Sweden academics who are employed by public universities have the full right to their inventions due to the so called ‘teacher’s exemption’.

employer. In these cases the inventor has no influence over decisions related to the patent. In fact, one inventor stated that the only patent he has no influence over is his own, because this was when he had to leave the room. About 37% of the respondents reported that the R&D activities that lead to the patent already from the beginning were ordered by the foreign firm. The remaining respondents (just above 11%) were inventors who had an influence on the decision on collaborating with a foreign firm.

Table 7: Influence on decision to collaborate with foreign firm

	Percentage
Employed inventor, with ownership of the invention belonging to the employer	51.8%
Inventor where the R&D activities that lead to the patent were already from the beginning ordered by a foreign firm	36.7%
Inventor having an influence on the decision (i.e., part of full ownership of the patent)	11.4%

The reasons for collaboration with a foreign firm for the group of inventors who had an influence on this decision are presented in Table 8 below. Here, inventors were asked to rate to what extent different reasons influenced their decision to collaborate with a foreign firm along a five point Likert-like scales (1=low extent, 5=high extent). As can be seen in the table, the most common reasons were that the foreign firm provided better opportunities to commercialize the patent compared to Swedish firms, and that the foreign firm could offer more money for financing development costs compared to Swedish firms. The least common reasons were previous employment in the foreign firm, and to increase the chances for future career opportunities.

Table 8: Reasons for collaboration with foreign firm

	Mean	Min	Max	Std.dev.
Lack of general competence for the technology which the patent is based on in Sweden	2.59	1	5	1.40
There were special competence in the foreign firm that is very hard or impossible to find in Sweden	2.63	1	5	1.46
The foreign firm provide better opportunities to commercialize the patent compared to Swedish firms	3.55	1	5	1.32
By collaborating with a foreign firm there was opportunities to make more money out of the patent	3.05	1	5	1.75
The foreign firm offered more money for the patent compared to Swedish firms	3.11	1	5	1.81

The foreign firm could offer more money for financing development costs compared to Swedish firms	3.48	1	5	1.54
Experience of earlier cooperation with the foreign firm in one or several research projects	2.35	1	5	1.70
Previous employment in the foreign firm	1.11	1	5	0.46
Informal contacts (friends, former colleagues etc.) in the foreign firm	2.66	1	5	1.64
The foreign firm had a better position on the market compared to similar Swedish firms in the area	3.18	1	5	1.65
Increasing the chances for future career opportunities	1.73	1	5	1.19
Increasing the chances for future research collaborations	2.56	1	5	1.61

5. Summary and conclusion

In this paper we have reported descriptive data from an exploratory study examining the reasons behind why Swedish domestically invented patents end up being owned a foreign company. In sum, the study show that international cooperation in patenting is a fast rising phenomenon but also that Sweden has about an equal number of domestic ownership of inventions that has been made abroad as there is foreign ownership of domestic inventions. We have also found that the Swedish inventors behind the foreign-owned patents are relatively experienced, both in terms of a high educational level and a high number of EPO-patents. We also find that a relatively low proportion of these inventors – only about 11% - have any influence on the decision to collaborate with a foreign firm. In most cases this is a decision by the firm where the inventor is employed, and in some other cases it is a result of that the R&D activities which results in the invention on which the patent is based is ordered by the foreign firm. However, in the case where inventors had any influence on the decision, the most common reasons for seeking international collaboration was that the foreign firm provided better opportunities to commercialize the patent compared to Swedish firms, and that the foreign firm could offer more money for financing development costs compared to Swedish firms. Hopefully, future studies will use the exploratory insights presented in this paper in their attempt to further increase our knowledge of international cooperation in patenting.

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Appendix: List of sectors to which the identified patents belong, following the classification of Breschi, Lissoni, and Malerba (2002)

Technology class	**No of patents**
Undefined	2
Electrical engineering	17
Audiovisual technology	9
Telecommunication	19
Information technology.	19
Semiconductors	2
Optics	5
Control technology.	18
Medical technology	33
Organic chem.	25
Polymers	7
Pharmaceutics	27
Biotechnology	21
Materials	10
Food chem.	5
Basic materials chem..	2
Chemical engineering	19
Surface technology	8
Materials processing	33
Thermal processes	3
Environmental technology	8
Machine tools	12
Engines	16
Mechanical elements	9
Handling	25
Food processing	1
Transport	39
Nuclear engineering	0
Space technology	1
Consumer goods	11
Civil engineering	7
Total no of patents:	**413**

R&D, patenting and patent quality in Sweden 1985-2002[1]

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Abstract

We use a comprehensive database covering Swedish industry and service firms 1985-1998, to examine trends in the ratio between patenting and R&D and for patenting quality among 10 sectors which cover almost the entire economy. Quality indices are composed of the indicators forward and backward citations, designated states and opposition. In contrast to earlier studies we find forward citations and opposition to have the highest weight in our indices.

Swedish data indicate no clear trend in patenting patenting/R&D ratios over the period 1985-2002 on the aggregate level. During the same period Swedish R&D has been rising fast. Among low- and medium tech manufactures, chemicals and transport vehicles and equipment R&D levels remain fairly constant. Patenting productivity and associated quality seems to be fairly high, However, quality seems to be lagging somewhat in low- and medium tech industries and transport vehicles and equipment. The fastest rise in R&D in absolute terms is seen in Electrical, electronics and precision equipment. Interestingly, this development is not associated with a loss in patenting productivity nor in patenting quality. There are also strong developments of R&D in services, which comprise telecom services, and also in R&D in engineering, science and medicine. The first signals strong investments of telecommunications services industries in Sweden and the second may be a consequence of outsourcing and developments of supporting knowledge-intensive business services. Patenting remains low, which may reflect that these sectors have less patentable inventions.

Our findings are therefore not supportive of the existence of 'the Swedish paradox'.

Keywords: R&D, patenting, quality-adjustment, Sweden, sectors.

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[1] Paper presented at the EPIP conference held in Lund on September 20-21, 2007. We thank Alfonso Gambardella and Mats Hagnell for useful advice. Copyright of the paper resides with the authors. Submission of a paper grants permission to the EPIP-2007 Conference Scientific and Organizing Committees to include it in the conference material and to place it on relevant websites. Comments are highly appreciated, but since the paper is preliminary we ask readers to cite our paper only after permission.

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1 Introduction

Sweden is one of the most business R&D-intensive countries in the world, but notions of the Swedish paradox question the efficiency of this R&D in generating innovations (Ejermo and Kander, 2007). This paper sheds light on the innovative outcome of Swedish R&D, based on a database of Swedish firms which has been matched with European Patent Office (EPO) patent data by us.

Research productivity as measured by the ratio of patents to R&D (the PR-ratio) has declined sharply in many countries and industries over the last decades. Between 1970 and 1990 the number of patents produced per US scientists and engineers nearly halved, and in Europe the decline has been even more striking (Evenson, 1984, Evenson, 1993). This has motivated attempts to sort out the reasons behind the decline, while maintaining a technological perspective. Lanjouw and Schankerman (2004) present an interesting effort in this direction. They suggest four potential reasons for a decline in the PR-ratio over time:

1) *Declining propensity to patent.* Different sectors protect innovations by various means and patenting is one of many. For instance, many firms in the 1993 Community Innovation Survey report that secrecy is a more important appropriation mechanism than patenting (Arundel, 2001). The PR-ratio in a sector may change over time if the propensity to patent shows a time trend, which could result from rising costs of patenting relative to other protection measures (Cohen et al., 2000).

2) *Decreasing returns to R&D.* Given the neoclassical assumption of decreasing marginal returns, a decline in the PR-ratio can simply be due to a substantial increase in R&D. Such an increase in total R&D has taken place because companies have increased their R&D expenditures in response to increased private returns as markets expand (Klepper, 1996). However it has been demonstrated that this effect is not large enough to explain the entire decline (Evenson, 1993, Kortum, 1993).

3) *Technological exhaustion*. If inventors have already come up with the best ideas, perhaps innovations are in the process of becoming exhausted. This is a very gloomy outlook, which has not been confirmed by econometric estimates of output elasticities of R&D (Hall, 1993a, Hall, 1993b, Griliches, 1994).

4) *Improved patent quality*. In contrast to the technological exhaustion idea, newer patents may be more valuable, since new ideas build upon previous ones. This would suggest that increasing quality of patents may compensate for lower quantity. It is also the explanation that Lanjouw and Schankerman (2004) address. They construct a four component composite index of patent quality for the US 1980-1993 based on

a) Claims: the principle claims of a patent define the essential novel features of the invention
b) Backward citations: number of prior patents cited in the application.
c) Forward citations: all subsequent patents that cite a given patent in their application.
d) Family size: the number of patents protecting the same invention in different countries

In their paper, claims and family size are regarded as the indicators that best show the economic value of the patent, while forward citations and backward citations better show technological diffusion. We obtained data on forward citations (*FCIT*), Backward citations (*BCIT*), Family size or designated states (*DCST*) in the European case, and opposition (*OPPOSITION*), which shows whether the granted patent was 'attacked' in court.

Lanjouw and Schankerman (2004) use a full dataset on patents applied for by US firms in the period 1975-1993, totaling 434 108 patents. For a subset of firms they have data on annual R&D expenditures, sales, capital stocks and market value. Firms and patents are classified following seven technology areas: drugs, biotech, other health, chemicals, computers, electronics and mechanical. They assess to what extent increased patent quality can explain the decline in research productivity (i.e. the PR-ratio) from 1980 to 1993 in the US. The answer partly depends on technology area. In drugs, quality improvement does not compensate for the fall in the PR-ratio. In two sectors quality improvements are important for offsetting the decline in the PR-ratio; in chemicals the decline is reduced from 20% to 7%, in the mechanical field from 40% to 29%. In "other health" and electronics there was no fall in research productivity in the first place, with quality adjustment the PR-ratio actually increases.

The US has experienced a "patent explosion" since 1984 (Kortum and Lerner, 1999, Kortum and Lerner, 2003, Hall, 2005). That research does not explicitly address the development of the PR-ratio, but it seems possible that the declining trend of the PR-ratio might have come to a halt at some point. We study an extended period for Sweden, one that continues beyond 1993.

The "explosion" in US patenting has been concentrated in the electrical, electronics, computing and scientific instruments industries. Patents became more likely to be upheld in litigation, with big penalties for infringers, implying that firms considered patenting more cost-worthy. In addition patents were used for cross-licensing and trading/negotiation with other firms in complex products, and for securing finance for startups (Cohen et al., 2000).

The original studies by Schmookler (1966) and Griliches (1984) assigned patents to industries and firms respectively, but did not assess patent quality. The use of quality adjusters and the validation of these measures is a more recent phenomenon. Most of these studies use indirect validation techniques, e.g. expert appraisal of innovations, and stock market value of patenting companies (Trajtenberg, 1990, Lanjouw et al., 1998, Harhoff et al., 1999, Jaffe and Trajtenberg, 2002, Harhoff et al., 2003, Lanjouw and Schankerman, 2004, Hall et al., 2005, Hall and Trajtenberg, 2005). Trajtenberg (1990) related patents in computed tomography (medical technology) to the estimated social surplus. He found no correlation with raw patents but found that citation-weighed patents were correlated. Harhoff et al. (1999) asked German patent holders to estimate a price at which they would have been willing to sell the patent right, and find correlation between this price and subsequent citations. Questionnaires sent to inventors and managers about the values of individual patents give direct validation, as in Gambardella et al. (2005). For a large sample, Hall et al. (2005) find correlation between the stock market valuation of publicly traded firms and the "patent citations/patent"-ratio over the period 1976-1995.

The paper proceeds as follows. First, we examine trends and trend breaks in patents in relation to R&D at the aggregate level and then use a 10 sector level division. Second, we use quality adjusted patents to examine whether trends are changed by adjusting patents for quality.have been offset by a change in the quality of patents. We investigate the different weight that quality indicators take for different sectors and finally we draw conclusions.

2 Data material

Our database consists of firm level data over the period 1985-2002 of which we use R&D data and sectoral codes in this paper. This data has been compiled by Statistics Sweden for a group of researchers at Lund University (Lundquist et al., 2005, Lundquist et al., 2006).

To this database we have matched on patents from the European Patent Office (EPO). Our indicators of quality, *FCIT, BCIT* and *OPPOSITION* are from a DVD compiled by the OECD and documented in Webb et al. (2005)[3] We added information on *DCST* as our fourth indicator from the webpages of Espacenet. We considered a patent Swedish if one of the inventors had a Swedish address. We had Statistics Sweden and a subcontractor (IRIS) to them helping us with the computerized matching. This work was complemented with time-consuming work by us to manually match names and addresses of applicants with firms in our database. Statistics on this matching is given in Appendix A. We used fractional counting, further described in Appendix A.

We deleted 4,794 Swedish firms owned by individuals which proved virtually impossible to match (5,027 when including also non-Swedish) from our material. This procedure left us with initially 19,082 applications made by Swedish applicants in the 1985-2002 period, whereof 9,549 were granted. Of these applications we managed to match 14,433 applications (76%) to the exact year. However, our matching revealed that we had found matches also with firms not present in our database for the *exact* year. The reason why firm data was missing for certain years rests in sampling, where especially smaller firms may not always be covered before 1996. Since our purpose was to examine sectoral patterns, we apportioned the patent to the sector of the firm from the closest year at hand. This raised our "matching-rate" to 17,453 applications and 11,223 grants, or 91% and 92% for applications and grants respectively as a share of all applications and grants when excluding individuals. Although we regard this result as highly successful, we were concerned that the matching-ratio could differ over the time-period under study. Indeed, our data confirmed that the matching-ratio was much higher in the latter part of the period under study. Among applications, the ratio for which we obtained a sector for patents was 74% in 1985 and 93% in 2002 (95% was obtained for some years). One reason could be that the database contains a much higher share of all existing firms since 1996, but it also seems likely that the reason why we got better matching rates towards the end of the period is because patent registers are continuously updated, whereas firm registers are not. We chose therefore to adjust the patent figures in each sector proportionally to the inverse of the matched ratio for individual years. This means that we

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[3] The version we use was distributed late 2006.

remove the time trends imposed because of differing matching rates, which is crucial for the objective of this paper.

The end-result is a database consisting of most Swedish firms from 1996 onwards, both in industry and services, and all large firms 1985-1995 together with a sample of smaller firms.[4] Only a small fraction of the firms perform any R&D at all, or submit patent applications, and the ratio is much smaller in service sectors than in industry.

There were roughly 5,000 industrial firms in the database per year 1985-1995. From 1996 and onwards the number increased to roughly 35,000, due to a fuller inclusion of smaller firms. Likewise for the service sector the firms increase from roughly 10,000 to around 250,000 between 1995 and 1996. This could pose a major problem for our investigation. However this does not seem to be the case, since only a minor fraction of the smaller firms that were added in 1996 do R&D. Actually, aggregate R&D in industry falls between 1995 and 1996, while there is a small increase in the service sector.

Our material comprises almost all Swedish firms that patent and/or do R&D. Thus, we obtained a high match-ratio and good overall coverage. We were also able to cover a fairly long period of time for such a material (1985-2002). For our quality indicators we choose to use and report data only for the period 1985-1998 since patents granted after 1998 are substantially less cited than earlier ones, which would distort our variable *FCIT*. Our material covers 3,490 individual firms, or an average of 392 per year, that conducts R&D and/or patents. As a comparison, the comprehensive Hall, Jaffe and Trajtenberg database for the US matched patents over a long time-period 1965-1995 but 'only' reached a match-ratio of 50-65% (depending on year). Their material covered an average of 1,700 manufacturing firms per year (or 4,864 in total) using data on firms listed in Compustat. Our R&D data has been deflated by a wage index of civil engineers.

Figure 1 shows aggregated deflated R&D and the ratio between granted patents and R&D ratio among Swedish firms 1985-2002. This graph indicates a different pattern from the experience of the US. Although Swedish R&D has also risen fast, the overall trend in the ratio between granted patents and R&D shows no clear trend.

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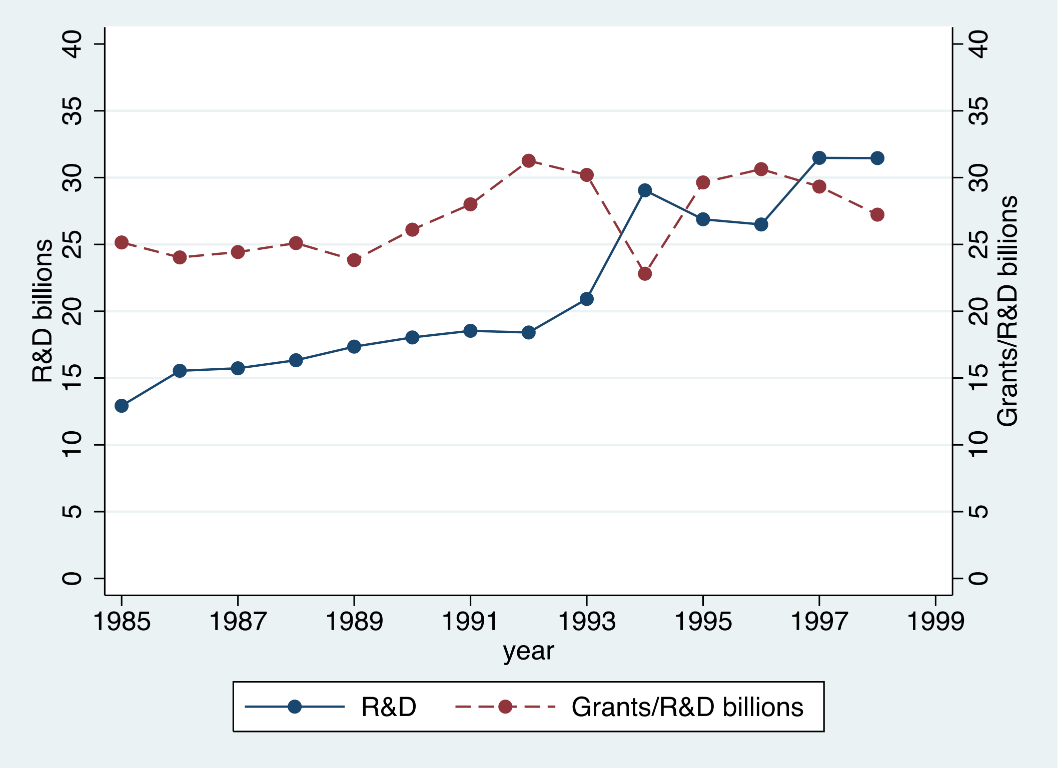
[4] 1985-1995 industrial firms with less than 15 employees and service firms with less than 50 employees are only partially included in the material, but 1996 onwards the coverage of small companies is nearly complete.

Figure 1. R&D in billion SEK deflated to 1985 and granted patents to R&D in billion SEK (right axis).



3 Sectoral division and quality-adjustment of patents

3.1 Sectoral division

We divided our material into rather broad groups. A reason for this is a change in sectoral classification in Sweden from SNI69 to SNI92.[5] Using rather aggregate sectors removes much of comparability problems over time. An additional advantage of this is that problems of arbitrary reclassifications of firms across sectors are reduced. Moreover, finer divisions that we originally used yielded very little R&D and/or patenting for certain sectors. The economy is here composed of 10 sectors. Our logic has been to keep R&D-intensive, i.e. OECD "high-tech" sectors separate from less intensive ones and to keep manufacturing sectors separate from service sectors. The exact division is given in Appendix B. There are 7 sectors in manufacturing and 3 in services. CIRCLE1 consists of low- and medium-technology intensive manufacturing industries and primary sectors. CIRCLE2-CIRCLE7 are high-technology intensive manufacturing sectors. CIRCLE8 consists of low- and medium-technology intensive service sectors, and CIRCLE9-CIRCLE10 are high-technology intensive service sectors.

R&D expenditures need to be deflated to facilitate comparison with patents. Since civil engineers are an important part of the work force in research, we chose to use the wage

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[5] These classifications closely correspond to ISIC rev 2 and ISIC rev 3 respectively.

index for this group as our R&D deflator which was used in Ljungberg (2006). Table 1 provides summary statistics on granted patents and R&D across our 10 sectors. The five highest average patenting rates over 1985-2002 (in increasing order) are found in the groups low- and medium-tech manufacturers, machinery and equipment not elsewhere classified, low- and medium-tech services and in electrical, electronics and precision equipment. Low- and medium-tech groups get high patenting rates not because they are technologically advanced, but because we aggregate many different industries to these groups. Most R&D 1985-2002 is performed by low- and medium-tech manufacturers, pharmaceutical related products, machinery and equipment n.e.c., pharmaceutical related products, transport vehicles and equipment and in electrical, electronics and precision equipment.

3.2 The quality of Swedish patents

As describe above we compose quality indices on our patent data based on *FCIT*, *BCIT*, *DCST* and *OPPOSITION*. The method follows that of Lanjouw and Schankerman (2004), Gambardella, et al. (2005) and Mariani and Romanelli (2006). There are time trends in our indicators, from which it is not clear whether they represent actual quality changes. In addition, the quality indicators are likely to be influenced by the share of patents in different technologies. To remove these effects we first regress the log of our indicators on yearly time dummies and dummies representing the technologies patents belong to[6]:

$$y_{ki} = \sum_j \beta_j x_{ji} + u_{ki}, \tag{1}$$

where i referes to the ith observation, y_{ki} is the kth indicator in logs.[7] The residuals of the four indicators, u_{ki}, are used to form a component according to:

$$u_{ki} = \lambda_k q_i + \varepsilon_{ki}, \tag{2}$$

where q_i is the component normalized to have unit mean and zero variance, λ_k are loading factors. The covariance matrix of the residuals u_k is written:

$$\Lambda = E[yy'] = \lambda\lambda' + \Phi \tag{3}$$

The matrix Φ represents the covariance between the ε terms. It is assumed diagonal. The common component is estimated by iterated maximum likelihood which involves estimating the parameters λ_k and σ_k^2 that makes the theoretical covariance matrix as closely as possible resemble the observed correlation structure.

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[6] There are 30 technology dummies based on the technology classification originally developed by HINZE, S., REISS, T. & SCHMOCH, U. (1997) Statistical Analysis on the Distance Between Fields of Technology. Fraunhofer-Institute Systems and Innovation Research (ISI): Karlsruhe.

[7] We have zero values among our indicators and therefore used the transformation (1+log $y_{ki} = (1 + \log Y_{ki})$) for the kth indicator.

From estimation of (1) it is found that year and time dummies are each always jointly significant respectively, thus validating their inclusion.

Table 1. Our division of the material into sectors and R&D in patenting in those sectors (after adjustment – see section 3 for details).

No.	Tech. level (L=low, M=medium, H=high), manufacturing (M)/service (S)	Short description of main industries	Sum patent grants (after adjustment) 1985-2002				Sum R&D (deflated), billion SEK 1985-2002			
			Min	Avg	Max	SD	Min	Avg	Max	SD
1	L&M, M	See Appendix B	25,0	78,0	128,5	30,5	1,4	2,2	3,2	0,5
2	H, M	Pulp, paper and paper products	4,0	24,2	42,5	11,1	0,5	0,9	1,4	0,3
3	H, M	Chemical products (excl pharma)	1,0	19,3	25,2	5,8	0,4	0,8	1,8	0,4
4	H, M	Pharmaceutical related products	10,0	27,0	63,5	14,5	1,4	6,1	13,7	4,5
5	H, M	Machinery and equipment n.e.c.	30,0	95,8	128,0	22,3	1,4	3,9	8,7	1,7
6	H, M	Electrical, electronics and precision equipment	37,0	140,8	261,0	77,0	3,3	17,9	44,1	14,2
7	H, M	Transport vehicles and equipment	15,0	45,9	88,5	23,2	3,6	9,7	27,0	5,6
8	L&M, S	See Appendix B	15,0	101,3	157,3	38,6	0,3	1,6	4,8	1,3
9	H, S	Service communication	0,0	11,9	36,0	12,4	0,0	1,9	4,7	1,8
10	H, S	R&D in science, engineering, and medicine	13,0	31,0	61,5	12,0	0,0	1,8	4,8	1,6

The quality component is given by:

$$E[\mathbf{q} \mid \mathbf{y}] = \boldsymbol{\lambda}'\boldsymbol{\Lambda}^{-1}\boldsymbol{\lambda} \tag{4}$$

Since we have logged our indicators, we took the antilog of the above calculated values to form our quality indices. This is necessary since we would otherwise sum negative quality values when examining time trends.

Table 2 shows the correlation matrix of the residuals obtained from the quality indicators pooling all patent data.

Table 2. Correlation matrix of residuals from quality indicators.

	FCIT	*BCIT*	*DCST*	*OPPOSITION*
FCIT	1			
BCIT	0.0470	1		
DCST	0.0735	0.0140	1	
OPPOSITION	0.0956	0.0081	0.0333	1

The results of the one factor model for the pooled model and the individual sectors are presented in Table 3. The one factor model could not be estimated for the groups 2: Pulp, paper and paper products nor 4: Pharmaceutical related products, since Heywood solutions or boundary solutions were obtained. In those cases, factor loadings for *OPPOSITION* and *BCIT* was 1 and there were negative factor loadings for other variables. We therefore chose not to present results for those sectors. From Table 3 we also find negative loadings on the variable *DCST* for sector 10: "Research within science, engineering, and medicine". These results are inconsistent with our theory that all indicators are positively related to the common factor. Since the results are not formally wrong we include them for completeness, but ask the reader to gauge those results with caution.

Normally a χ^2 test is done to test the suitability of the estimated model, but that test is best suited to samples of 75-200 observations; for our larger samples, the χ^2 test has too strong power. Instead, the row RMSEA(2) displays the results of Root Mean Square Error Approximation tests, which is a test on the suitability of the estimated model which can be used for larger samples (Bollen and Long, 1993). This test is written:

$$RMSEA = \sqrt{(\chi^2 / df - 1)/(n-1)}, \tag{5}$$

where χ^2 is the "normal" test statistic of the restricted vs. the unrestricted model. RMSEA(2) tests the restrictions of the one factor model. Values below 0.05 are considered as non-rejections. For the pooled sample and all sectors this test does not reject the one factor model. For sectors 9 and 10 the standard χ^2 test had to be used, since the RMSEA(2) statistic is not defined, but the model is also not rejected here. More formally, given that our covariance matrix has $K(K+1)/2$ elements and there are

$2K$ parameters to be estimated, we have $K(K-3)/2$ overidentifying restrictions. Our tests imply that those restrictions are never rejected for the one factor model.

Table 3. Factor loadings in the one factor model, pooled and across sectors.

Logged variables	Pooled	1	3	5	6	7	8	9	10
FCIT	0.6260	0.1961	0.9484	0.8944	0.4612	0.3802	0.4961	0.4597	0.2544
BCIT	0.1141	0.1599	0.1405	0.0874	0.1541	0.153	0.1811	0.2298	0.782
DCST	0.1257	0.3164	0.1634	0.0416	0.2319	0.1544	0.1719	0.4327	-0.0896
OPPOSITION	0.1601	0.1149	0.2112	0.0825	0.161	0.3191	0.2562	0.0946	0.1226
Observations	12,387	1,871	599	2,417	3,324	947	1,499	188	404
RMSEA(2)	0.0168	0.0073	0.0306	0.0402	0.0468	0.0377	0.0194	-	-
$\chi^2(2)$ p-value	-	-	-	-	-	-	-	0.43 (0.81)	1.77 (0.41)

Table 4. Percentage weights of indicators in the one factor model, pooled and across sectors.

Logged variables	Pooled	1	3	5	6	7	8	9	10
FCIT	72%	24%	95%	95%	51%	40%	51%	40%	12%
BCIT	8%	20%	1%	2%	14%	14%	14%	17%	87%
DCST	9%	42%	2%	1%	21%	14%	14%	37%	-4%
OPPOSITION	11%	14%	2%	2%	14%	32%	21%	7%	5%

3.3 Weights of different indicators

The weight vector for the contributing indicators can be calculated as:

$$\mathbf{w} = \boldsymbol{\Lambda}^{-1}\boldsymbol{\lambda}/\boldsymbol{\iota}'\boldsymbol{\Lambda}^{-1}\boldsymbol{\lambda}, \tag{6}$$

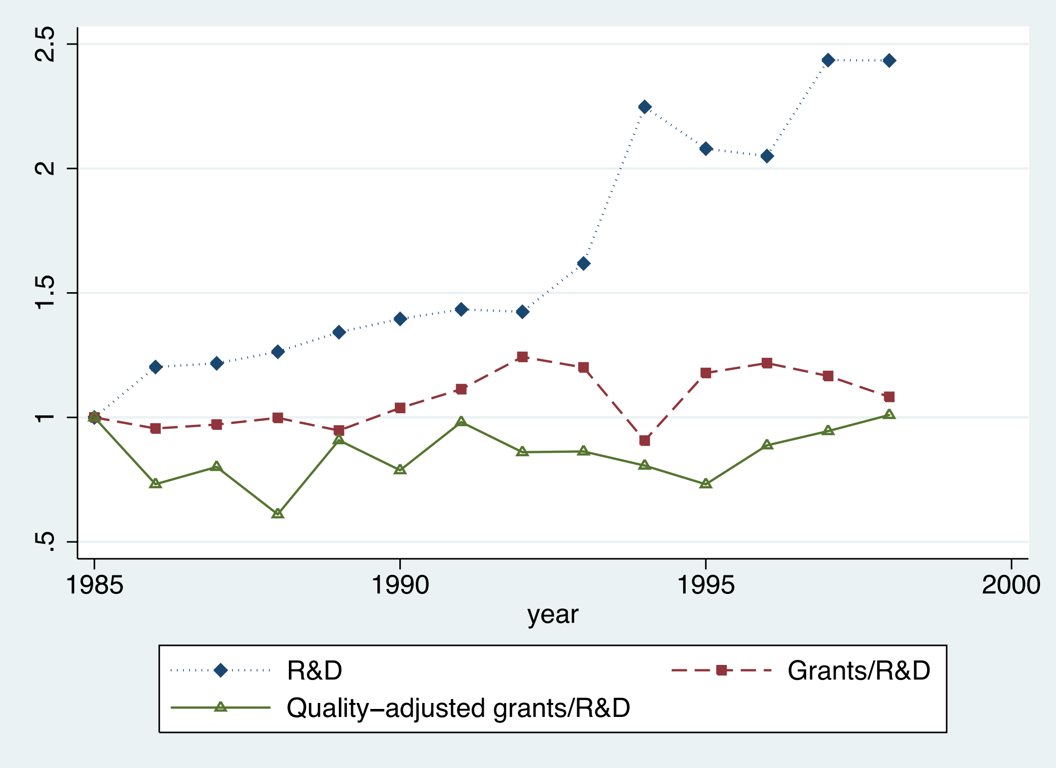
where $\boldsymbol{\iota}$ is a unit vector. The weights are thus expressed as their contribution as a share of all contributing indicators. Table 4 shows the calculated weights. For the pooled sample, *FCIT* has the highest weight or 72 % and opposition has the second largest. *FCIT* has the highest weight on the index in all sectors except "low- and medium tech manufacturing sectors" and "Research within science, engineering, and medicine".

Intuitively, we would think that *FCIT* and *OPPOSITION* would be best correlated with value, and the literature seems to confirm this see e.g. (Harhoff et al., 2003). This stands in contrast to the results of Lanjouw and Schankerman (2004). Instead of our *OPPOSITION* they use the *CLAIMS* indicator. *CLAIMS* get their highest weights for 7 of 8 technologies. A major difference between the two studies is that we use EPO data while Lanjouw and Schankerman (2004) uses USPTO data. It has been shown that US patents tend to cite many more patents than European ones (Michel and Bettels, 2001). Therefore, while US forward citations may be indicative of value and prior knowledge (Jaffe et al., 2000) they are more noisy. It seems likely that the forward citations reported here are more indicative of quality, which could explain their higher weight in the indices.

3.4 Development of quality over time

Figure 2-Figure 10 show the development of R&D, grants to R&D ratios and estimated quality-adjusted grants to R&D ratios in our sectors. Figure 2 reveals that R&D in Sweden has been rising 2.5 times the level of 1985. Patenting has also risen by roughly the same proportion, making the ratio stay more or less constant. Quality-adjusted granted patents seemed to have a shaky development through the period up and until 1995, after which quality has picked up to reach the levels of 1985 again by 1998.

Figure 2. Pooled sample, R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.



For low- and medium tech manufacturing industries (Figure 3), patenting productivity in terms of number of patents produced exceeds that of R&D. R&D levels are roughly constant throughout the period, but patenting and, especially its quality has risen dramatically. This seems to corroborate earlier findings that firms with low R&D levels have generally higher productivity in terms of patenting. R&D-intensive industries often conduct more process-oriented research which is not always patentable.

Chemical industries (except pharmaceuticals) have had quite an erratic pattern. While R&D levels stay on roughly the same level, patent grants and especially quality displays hikes in 1988 and 1997. There are substantial drops in quality from 1990 to 1991 and 1997 to 1998. Machinery and equipment n.e.c. a quite even development. R&D levels seem to be slowly rising throughout the period to a level roughly double that of the 1985 level. Patenting levels are roughly constant at 1 or slightly lower as a share of R&D. The same goes for quality, with exception for a strong peak in 1991, which seems to be indicative of a 'technological hit'.[8] In electrical, electronics and precision equipment we find traces of the Swedish ICT boom: R&D levels have risen 4-5 times its 1985 level. At the same time patenting has also exploded, so that the patenting to R&D levels remain roughly on par. Quality levels follow patenting levels very closely.

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[8] We plan to investigate this phenomenon more closely.

Figure 3. Low- and Medium-technology-intensive manufacturing sectors. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.

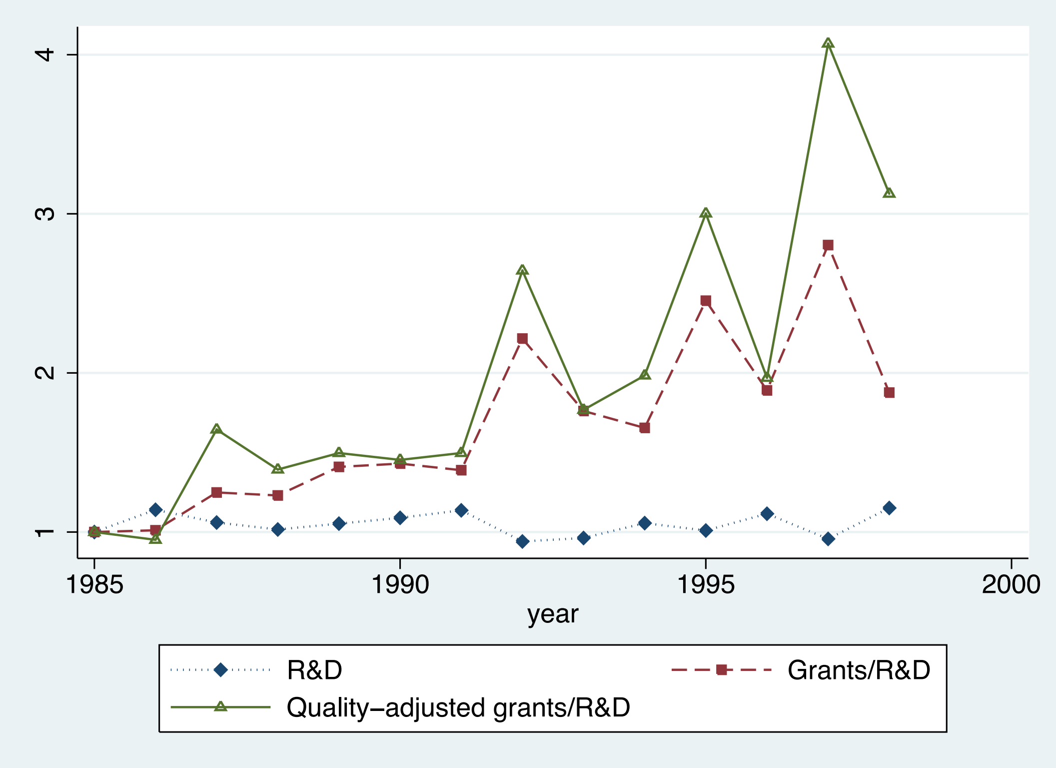


Figure 4. Chemical products. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.

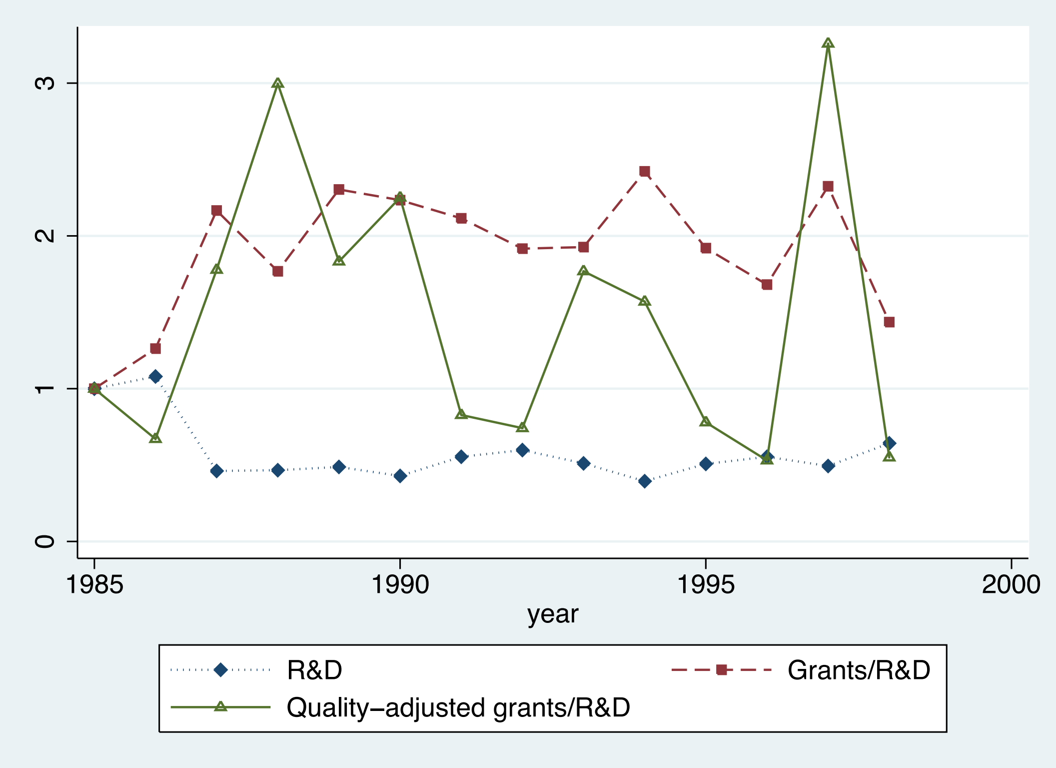


Figure 5. Machinery and equipment n.e.c.. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.

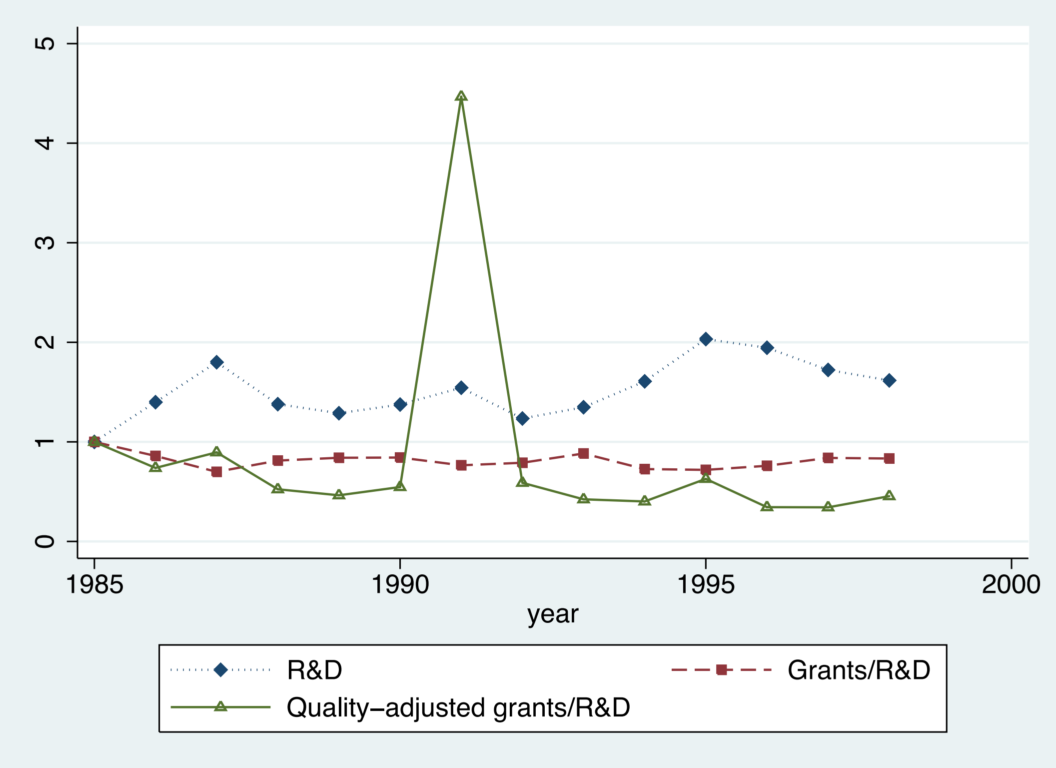
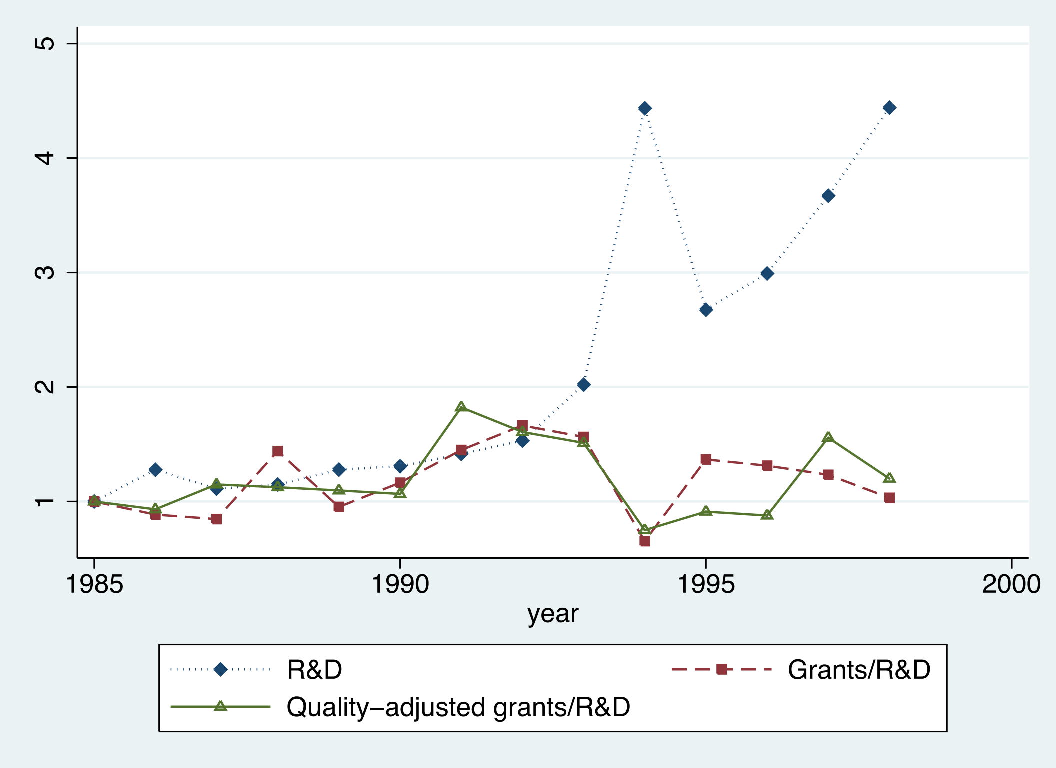
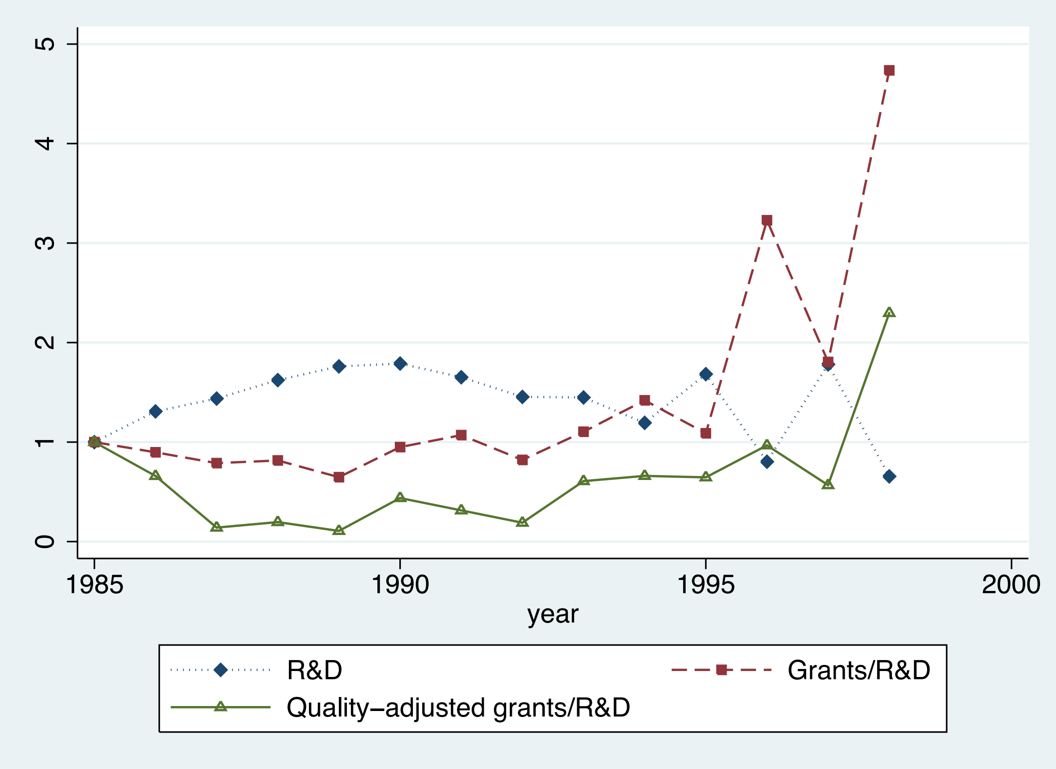


Figure 6. Electrical, electronics and precision equipment. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.



In transport vehicles and equipment, a second major Swedish production area, R&D levels rise somewhat from 1985 to 1990, with a secular and somewhat erratic falling trend from 1990 to 1998. Patenting rises dramatically from 1995 to 1998, but quality seems to be lagging behind.

Figure 7. Transport vehicles and equipment. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.



Low- and medium tech services display what seems like highly disordered data. R&D levels seem to have been rising quite a bit to about 2.5 times its 1985 levels. The grant to R&D and quality to R&D ratios have highly fluctuating developments from half its 1985 levels to twice its 1985 level. Service communications include telecommunications services, and here we find a second sign of the Swedish ICT boom. R&D levels have been rising firmly to more than 80 times its 1985 level. At the same time patenting and associated quality has remained stable.

Even more extreme are developments in the sector R&D in science, engineering and medicine. R&D levels were very low in the mid 80's before rising rapidly. From 1988 to 1990 the rise was about 500 times and levels were rising four times that level by 1998. Patenting and quality, on the other hand, remains the lowest of our investigated sectors. We think that the developments here may arise due to the development of business services and outsourcing of R&D from larger companies to smaller ones and start-up of R&D-intensive firms supportive of developments in major companies mainly in telecommunications.[9]

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[9] This would need further research to be corroborated.

Figure 8. Low- and Medium-technology-intensive service sectors. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.

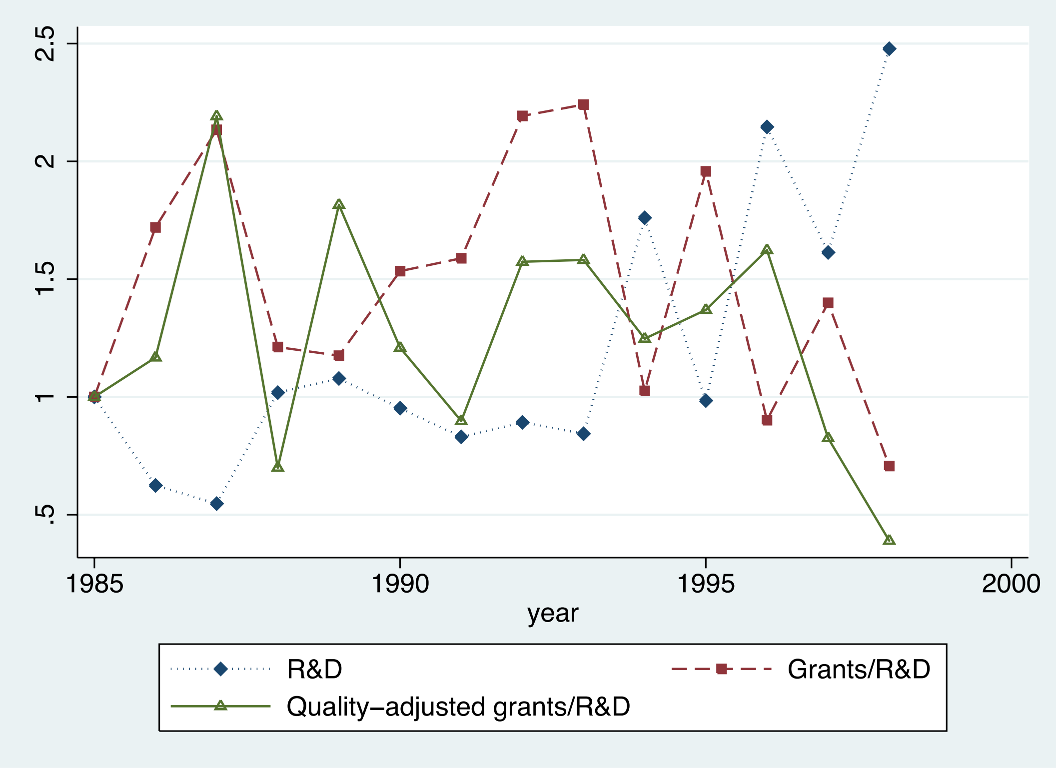


Figure 9. Service communication. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.

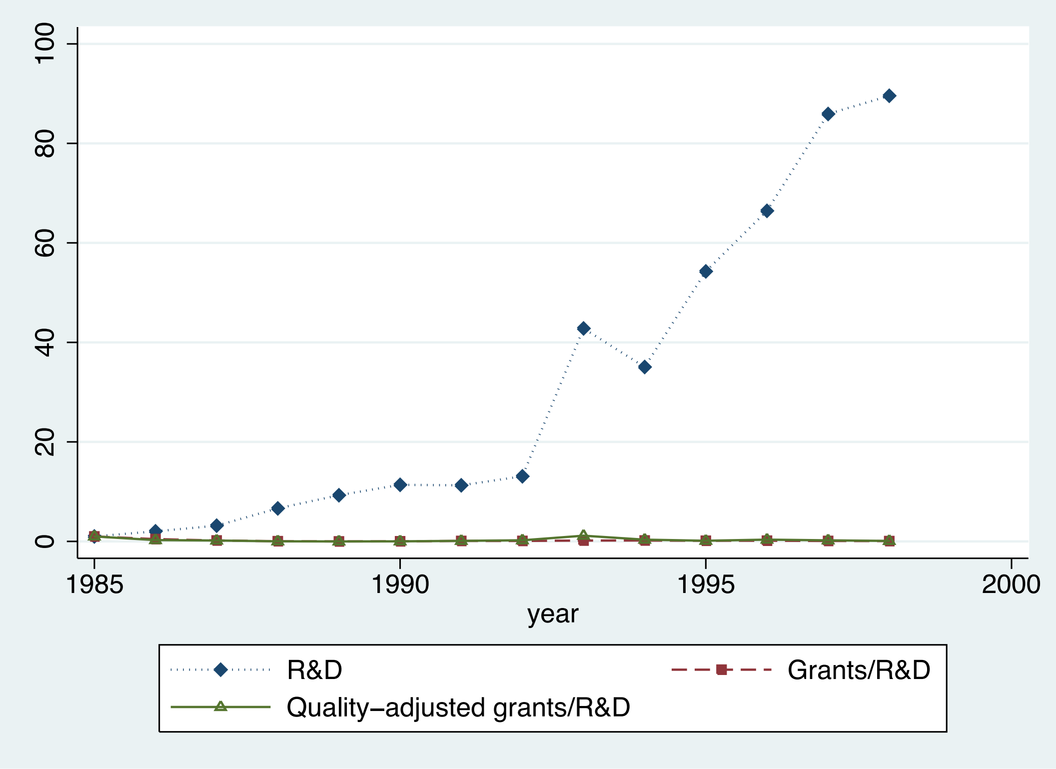
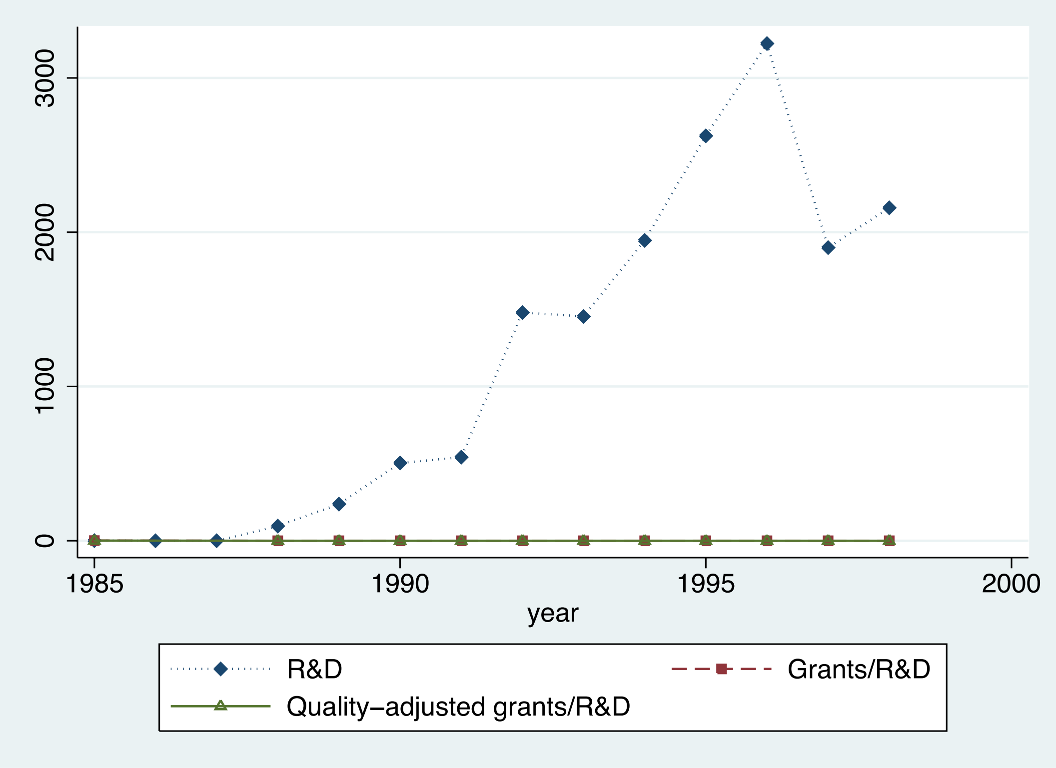


Figure 10. R&D in science, engineering, and medicine. R&D, grants/R&D and quality-adjusted grants/R&D. Index 1985=1.



4 Conclusions

This paper relies on a new database covering the entire Swedish economy at the firm level 1985-2002, with data on R&D and patents with quality information used in this paper. The research questions are: 1) Whether patents/R&D ratios decline in the longer perspective, and 2) If patents become more or less valuable over time. The results are partly similar and partly different to the results based on US data (Lanjouw and Schankerman, 2004, Hall et al., 2005).

In contrast to the US, in the aggregate Swedish data indicate no trend in patenting patenting/R&D ratios over the period 1985-2002 on the aggregate level. During the same period Swedish R&D has been rising fast. On the sectoral level, low- and medium tech manufactures, chemicals and transport vehicles and equipment are industries where R&D levels remain fairly constant. Patenting productivity and associated quality seems to be fairly high, however, although quality seems to be lagging somewhat in low- and mediumtech industries and transport vehicles and equipment. The fastest rise in R&D in absolute terms is seen in Electrical, electronics and precision equipment. Interestingly, this development is not associated with a loss in patenting productivity nor in patenting quality. This suggests that developments here may be of a lasting character. Another striking finding are the strong developments of R&D in services, which comprise telecom services, and also in R&D in engineering, science and medicine. The first signals strong investments of telecommunications services industries in Sweden and the second may be a consequence of outsourcing and developments of supporting knowledge-intensive business services. Patenting remains low, which may reflect that these sectors have less patentable inventions.

A methodologically relevant result is that for our quality indicators, we find that forward citations plays a dominant role with opposition being second. This is in contrast to the quality indicators of Lanjouw and Schankerman (2004) who finds that number of claims is the most important quality indicator. We think this has to do with differences in use of patent data (USPTO vs. EPO).

Appendix A: Statistics on matched patent applications

We did not count number of patent applications, but rather patent application *fractions*. Among the *applicants* of a patent, there may be non-Swedish ones. Moreover, we found that many applicants were actually individuals and not firms. Among the fractions, individuals were never counted as actual contributor to a patent, since we consider only patents matched to firms. In addition, non-Swedish applicants were excluded, but they were included among the total number of applicants for the purpose of counting fractions, unless they were individuals. For example: Patent A has five applicants, two Swedish individuals, two Swedish companies, one Danish individual and one Danish company. Exclusion of all individuals leaves us with three applicants to the patent, whereof Swedish firms are given 2/3 of the patent.

Appendix B: Sectoral division to CIRCLE10

CIRCLE 1: Low- and Medium-technology-intensive manufacturing sectors (LM) and in addition primary sectors.

Agriculture, forestry, hunting and fishing, extraction, mining and quarrying of natural resources (gas, oil, minerals, peat etc.), food products, beverage and tobacco industry, textiles, clothing and leather, wood, cork, wood products, publishing, printing and reproduction of recorded media, industries for coke and petroleum products, rubber and plastics products, other non-metallic mineral products, basic metals, fabricated metal products, building and repairing of ships and boats

CIRCLE 2: High-technology intensive in manufacturing (HM); "Pulp, paper and paper products"

CIRCLE 3: High-technology intensive in manufacturing (HM); "Chemical products"

CIRCLE 4: High-technology intensive in manufacturing (HM); "Pharmaceutical related products"

CIRCLE 5: High-technology intensive in manufacturing (HM); "Machinery and equipment n.e.c."

CIRCLE 6: High-technology intensive in manufacturing (HM); “Electrical and electronic equipment, and precision equipment”

Office machinery and computers, electrical machinery and apparatus n.e.c., radio, television and communication equipment and apparatus, precision, medical and optical instruments

CIRCLE 7: High-technology intensive in manufacturing (HM); “Transport means”

Motor vehicles, trailers and semi-trailers, railroad equipment and transport equipment, n.e.c., aircraft and spacecraft

CIRCLE 8: Low- and Medium-technology-intensive service sectors (LMS)

Manufacture of furniture; manufacturing n.e.c.; recycling, rental of machinery and leasing, financial and legal services, technical consultants, commercial/advertising, organizational and design consultants, wholesale - production oriented, management of real estate, security, sales of food products, tobacco and beverages; department stores and warehouses, consumer durables, wholesale - consumer oriented, recreation and cultural services, other personal services, education, research in social sciences and humanities, healthcare, other social activities (daycare, criminals, etc.), public administration, police, defence, banking and insurance, restaurants and hotels, activities of membership organizations, embassies and international organizations, cleaning; sewage and refuse disposal, sanitation and similar activities, sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel, electricity, gas, steam and water, construction

CIRCLE 9: High-technology intensive in services (HS); “Service communication”

Data and IT services; communication incl. transportation, postal services, telecommunication

CIRCLE 10: High-technology intensive services (HS); “Research within science, engineering, and medicine”

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Does IPR protection affect high growth entrepreneurship? A cross-country empirical examination

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August 31, 2007
Working draft‡

Abstract

The objective of this paper is to determine whether a country's level of intellectual property rights (IPR) protection influences high expectation entrepreneurship. Based on the Baumol's assumption that entrepreneurs, as an allocatable resource, can be reallocated from one domain to another by changing the relative profit prospects offered by the available economic activity alternative, we examine whether and how IPR protection affects the local entrepreneurship prevalence. Using a new entrepreneurship dataset from the Global Entrepreneurship Monitor (GEM), we undertake cross-country empirical investigation to answer the following questions: (i) does IPR protection affect the expectations of high growth entrepreneurship level; and (ii) whether a change in IPR protection affects developing and developed countries differently. We find few interesting results in the differences of IPR impact on developed versus developing countries. Further examination is required.

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‡We are grateful to Heiko Bergmann from the University of St. Gallen, Switzerland, for providing us with the Global Entrepreneurship Monitor data on high expectation entrepreneurship. We would also like to thank the participants of The Economics of Technology Policy held at Monte Verità, Switzerland on June 17-22, 2007, particularly Manuel Trajentenberg for his valuable comments and feedback on an earlier version of this paper.

1 Introduction

How does intellectual property rights (IPR) protection affect local economies? Given the impending deadline for the implementation of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) by the year 2016, scrutiny of the effects of this global IPR protection system is required. This harmonized minimum IPR protection standard, in addition to the various World Trade Organization (WTO) agreements, narrows the policy space for governments in developing countries to build and develop their own capacities for innovation along similar lines of developed countries. We undertake to study the impact of IPR protection on local entrepreneurial activities to improve our understanding of how this policy will affect developing countries and their innovative activities We attempt to show that TRIPS is an institutional factor that impacts local entrepreneurial activities, according to their levels of economic development.

Examining how IPR system affects entrepreneurial activities is not a new research question. Direct empirical relationship between IPR protection and entrepreneurial activity has not been established particularly due to the difficulty of attributing the exploitation of entrepreneurial activities to the strengthened property rights (Shane, 2003). Using a new entrepreneurship dataset from the Global Entrepreneurship Monitor (GEM), we run cross-country empirical investigation to answer the following questions: i) does IPR protection affect local entrepreneurial activities; and ii) whether this impact varies across levels of economic development. Our study is timely because the cutoff date for TRIPS implmentation allows us to carry out a natural experiment to examine the impact of IPR protection, especially on developing and least developed countries (LDCs).

This paper is divided into 5 parts. In the following section we set the foundation for our investigation, briefly recalling the objective of TRIPS and its economic arguments and expounding on the theories of Baumol on the allocatability of entrepreneurs across economic activities. The third section provides information on the data collected for the empirical study and discusses specific aspects of the data. The penultimate section discloses, analyses and discusses the results of the empirical study. And finally the last section concludes with a brief summary of the paper.

2 TRIPS and its impact on entrepreneurship

In this section we build our case for pursuing our research question. First, we provide a brief outline of the TRIPS agreement as well as the current discussion on global IPR protection. We then utilize Baumol's proposition that entrepreneurs can be allocated across economic activities by changing the reward structure to show how TRIPS can impact countries of differing levels of economic development. Finally, we set forth the propositions to carry out our empirical investigation.

2.1 TRIPS: global IPR protection regime

TRIPS was part of the Uruguay Round of negotiations' single package agreement signed in 1994 by members of the then-GATT (General Agreement on Tariffs and Trade) organization.[1] It is an internationally binding agreement that sets out minimum standards for the granting and protection of IPR in areas such as copyrights, trademarks and patents. The agreement contains certain margin of flexibility for member countries to implement its provisions smoothly in line with their own legal system and practice (TRIPS, Art. 1.1) and according to certain transitional arrangements (TRIPS, Art. 65). In general member countries are obliged to implement the agreement in its entirety one year after the date of entry into force of WTO agreements. However, developing countries are allocated an additional four years[2] to implement them, and in countries which has to introduce product patent protection in technological areas not in existence before, such as pharmaceutical products, an additional five years is applicable. During the Doha Ministerial, WTO extended this transitional arrangement for least-developed countries until 2013.[3] Unlike the international agreements administered by the World Intellectual Property Organization (WIPO)[4], TRIPS agreement is enforceable through the WTO's effective dispute settlement body (DSB). The most recent case between developed and developing countries to be brought to the DSB is the United States complaint against China's deficient IPR protection regime.

Global IPR protection is a highly controversial matter. For one, it has not been clearly established whether IPR has played a crucial role in economic development, even in countries with long traditions of IPR protection (Granstrand, 1999). Rather, historical examinations of economic growth in those countries show that IPR protection were strengthened and weakened according to national interests and needs (Khan, 2002; Granstrand, 1999).

Secondly, developing countries tend to be technologically dependent (see the comparison table of patent application fillings between residents and non-residents in LDCs). Global IPR system could exacerbate fundamental asymmetry between countries with few or no innovative capacities and those innovating at the technological frontier. Adoption of stronger IPR pro-

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[1] The Marrakesh agreement stipulated that the GATT organization would be replaced by the World Trade Organization, and that all the agreements negotiated during the Uruguay Round of negotiations would be administered by the WTO.

[2] Except for obligations regarding the WTO's national- and most-favored nation treatments, in which case the initial one year deadline is applicable.

[3] Compliance with pharmaceutical patenting was also extended to 2016.

[4] WIPO succeeded the United International Bureaux for the Protection of Intellectual Property (BIRPI).

tection in developing countries would make it more costly and difficult to access knowledge in vital areas such as health and education sectors, and/or to catch-up with the world's technological frontier as countries like Hong Kong, Singapore, South Korea and Taiwan have done. These countries have managed to catch-up with the world's technological frontier by adopting a "soft" IPR regime, which enabled them to adopt, adapt and assimilate technologies from developed nations (Kumar, 2002).

Year	Non-resident patent application	Resident patent application
1995	172	73
1996	195 116	27
1997	261 141	6
1998	449 616	70
1999	570 676	18
2000	978 409	18
2001	1 352 635	23
2002	1 753 699	6

Table 1: Patent application by residents and non-residents in LDC (Source: WIPO, 2006)

Finally, it is not clear if extending IPR protection globally would increases society's welfare. In their theoretical analysis of examining the welfare implications of global IPR protection, Deardoff (1992), Grossman and Lai (2002), and Chin and Grossman (1990) argue that the gains from adopting global IPR regime would accrue only to inventing countries at the expense of the world. Stylized facts also raise questions as to whether the implementation of IPR regime globally would be beneficial. Developed countries, or countries innovating at the technological frontier, would gain from extended IPR protection in form of increased market for their innovations. However, the benefit for developing countries would vary according to several factors, notably their innovation capacity framework. The World Bank (2001) point out that: (1) LDCs usually do not have resources to devote to innovative activity and thus existence of any IPR regime is unlikely to benefit local innovation; (2) developing countries with some technological capabilities tend engage in adaptive innovation through reverse engineering; and (3) developing countries with more sophisticated technology capabilities gravitate toward higher IPR protection levels. Thus, while historical evidence show that the existence of IPR regime tended to reflect the nation's current national innovative capacities and capabilities will no longer hold true under the TRIPS regime and the effects of this regime is uncler. Other factors such as openness, market size, and macroeconomic policies also play a crucial role in determining how IPR affects the countries in question (Correa, 2000; Bank, 2001). Furthermore it seems that IPR only enhances countries' welfare for some sectors, some innovations and under certain circumstances (Ferrantino, 1993; Helpman, 1993; Lall, 2003; Falvey et al., 2006).

Nevertheless, some gains are attributable to global IPR protection for countries. Inventing countries would be able to recoup their investments in research and development, and welfare increasing innovative activities could be stimulated. The table below outlines the static and dynamic costs and benefits for a given country resulting from stronger IPR system.[5]

Stronger IPR	Static	Dynamic
Cost	Knowledge purchased at monopoly price (above marginal cost of production), possible welfare loss	Barriers to access modifiable technologies increase
Benefits	Knowledge sold at monopoly price allows firms to recoup their R&D investments and capture economic rents	Innovative activities become more profitable, attracting more competitors in this domain.

Table 2: Cost and benefits of a stronger patent system

2.2 Effects of IPR on entrepreneurship

Recent literatures on the impact of IPR protection on developing countries have provided some insights on how it affects trade (Fink and Braga, 1999; Maskus and Penubarti, 1995), foreign direct investment (Smarzynska Javorcik, 2004; Lee and Mansfield, 1996; Mansfield, 1994), and economic growth (Thompson and Rushing, 1999; Rapp and Rozek, 1990), to name a few. We have undertaken to pursue research work in this area by shifting the focus of IPR study from the macroeconomic variable such as trade and FDI to microeconomic one, in particular the entrepreneurial firm. Our rationale for concentrating on entrepreneurial firms is because: i) entrepreneurs tend to spot changes in economic environment quickly enabling them to respond to these changes swiftly; and ii) as Shane (2003) states, "[a]lmost every explanation for business and, for that matter, capitalism itself, relies on entrepreneurship as a cornerstone."

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[5] The cost of building a legal system is not considered in Table 1, which can be prohibitively high for countries where such system does not exist yet, or where the legal system functions ineffectively.

The link between IPR protection and entrepreneurship is a clear one, albeit not directly proven (Shane, 2003). IPR protection provides a mechanism for entrepreneurs to appropriate her returns to innovation. However the effectiveness of IPR protection and the extent to which the innovator can fully capture the returns varies according to the type of protection used and the nature of innovation (Teece, 1986). Once an innovator creates a novel product or service, she can either produce and commercialize it herself via firm formation á la Schumpeter (1942), or contract this innovation out to another firm with the necessary complementary assets to produce it either through licensing or a joint venture. For this research study, we focus on the link between IPR protection and firm formation. Shane (2001) using patent data assigned to Massachusetts Institute of Technology between 1980 and 1996, finds that the effectiveness of patents increased the probability that the new technology will be exploited through firm formation. Baumol's theory on entrepreneurs as an allocatable resource provides a suitable theoretical foundation explains this link better.

Baumol (1993) argues persuasively that entrepreneurs can be allocated across economic activities by changing the structure of rewards of those activities.[6] He points out that entrepreneurs exist in any economy and they tend to operate in domains that promise greatest monetary returns, although not necessarily in the innovative domain. He states that, "there are a variety of roles among which entrepreneur's effort can be reallocated; and some of those roles do not follow the constructive and innovative script that is conventionally attributed to them" (2002). Thus the areas in which the entrepreneurs function given the socio-economic system depends on the economy's payoff structure. Baumol further argues that entrepreneurs, when faced with a given set of alternative economic activities, can be reallocated from one activity to another by a change in the relative profit prospect from undertaking that particular activity *ceteris paribus*. And given the inherent characteristics of the entrepreneur, when the reward structure in an economy changes either due to political, institutional or market reasons, entrepreneurs will be the first few economic agents who would identify the opportunities from these changes and respond to them. As such, studying entrepreneurs' reaction to strengthening of IPR protection would likely suggest the direct effect of IPR protection on the economy.

Historical evidences from the United States give support Baumol's theory. Among the recent IPR changes in the United States include (cf. Sampat (2001)): i) widening patentability fields to include living organisms, software and business methods; ii) implementation of the Bayh-Dole Act which enables federally-funded research work to apply for patents; iii) court decisions

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[6] We refer to *entrepreneurs* here generically, i.e. economic agents that can identify, evaluate and exploit profit opportunities in the economy through arbitrage, speculation or innovation.

in the 1980s and 1990s in favor of widening the scope of patents; and iv) the importance of patents to new innovative firms to be eligible on the NASDAQ. Technological advances, effective knowledge infrastructure and these IPR-friendly institutional changes have prompted an influx of entrepreneurs towards these innovative activities. For example, Shane (2004) examining the effect of Bayh-Dole Act on university patenting in the United States confirms that the introduction of the Act provided incentives for universities to increase patenting, especially in fields where "licensing provides an effective mechanism for acquiring new technical knowledge".

We apply Baumol's theory to link the relationship between entrepreneurship and IPR protection. We argue that strengthening IPR protection in a given country would change the payoff structure of the economy by increasing potential returns from undertaking innovative activities. This change in the payoff structure relative to other economic activities would then induce the allocation of entrepreneurs accross different economic domains, leading to a concentration of entrepreneurs in the innovation and technological areas.

2.3 Research questions

Using Baumol's theory, we attempt to establish a relationship IPR protection and entrepeneurship and examine whether this relationship differs across different levels of economic development, given the necessary preconditions. These necessary preconditions include sustainable national innovative capacity framework, stable macroeconomic conditions, openness and effective legal infrastructure. National innovative capacity, which includes education system, ensures that the entrepeneurs would have the necessary skills and infrastructure to carry out innovative activities (Lall, 2003). Stable macroeconomic conditions and effective legal infrastructure provides the environment for entrepreneurs to operate their firms effectively. And finally openness enables exchanges of new knowledge, allowing the entrepeneurs to learn and thus improve existing technologies.

IPR protection provides an incentive for innovative activities that encourages innovation, which can be commercialized through firm formation. The implementation of the TRIPS agreement introduces and strengthen IPR protection level in a country and makes legal innovative activities attractive and illegal imitative activities such as piracy more costly to undertake for economic actors. Theoretically, this would encourage more entrepeneurs in innovative activities. Put in another way, stronger IPR protection should encourage the presence of higher levels of entrepreneurial opportunities and thus facilitate the undertaking of more entrepreneurial activities.

Proposition 1 *Stronger IPR protection encourages more entrepreneurial activities.*

Most of the analyses examining the effects of IPR protection on countries differentiate between high and low development level countries, and we follow this correctly identified assumption in our research as well. Several studies find different effects of IPR protection for different development levels. Falvey et al. (2006) conducted an empirical analysis of the link between IPR and economic growth and finds that low and high income countries are positively and significantly affected by IPR protection but not for middle income countries. They conclude that middle income countries "may have offsetting losses from reduced scope for imitation." This suggests that there is a U-shaped relationship between IPR protection and economic development. Interestingly, Smith (1999) in her examination US exports to developing countries find that the strength of IPR protection had a stronger impact on exports to developing countries with strong absorptive capacity. Thus, the impact of IPR protection on entrepeneurship would differ according to their levels of economic development. This leads us to our second testable hypothesis:

Proposition 2 *The effect of IPR protection on entrepreneurial activities differs according to income levels*

In the following section, we explain our methodology for carrying out our test of the hypotheses.

3 Methodology

Outside the confines of developed economies, the effect of IPR protection on creating entrepreneurial opportunities and encouraging the exploitations of these opportunities is not clear. This is due to difficulty in finding a proxy to capture this activity. Firstly not all developing countries have had IPR protection or have adequately enforced IPR until the recent TRIPS agreement. Thus the usual measure of entrepreneurial activity via firm formation, along the lines of Shane (2001) of using patent data, is not feasible. Secondly cross-country comparison of entrepreneurship activities has been made difficult due to differing definitions of entrepreneurship and the method of collection. This is why we resort to using high expectation entrepreneurship data and refrain from exploiting the patent data.

3.1 Data

We examine high expectation entrepreneurship data collected from GEM consortium for 55 countries over the time period of 2002 – 2006. High expectation entrepreneurship refers to the subset of entrepreneurs who expect their businesses to employ at least 20 employees over the next 5 years. This measure is preferable over the patent data for two reasons: (i) it allows for cross-country comparison of entrepreneurial activities across various income levels and (ii) it does not depend on the enforcement of IPR protection in order to capture the exploitation of opportunities via firm formation.

3.1.1 Dependent variable

Schumpeter's entrepreneur is both an innovator and part of the engine of economic growth. It has been difficult to adequately capture a measure of entrepreneurship that proxies Schumpeter's entrepreneur. We choose to focus on high expectation entrepreneurship variable as our dependent variable. This variable proxies the prevalence of high growth entrepreneurship, thus it captures the kind of entrepreneurial activity that generates employment crucial for economic development. Autio (2005) examines this measure in detail and argues that high expectation entrepreneurial activity accounted for "the bulk of expected new jobs by startups and newly formed businesses" (p. 8). He further concludes that policies designed to encourage knowledge transfer from universities or R&D firms to spin-offs could have a positive impact on high expectation entrepreneurship (p.11).

There is another variable collected by the GEM consortium that may reflect the kind of entrepreneurial activities that we would like to capture better. This variable is referred to as the *high growth potential entrepreneurship* which are defined as new ventures that expect to have: i) high growth intentions (proxied by plan to employ more at least 20 employees in the next five years); ii) innovativeness in product or service (captured by looking at expected market expansion impact); iii) international distinctiveness (measured by percentage of customers living abroad); and iv) employs new technological base in its production (technology cannot be widely avaible more than a year before). However, there are several empirical drawbacks to using this data, particularly in regards to its reliability and consistency of capturing this variable over the years that we are interested in.

We collect annual aggregated data from the Global Entrepreneurship Monitor on various measure of entrepreneurship (please refer to appendix for the list and their definitions). The database collection began in 1998, but we choose the time period of 2002 to 2006 based on the availability of widest possible range of country income levels in the database. The data covers approximately 55 countries but not all data is available for all countries in the time frame selected for this study.

The GEM survey asks individuals if they are in the process of establishing a new business, referred to as nascent entrepreneurship, or owning/managing a baby business, termed as baby business. Of the individuals who have responded affirmatively to either one of these entrepreneurship activities, they are further asked if they expect their business to employ at least 20 employees in the next 5 years. This is the definition of high expectation entrepreneurship.

3.1.2 Predictor variable

The other variable of interest, besides the high expectation growth entrepreneurship variable, is the intellectual property rights (IPR) protection variable. There have been two approaches in quantifying the strength of IPR protection: legislation- and survey-based approaches, both approaches have been criticized because of their respective collection and quantification methods. The legislation-based approach, exemplified by Ginarte and Park (1997), has been criticized for overestimating the level of protection accorded because it had only taken into consideration the enforcement element of IPR protection. On the other hand the survey-based approach, typified by the Yale survey from Levin et al. (1987) and Lee and Mansfield (1996), is considered subjective, perhaps reflecting some "ideological tendencies" of those who built the survey and those who answered it (Kauffman et al., 2004).

We use the IPR enforcement index collected by the World Economic Forum (WEF) as a measure of IPR strength because of its coverage of countries over the time period of investigation. This index is built based on answers from local professionals and is bi-annually published in the WEF annual Global Competitiveness Report. Furthermore, this index captures the enforcement component of IPR protection which reflects the current law perspectives and practices on its protection. The survey asked whether, "[I]ntellectual property protection in your country is: (1=weak or non-existent, 7=equal to the world's most stringent)." Responses from the experts are tabulated and averaged for each country in question.

3.2 Control variables

We include factors other than IPR protection that have been found to be a significant factor in the determination of entrepreneurship activities. By doing so, we control for factors that could influence IPR protection and ensure that the variable that we am concerned with, IPR protection, influences the high expectation entrepreneurship beyond what previous researchers have found. The variables we employ here are to control for macroeconomic determinants of entrepreneurship. All of the control variables are from the World Bank's World Development Indicator 2007. A list of their definition can be found in the appendix.

Entrepreneurship rates have been found to be higher during economic boom periods and decline during economic recessions. We chose the variable GDP growth rate to proxy for economic growth of the economy.

High inflation rate tend to indicate times of economic instability, wherein which it has been found that entrepreneurship activity decreases. We use the inflation rate as measured by the GDP deflator of a country to control for times of economic instability.

Highfield and Smiley (1987) argue that low unemployment rate positively influence firm formation. However, they stipulate that under "opportunistic" competition, high unemployment rate positively influence firm formation because the cost of attracting and hiring qualified workers would be lower.

It is more difficult to open a new firm when the cost of borrowing money is high. Audretsch and Acs (1994) in their study on the relationship between new firm startups and macroeconomic fluctuations, use the average three-month interest rate paid on the U.S. Treasury Bills. However, given that we do not have access to all of the government bond rates for each country in our study, we use real interest rate as a proxy to measure the cost of capital.

3.3 Descriptive statistics

We have 55 countries in our sample, both developed and developing countries between 2002 and 2006. However, we end up with an unbalanced panel dataset due to the missing data in some years. We also had to drop our observation on Chinese Taipei due to the lack of data reported by the World Bank on the macroeconomic variables.

Table 1 summarizes the variables in this study. Note that the mean for high expectation entrepreneurship is approximately 1 percent. This indicates that on average only 1 percent of the total working population in the countries studied are engaging in high expectation type of entrepreneurship. The highest high expectation entrepreneurship percentage of the total working population is found in Chile with 4.5 percent in 2002, China with 3.8 and 3.1 percent in 2002 and 2006 respectively, and Colombia with 3.4 percent in 2006. Further examination of this entrepreneurship variable for developing countries shows that the mean of high expectation entrepreneurship rate is 1.3 percent of the population, slightly higher than for the whole sample. Just for comparison, range of high expectation entrepreneurship variable for the United States is from 1.04 to 2.18 percent of the population.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
High expectation entrepreneurship	174	1.021	0.835	0.000	4.530
Economic growth rate	269	3.959	3.238	-11.032	17.855
Real interest rate	186	5.824	9.617	-9.710	84.050
Inflation rate	269	4.937	6.213	-6.347	44.134
Unemployment rate	153	8.477	5.017	1.500	30.700
IPR	271	4.499	1.255	2.200	6.600

Table 3: Descriptive statistics

Table 2 is a correlation table between the important variables we collected for this study. As the table shows, the highest correlation between any two independent variables is -0.54 between IPR proxy and the inflation rate. While the table shows that there is no problem of multicollinearity, or high correlation problem, it does suggest that the factors that we are using in our investigation are not completely independent of one another.

Simple Pearson pairwise correlation of high expectation entrepreneurship variable and economic growth proxy measured by GDP growth rate show a positive and significant correlation, reaffirming Autio's earlier argument that this variable may positively influence economic growth. Notice that the Pearson pairwise correlation between the high expectation entrepreneurship variable and the IPR protection variable is negative and significant; however the variable "IPR*dev" which is found by interacting the IPR protection variable with the dummy for developing countries (dev), the correlation is positive and significant. This indicates that there is different effect when we consider the sample as a whole and when we consider developing countries only.

	1	**2**	**3**	**4**	**5**	**6**	**7**
1. High expectation entrepreneurship	1						
2. Growth rate	0.1917*	1					
3. Real interest rate	0.0257	-0.2896*	1				
4. Inflation rate	0.3049*	0.0409	0.0465	1			
5. Unemployment rate	-0.1306	-0.1414*	0.2538*	0.3324*	1		
6. IPR	-0.2606*	-0.3248*	-0.1042	-0.5391*	-0.3899*	1	
7. IPR* dev	0.2096*	0.3253*	0.1799*	0.3452*	0.4176*	-0.6397*	1

Table 4: Correlation table

4 Analysis

The purpose of this study is to examine whether a country's level of IPR protection influences local entrepreneurial activity across countries of differing economic development activities. We test the two following hypotheses: i) *stronger IPR protection encourages more entrepreneurial activities;* and ii) *the effect of IPR protection on entrepreneurial activities differs according to income levels.*

4.1 Regression method

We collect data for 55 countries over the period 2002 and 2006 but are left with an unbalanced panel set of approximately 134 observations. We test for heteroskedasticity and reject the null hypothesis that there is no cross-section heteroskedasticity in our panel set. Thus, we correct for the groupwise heteroskedasticity and the correlation of the error term over time by running normal Ordinary Least Square (OLS) regression clustering by country with robust standard errors. We also run Generalized Least Square (GLS) regression, correcting for panel heteroskedasticity. We report and analyze the results in the following subsections. Given our panel heteroskedasticity assumption, the GLS estimation is more efficient and preferred over the OLS with cluster by country estimation. We report both OLS with cluster and the GLS regression for completeness.[7] The OLS with cluster regression although not efficient in the case of panel heteroskedasticity is reported because its estimates will be correct in either case of with or without panel heteroskedasticity.

4.2 Results

4.2.1 Proposition 1

Our first hypothesis is that stronger IPR protection encourages more entrepreneurial activities. We run the test using the following model:

$$y_{it} = \alpha + \beta_{it} x_{it} + \varepsilon_{it}$$

where x_{it} represent all the explanatory variables, including the IPR measure. Table 4 reports our findings from a normal OLS regression, clustering robust standard errors by countries. The F-statistics test finds that all the coefficients in the models are significant.[8] The R-square values improve the as we move from the baseline model to Model 4.[9]

Model 1 shows that the coefficients of GDP growth rate and inflation rate are positively related to the entrepreneurship variable, and are statistically significant from zero. Interestingly the unemployment rate is negatively related to the dependent variable, and statistically significant from zero. Model 2 adds the intellectual property rights variable. As in Model 1, the coefficients GDP growth rate and inflation rate are positively related to the entrepreneurship variable, and statically significant from zero. However, the IPR variable is negatively related to the entrepreneurship variable but statistically significant from zero.

4.2.2 Proposition 2

We test the second hypothesis, i.e. whether the impact of IPR protection on entrepreneurship differs according to levels of economic development.

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[7] The OLS with cluster regression although not efficient in the case of panel heteroskedasticity is reported because its estimates will be correct in either case of with or without panel heteroskedasticity.

[8] The F statistics tests that the coefficients on the regressors listed in the table are all jointly zero.

[9] The R^2 is usually improves when one adds more variables, and so a more adequate measure to capture whether the variables added improves the model is the adjusted R^2. However, we do not report the adjusted R^2 because it is not available.

We create a dummy variable called *dev*, which differentiates countries that are developed from those who are developing following the World Bank classifications. The dummy takes a value of 1 if the country in question is a developing or least developed country and 0 if otherwise. The regressions for this hypothesis is shown in both Tables 5 and 6 as Models 3 and 4.

Models 3 and 4 are replicas of models 1 and 2 but with the interaction terms of developing countries. We test:

$$y_{it} = \alpha + \beta_{it} x_{it} + \delta_{it} x_{it} * dev + \varepsilon_{it}$$

where "dev" is a dummy variable that takes on the value 1 if the country is a developing nation and 0 otherwise. All the coefficients for the whole sample in Model 3 are insignificant except for unemployment rate, which is negatively related to the entrepreneurship variable and statistically significant from zero. In Model 4, the unemployment rate is negative and statistically significant from zero for the whole sample. The growth rate interaction and the unemployment interaction terms are positive and statistically significant from zero. IPR variable, for developing countries, is negative and statistically significant from zero.

Checking for robustness, we test whether the coefficients between the two samples (whole sample and developing countries' sample) are the same and reject the null hypothesis that they are. This implies that IPR level and strength affects countries with different income levels differently.

	Model 1	**Model 2**	**Model 3**	**Model 4**
GDP growth rate	0.0701***	0.0620**	0.0605	0.0168
	(0.023)	(0.026)	(0.051)	(0.053)
Real interest rate	-0.00179	-0.00259	0.0237	0.0277
	(0.011)	(0.011)	(0.019)	(0.018)
Inflation rate	0.0609***	0.0544***	0.0398	0.032
	(0.014)	(0.018)	(0.04)	(0.042)
Unemployment rate	-0.0363***	-0.0382***	-0.0721*	-0.111**
	(0.0091)	(0.01)	(0.041)	(0.046)
IPR		-0.0473		0.0553
		(0.095)		(0.11)
GDP growth rate*dev			0.0785	0.168**
			(0.061)	(0.068)
Real interest rate*dev			-0.00105	-0.000862
			(0.00077)	(0.00055)
Inflation rate*dev			-0.081	-0.0592
			(0.064)	(0.068)
Unemployment rate*dev			0.0342	0.0939*
			(0.033)	(0.047)
IPR *dev				-0.253**
				(0.12)
Constant	0.724***	1.025	0.839**	0.913
	(0.14)	(0.62)	(0.39)	(0.85)
N	86	85	56	55
R-squared	0.24	0.24	0.42	0.47

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: OLS regression with heteroskedastic panel

	Model 1	Model 2	Model 3	Model 4
GDP growth rate	0.0740***	0.0676***	0.0762***	0.0445***
	(0.0092)	(0.014)	(0.018)	(.017)
Real interest rate	0.00521	0.000795	0.0198*	0.0200*
	(0.0053)	(0.0074)	(0.011)	(0.011)
Inflation rate	0.0662***	0.0616***	0.0396***	0.0333**
	(0.0061)	(0.0091)	(0.014)	(0.014)
Unemployment rate	-0.0379***	-0.0349***	-0.0709***	-0.0940***
	(0.0037)	(0.0055)	(0.012)	(0.012)
IPR		-0.0197		0.0874*
		(0.038)		(0.051)
GDP growth rate*dev			0.0592*	0.135***
			(0.032)	(0.035)
Real interest rate*dev			-0.000833***	-0.000998**
			(0.00029)	(0.00042)
Inflation rate*dev			-0.0577*	-0.0304
			(0.03)	(0.033)
Unemployment rate*dev			0.0301**	0.0842***
			(0.012)	(0.017)
IPR *dev				-0.259***
				(0.059)
Constant	0.633***	0.751***	0.766***	0.557**
	(0.06)	(0.27)	(0.099)	(0.27)
N	86	85	56	55
ID	41	40	36	35
Log-likelihood	-35.42894	-37.44926	-11.39054	-10.21097

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: GLS regression with heteroskedastic panel

4.2.3 Discussion of the results

The results from our regressions are interesting but preliminary. The results show that for developed countries, increases in the IPR regime positively affect the formation of high growth expectation entrepreneurship but negatively for the developing countries. This suggests that for developed countries marginal strengthening of IPR protection level facilitates more entrepreneurial activities, partially confirming our application of Baumol's theory. By strengthening IPR protection, innovative activities become more rewarding and there is a surge in this particular type of entrepreneurship. However, based on the evidences that we currently have, we cannot confirm whether there is a shift of entrepreneurs from one domain to another.

As for the developing countries, this marginal increase in IPR protection leads to decrease in the current entrepreneurial activities, contradicting Baumol's theory. There are two possible explanations for this interesting result. The first possible explanation is that there is no reallocation process in developing countries particularly because there is no scope for this process to take place. For example, it could be the case that the national innovative framework has been insufficient to facilitate the types of entrepreneurial activities that are IPR-sensitive. Even if the national innovative framework is conducive to IPR-sensitive entrepreneurial activities, it is likely that these type of entrepreneurs cannot be spontaneously generated nor can shift from one entrepreneurial acitivity to another take place instantaneouly. Thus a longer time period is required to carefully study this reallocation effect. A second possible explanation has to do with the legality of the entrepreneurial activity. Perhaps what we are witnessing with the decrease in entrepreneurial activity given the strengthening of IPR protection is an exit of entrepreneurial firms due to the "illegality" of their activity. Stated in a different way, strengthening IPR protection increases the cost of undertaken this "illegal" activity and thus firms would have to exit or prefer not to enter that particular activity. Consider India's case as an example. Prior to TRIPS, India allowed process patenting but not product patenting. This enabled Indian generic producers to copy a drug and re-engineer it using a different processes. Post-TRIPS, this type of innovative activity is now "illegal" and the producers would have to stop their infringement of the product patent. If the second explanation is the case, then this interesting result for developing countries would also partially confirm Baumol's theory. Again, we are not able to deduce that there is a reallocation effect due to the limitations of the data that we have gathered.

Our empirical model suffers from data problems. In particular, due to the methodology and collection of the dependent variable, we are not privy to know whether the entrepreneurial firms are IPR-sensitive or not. This brings several drawbacks to our investigation. Arguably, the entrepreneurial firms in developed countries are IPR-sensitive and as such would respond positively to the strengthened IPR system. However, the same cannot be said for entrepreneurial firms captured by the data for developing countries. As mentioned earlier, we could've circumvented this data problem by using the high growth potential entrepreneurship variable, which seems to track innovativeness of the firm. However, because we cannot confirm the reliability and consistency of this variable, we choose not to use it.

Further research investigation is needed in this subject matter. It would be useful to have a longer time period to properly assess the allocation effect of entrepreneurs in an economy. Furthermore, capturing the sectors in which these entrepreneurs participate would allow us to better assess the applicability of Baumol's theory in practice.

5 Conclusion

Our examination of the impact of IPR protection on high expectation entrepreneurship yields interesting results. High expectation entrepreneurship responds positively to IPR protection in developed countries but negatively in developing countries. For developed countries the result partially concurs with Baumol's theory. An increase in IPR protection makes IPR-sensitive activities more attractive as these activities now yield higher payoffs in comparison to other activities. While the Baumol's theory may partially apply in developed countries, our result shows the contrary for developing countries. The negative relationship suggest that strengthening IPR protection is costly for their local high expectation entrepreneurs. As we have discussed in our previous section, two possible explanations can justify this interesting results. For one, developing countries may not have adequate supply of entrepreneurs who can readily participate in IPR-sensitive activities. Thus, the problem for developing countries can be attributed to problem of production rather than problem of allocation of entrepreneurship. Secondly, it is possible that the types of entrepreneurial activities captured by high expectation entrepreneurship variable may have been "legal" prior to TRIPS and "illegal" post-TRIPS. Therefore an exit of high expectation entrepreneurs is likely given the costliness of participating in this "illegal" activity.

Our research sheds adds to the discussion of how TRIPS impact developing countries. Given our preliminary research finding, TRIPS may not be beneficial for developing countries. However this may reflect certain supply-side constraints, such as human capital, that responds negatively to this institutional change. It is clear that TRIPS is not a magical solution to entrepreneurial, R&D and innovation deficit in developing countries. Sufficient and sustainable national innovative capacity framework as well as other institutional framework should be in place to support the developmental growth of the economy. Our research sheds light on the importance of examining strategic complementarities between various institutional changes and processes. For example, studying the evolution of IPR regime and the transformation of education system would perhaps generate a better view of how these institutional changes affect economic activities. Milgrom and Roberts (1990) underline the importance of mutual complementarities of institutional changes that should be adopted together to enhance the positive impact that these changes would bring to the economy. There is, thus, potential for systemic transformation that results entirely from the positive feedback effects that each institutional change has on the other changes. When properly managed, such strategic complementarities among institutions can account for the emergence of a persistent pattern of change.

However, further study should be undertaken to better assess the situation.

A Appendix

Measure	Proxy	Units	Source
Entrepreneurship	High expectation entrepreneurship	% of total working population	GEM
Economic growth	GDP growth	% change annually	WDI
Cost of capital	Real interest rate	%	WDI
Economic stability	Inflation rate	% change annually	WDI
Ease of hiring	Unemployment rate	Total unemployment as a % of total labor force	WDI
IPR protection	IPR index	1 to 7 scale	WEF

Table 6: Variables collected

Variable	Obs	Mean	Std. Dev.	Min	Max
High expectation entrepreneurship	63	1.319	1.016	0.058	4.530
Economic growth rate	129	5.093	3.719	-11.032	17.855
Real interest rate	101	7.323	12.579	-9.710	84.050
Inflation rate	129	7.914	7.549	-3.855	44.134
Unemployment rate	76	10.637	6.010	1.500	30.700
IPR	127	3.428	0.783	2.200	5.100

Table 7: Descriptive statistics for developing countries

Variable	Obs	Mean	Std. Dev.	Min	Max
High expectation entrepreneurship	111	0.852	0.660	0.000	3.911
Economic growth rate	140	2.913	2.277	-1.198	11.900
Real interest rate	85	4.043	3.067	-4.050	12.120
Inflation rate	140	2.193	2.476	-6.347	14.286
Unemployment rate	77	6.345	2.328	2.900	11.400
IPR	144	5.444	0.718	3.800	6.600

Table 8: Descriptive statistics for developed countries

B List of countries in the sample set[10]

United Arab Emirates
Australia
Belgium
Canada
Chile*
Chinese Taipei
Czech Republic
Germany
Spain
France
Greece
Croatia
Indonesia*
Ireland
Israel
Jamaica*
Jordan*
Latvia*
Malaysia*
Norway
Peru*
Poland*
Russia*
Slovenia*
Thailand*
Uganda*
United States
South Africa

Argentina*
Austria
Brazil*
Switzerland
China*
Colombia*
Denmark
Ecuador*
Finland
United Kingdom
Hong Kong
Hungary
India*
Iceland
Italy
Japan
South Korea
Mexico
Netherlands
New Zealand
Philippines*
Portugal
Singapore
Sweden
Turkey*
Uruguay*
Venezuela*

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[10] Countries with asteriks (*) are developing countries as classified by the World Bank.

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The governance of the patent system in Europe: intersections between the EPO's supranational autonomy and the European Union's strive for technology specific patent legislation

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Please note: the paper for this section was sent to the discussants and will be available in Lund.
Some of the arguments brought forward can be read online at:
http://documents.epo.org/projects/babylon/eponet.nsf/0/F172DE5BB2B9B15BC12572DC0031A3CB/$File/Interview_Schneider.pdf

and a very short version of the main points at:
www.tekno.dk/pdf/projekter/patent-system-STOA/background_document.pdf, pp.47-49

Abstract for EPIP 2007, Section 4A "*Governance, Patents & Innovation Systems*"

My paper derives from governance studies in the political sciences, focussing particularly on the links between horizontal and vertical governance processes and questions of input/output legitimacy1.

First, I will analyze the dominant mode of governance of international patent systems after WW II, which can be described by two intersecting interactions:

- the interaction between applicants and the patent office;
- the interaction between patent offices' granting practices (executive) and court decisions (jurisdiction).

Patent systems so far have been hardly governed by legislative ruling. For many decades, patent systems remained largely self-regulated by administrative granting practices, by technicians and lawyers as an epistemic community, and by courts.

The Patent system in Europe exhibits some particular features and is characterized by a "unique, multipolar constellation" (Artelsmair 2005)2. Due to the "birth failure" of the EU Community Patent, a double structure between the European Patent Organization (EPO) and the European Union has come into existence at the supranational level. Patents were regulated by the 1973 European Patent Convention (EPC) as an intergovernmental treaty, governed by the European Patent Organization (EPO) and executed by the European Patent Office (EPO).

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[1] Mayntz, R. 1998: New Challenges to Governance Theory. Jean Monet Chair Papers No 50, European University Institute; Borrás, S. (2006): "The Governance of the European Patent System: Effective and Legitimate? In Economy and Society, Vol. 35, no. 4, pp. 594-610

[2] Artelsmair, G. 2005: A Comprehensive Patent System Needed for Europe, in: A. Kur et al. E. (Ed.): „…und sie bewegt sich doch!" Patent Law on the Move. Cologne, pp. 5-30: 19

Unless the EPLA will be ratified, the lack of a European Patent Court means that the enforcement and validation of European bundle patents is still left to the national courts.

The EPO system oscillates between intergovernmentalism and supranationalism. As a supranational organization at the public/private divide, the European Patent Office enjoys a high degree of autonomy and is self-funded by the applicant's fees. I will analyse, in which respect control by the EPO's Administrative Council is exercised and how the tension between national patent offices and the EPO is played out. I will also regard, how substantive patent law for new technological fields has evolved in the interplay between the granting departments and the EPO's opposition chambers and its boards of appeal which are quasi-judiciary bodies. The EPO's „technocratic self-determination"3 will be critically interrogated.

Despite the lack of direct legislative powers on patents[4], the European Commission aimed at IPR legislation in the context of the single market objectives, and later in the context of international economic competition and knowledge-based societies (Lisbon Agenda). It was exactly the "incompleteness" of the European patent system – particularly the lack of a European Patent Court – which prompted the European Commission (EUC) to propose legislative directives for patents in biotechnology and later software to provide for legal clarity in these new technological areas. Both the biotech directive (98/44/EG) and the software directive (2002/0047/COD) strived for pre-emptive harmonization of the national patent law of the EU member states to prevent diverging national court judgements in new technological areas which would possibly have fragmented the European patent system.

Despite of incongruity in the contracting states and full institutional independence, some institutional co-evolution between the EU and the EPO system has emerged. This can be made explicit by parallel member state extension, but also by the EU's legislative actions which aimed at securing the EPO's granting practice by clear statutory norms at the EU level. This indirect (co-)regulation of the EPO system is also related to institutional problems within the EPO itself, whose constitutional treaty EPC has been considered as structurally "non-revisable"5 for contentious issues.

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[3] Ullrich, H. 2004: Harmony and unity of European intellectual property protection, in: D. Vaver, L. Bently (Ed.), Intellectual Property in the New Millennium. Cambridge, pp. 20-46: 77

[4] Borrás, Susana 2003: The Innovation Policy of the European Union. From Government to Governance. Cheltenham, UK and Northampton, USA

[5] Bossung, O. 2003: A Union Patent Instead of the Community Patent – Developing the European Patent Into a EU Patent, in: International Review of Intellectual Property and Competition Law (IIC), Vol. 34, No.1, pp. 1-30.

As I will argue, these attempts for legislative regulation of substantive patent law must be evaluated as steps towards the politicisation and democratisation of patent governance in Europe. They have brought patentability standards to the arena of policy-making and allowed for the involvement of “unusual actors“ in the deliberation processes.

As a case study, I will refer to the contentious EU biopatent directive (98/44/EG) which led to protracted negotiation processes at the EU (1988-1998) and the national level concerning directive’s implementation (1999-2006).

I will discuss some effects of the EU biopatent directive on the patent system in Europe.

- Has legislative governance by the EU cast the “shadow of hierarchy” upon the self-regulatory structure of the EPO patent system? Did agenda setting at the EU level just ratify the rules developed at the EPO level or did the legislative outcome make a difference? How was EU legislation “transposed” to and implemented by the EPO?
- How were questions about separation of powers, transparency, and accountability of the EPO system addressed by the European Parliament?
- Caused by endogenous and exogenous factors, the EPO patent system currently seems to be in crisis, articulated inter alia in claims about inefficiency, decreased patent quality, capture by the clients, “anti-commons” effects, and political contestation of the legitimacy of certain patent granting practices (concerning subject matter and scope). What has been the EPO’s response, did external challenges result in internal reflexivization and proceduralization?
- Did politicization and vocal contestation of patents in the public sphere impact on the self-regulatory structure of the EPO patent system? How did the emergence of new actors - apart from economic competitors - in EPO’s opposition proceedings influence the decision-making processes?
- Can the biopatent directive be regarded as a step towards a new, reflexive governance structure which establishes feedback loops between the EPO and the EU system? Or is legislative patent governance – after the failure of the software directive – but an episode in the European patent system?

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Patent Scope and Technology Choice[*]

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September 5, 2007

Abstract

The purpose of this paper is to analyze the effect of an increase in patent scope on investments in R&D and on the rate of innovation. Patent scope affects incentives for innovation via the research strategies firms choose; a broad scope on the patent for the state-of-the-art technology can induce entrant firms to choose to do research on alternative technologies to avoid patent infringement. If the alternative technologies have a lower probability of success, this reduces incentives for investment in R&D by entrant firms and the probability that they innovate. On the other hand, the allocation of total R&D across projects is improved, since there is less wasteful duplication of R&D investments. This paper presents a model where the trade-off induced by patent scope can be analyzed. The model predicts that an increase in patent scope can increase the probability of innovation, and consequently the negative effects of R&D duplication can be large enough to warrant a broad patent scope. This holds if the incumbent's increase in profits from innovating is large, and the patented technology has a small advantage relative to alternative technologies. Otherwise, the probability of innovation decreases. However, when the model is extended to allow for Stackelberg competition or license agreements, the benefit of a broad patent scope to a large extent disappears. Hence, the effects of an increase in patent scope depend on innovation and industry characteristics and unless several conditions are met, an increase in patent scope reduces innovation.

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[*] I would like to thank Daron Acemoglu, Martin Bech Holte, Bengt Domeij, Ante Farm, John Hassler, Stephen Parente, Lars Persson, Fabrizio Zilibotti and seminar participants at MIT and IIES for valuable comments and suggestions. All remaining errors are my own.

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1 Introduction

According to several economists, it is widely perceived that the scope of intellectual property rights in the US has increased over the last two decades (See for example Jaffe 2000 and Gallini 2002). They point to two factors that suggest this is the case. Firstly, patent holders have been awarded greater power in infringement lawsuits by a broadening of the interpretation of patent claims. Secondly, patent protection has been extended to cover new areas, notably software, business methods and biotechnology, where a large number of patents with broad scope have been granted. The purpose of this paper is to analyze how an increase in patent scope affects subsequent investments in R&D and the rate of innovation.

Suppose that there are several research strategies firms can pursue in order to find the next generation product in a market. Either they do R&D using the patented state-of-the-art technology to make an incremental improvement on that technology, or they choose alternative R&D strategies. The alternative strategies entail using different technologies than the current state-of-the-art. If the state-of-the-art technology is covered by a patent which is broad in scope, that may induce firms other than the patent holder to pursue an alternative research strategy; use a different technology to avoid the risk of patent infringement.[1] Lerner (1995) finds that firms with high litigation costs tend to avoid research areas that are occupied by other firms, particularly when these firms have low litigation costs. Walsh, Arora and Cohen (2003) analyze the effect of patents on R&D in the pharmaceutical industry. They find that firms tend to direct R&D investment to research areas less covered by patents.

It is probable that pursuing an alternative research strategy is more costly or involves more uncertainty than pursuing a strategy which makes incremental improvements of the technology currently in use. A broad patent scope on the state-of-the-art technology therefore reduces the incentives for research by entrant firms, and their innovation rates. However, research efforts may be better allocated across potential projects. If many firms were to do R&D in order to develop the same technology there may be wasteful duplication of research investment. Firms may for example build parallel labs and carry out identical experiments or build identical prototypes, which from a welfare point of view is a waste of R&D resources. If they do R&D using different technologies, they are less likely to carry out identical experiments, and there is less wasteful duplication. Direct evidence of duplication of R&D are given by simultaneous innovation, which is common in science. Two examples discussed by Chatterjee and Evans (2004) are the parallel inventions of the first electronic mini-calculator by Casio and Texas Instruments in 1972, and the parallel discovery of the process for synthesis of leukotrienes by two competing research teams

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[1] According to patent law, an invention which builds on a patented invention infringes that patent, even if it is patentable in its own right.

in 1979. Duplication of research effort which does not directly result in innovations is certainly more common. Domeij (2000) argues that patents that are broad in scope have resulted in diversification of research among pharmaceutical companies, as competitors to the patent holder strive to find pharmaceuticals based on other types of molecules than the one patented, which do not infringe on the patent.

In sum, an increase in patent scope has several effects on the investments in R&D and on the rate of innovation in the economy. It reduces entrant firms' incentives for research and their innovation rates. At the same time, an increase in patent scope decreases duplication of research effort, and directs research towards potentially fruitful new technologies and methods. The question is whether an improvement in allocation across projects can offset any decrease in individual firms' innovation rates, and if so, under what conditions.

In this paper, I construct a model to analyze this trade-off caused by patent scope. For simplicity, I use a duopoly model with an incumbent firm and an entrant firm. The incumbent owns a patent connected to the state-of-the-art technology, and is producing the corresponding product. There are two possible research strategies to follow: the first one is to build on the state-of-the-art technology, and the second to use an alternative technology, which is less promising. I consider two alternative scenarios for patent scope: one in which the patent scope on the state-of-the-art technology is narrow, and one in which the patent scope is broad. In the case of a narrow scope, both firms can choose to do research on the state-of-the-art technology. In the case of a broad scope, the entrant has to choose the alternative, less promising, technology in order to avoid infringing on the patent. I describe the possible equilibria that can arise under narrow and broad scope respectively, and compare the resulting R&D investments and probabilities of innovation.

The model suggests a new explanation for the empirical finding that incumbent firms have high innovation rates relative to entrants. In the standard R&D race models, the incumbent invests less than entrant firms due to the Arrow effect: the incumbent has a lower incentive to innovate since he by innovating to some extent replaces his current profits. In this model, when the incumbent firm holds a patent which is broad in scope, it gives him a monopoly on research that has the highest expected payoff. This effect can increase the incumbent's incentives for R&D sufficiently to outweigh the Arrow effect. Hence, the incumbent can be more likely to innovate than the entrant when he has an advantage originating from policy, namely the scope of the patent he owns.

The model predicts that if the incumbent firm has a high stand-alone incentive to innovate, i.e. the difference in his profits after versus before he innovates is large, or if the patented technology has a small advantage relative to other technologies, a broad patent scope gives a higher probability of innovation than a narrow scope. Hence, the negative effects of R&D duplication are under some conditions large enough to warrant a broad patent scope. Conversely, when the incumbent's stand-alone incentive to innovate is low, or the patented technology has a large advantage, a narrow scope gives a higher probability of innovation. If the incumbent is able to commit to an investment level or if license agreements can be made, the first result is partly reversed; in instances where previously the highest innovation probability was given by a broad scope, it is now obtained under a narrow scope. Hence, the benefit of a broad patent scope largely relies on the assumptions that the firms act simultaneously, and that there are no possibilities for license agreements. Consequently, the effects of an increase in patent scope depend on innovation and industry characteristics, and unless several conditions are met, an increase in patent scope reduces innovation.

The paper is organized as follows. The related literature is presented in Section 2, and an introduction to the determination of patent scope is given in Section 3. Section 4 describes the model. The equilibria of the model are characterized in Section 5. Section 6 describes the investments and the probabilities of innovation resulting from the narrow and broad patent scope respectively. Section 7 entails a comparison of the innovation probabilities, and describes the conditions under which each patent regime gives the highest innovation probability and the highest social surplus. Section 8 extends the model to allow for Stackelberg competition and licensing. Section 9 concludes.

2 Related literature

There is a large theoretical literature on the economic effects of intellectual property rights. An increasingly spreading view is that the current system of intellectual property rights in the US offers innovators too much protection of their innovations. Heller and Eisenberg (1998) argue that there is a "tragedy of the anticommons" in biomedical research as there are numerous patents to each separate building block for a new product. Acquiring the rights to use all of them is costly and potentially difficult, as the owners of the rights may have heterogeneous interests. Therefore, patenting can constitute an obstacle to future research. Similarly, Shapiro (2001) argues that in several industries, such as semiconductors and software, the current patent system is creating a patent thicket, an overlapping set of patents, which requires innovators of new technology to obtain licenses from multiple patent holders. The high transaction costs involved implies that stronger patent rights may stifle innovation. Bessen and Maskin (2002) show that when innovations are sequential stronger intellectual property rights protection may reduce innovation even in the case when there is only one patent holder. On the other hand, Green and Scotchmer (1995) also present a model of sequential innovation and find that a broad patent scope can be necessary to give the first innovator sufficient incentives to invest.

In the law and economics literature, Kitch (1977) argues that pioneering technologies should be granted patents with broad scope, since it will allow the innovator to coordinate further development of the technology by granting licenses and thereby wasteful duplication of effort is reduced. His view is challenged by Merges and Nelson (1990). Their argument is that uncertainty and high transaction costs of licensing reduce the effectiveness of coordination, and that broad patent scope can instead block technology development. Technical advance is likely to be faster when there is competition, as the patent holder then has higher incentives to develop his technology. Domeij (2000) discusses the trade-off between total investment in R&D and duplication of investments induced by patent scope in the context of the pharmaceutical industry. When the second generation product is a new indication, i.e. the same compound is used to treat other types of illnesses, Domeij argues that the patent holder has a high incentive to search for new innovations, since they are intended for new markets. In addition, the patent holder has a technological advantage over competitors in finding this type of innovations. Consequently, he concludes that a broad patent scope is preferable.

In the literature on firms' choices of research strategies, Dasgupta and Maskin (1987) find that competition encourages firms to choose research projects that are too similar from a welfare point of view. Chatterjee and Evans (2004) show that if the projects differ in other dimensions than the probability of leading to an innovation, firms may either choose projects that are too similar, or projects that are too different relative to what is socially optimal. Previous literature on duplication of effort in research and development includes for example Tandon (1983), Jones and Williams (2000) and Zeira (2003). They model identical firms and do not take into account the different incentives facing incumbent and entrant firms. Cabral and Polak (2004) present a duopoly model with an incumbent and an entrant. They investigate how an increase in consumer valuation of the incumbent firm's good, interpreted as an increase in its dominance, affects the amount of duplication of R&D by the two firms and the rate of innovation. Their conclusion is that increased dominance has a positive effect on innovation when intellectual property rights are strong. However, neither of the models has a mechanism by which entrant firms' technology choices affect the duplication of R&D.

This paper is also related to the literature concerned with why incumbent firms have high innovation rates relative to entrant firms. As shown by Reinganum (1983), when the innovation process is stochastic an incumbent firm invests less in R&D than an entrant, and is less likely to innovate. However, empirical evidence points to the opposite. For example, Blundell et al. (1999) find that within industries, firms with high market share innovate more. Several explanations for this observation have been proposed, most of them relying on a technological advantage for the incumbent. One example is Segerstrom and Zolnierek (1999) where the incumbent has lower costs of R&D than entrant firms. Another is Etro (2004), where the explanation is a first mover advantage for the incumbent in combination with free entry.

3 Determination of patent scope

The scope of a patent is central to this analysis. Therefore, I will start with a brief introduction to the determination of patent scope in patent law and practice, as described in Merges and Nelson (1990). A patent application consists of a specification of the innovation and a set of claims. The specification is written as an engineering article and describes the problem the innovator faced, and how it was solved. The claims define what the inventor considers to be the scope of the innovation, the "technological territory" in which he can sue other parties for infringement. The general rule is that a patent's claims should extend beyond the precise disclosure of the innovation in the specification. Otherwise, imitators could make minor changes to that example without infringing and the patent would have little value. The inventor naturally wants to make the claims as broad as possible, and the patent examiner must decide what scope is appropriate, which claims should be admitted and which should not.

In infringement cases the court first examines whether there is "literal infringement", namely the product literally falls within the boundaries of the patent claims. If not, the court also examines whether the product infringes under the doctrine of equivalents. The doctrine of equivalents says that a product is infringing if it does the work in substantially the same way and accomplish substantially the same result as the patented product. Consequently, patent scope is determined in two instances, by two separate authorities. Ex ante, if the patent holder has not sued any other party for infringement, the patent scope is defined by the claims as determined by the Patent Office. Ex post, in an infringement case, the patent scope is determined by the court, in its decision whether the patent has been infringed.

4 Model

The economy has two firms, an incumbent and an entrant. Both firms make investments in research and development in order to find the next innovation, which has private value V when patented. Both firms have quadratic investment costs. The incumbent firm holds a patent connected to the current state-of-the-art technology, and earns a profit from producing the corresponding product. The profit is expressed as a share of the value of the next innovation, αV, where $\alpha \in [0, 1]$. The entrant earns no current profits. Innovation is drastic; new innovations replace previous ones.

There are two possible research strategies for a firm to pursue. Strategy C is to build on the current state-of-the-art technology, technology C, and make an improved product. Strategy A is to use an alternative technology, technology A, for which there is no risk of patent infringement. In this context, a technology should be interpreted more broadly as using another material, algorithm, chemical compound etc., depending on the industry and the nature of the product. Irrespective of which technology is used in R&D, the private value of an innovation is V. There is no strong reason to believe that using different technologies to develop a certain product will generate innovations of exactly the same value. However, this simplification enables me to distinguish the effects of different patent regimes on innovation from effects of a higher value of an innovation.

Each technology has an exogenous probability γ_i, $i \in \{C, A\}$, of leading to the next innovation. The alternative technology has a lower probability of leading to the next innovation than the state-of-the-art: $\gamma_A < \gamma_C$. The difference between γ_C and γ_A reflects the relative advantage the state-of-the-art technology has. I assume that either technology C or A leads to a new innovation, but not both. This is a simplification of technology development, but is made for tractability. I will discuss the implications of the assumption further below. In addition, I normalize the sum of γ_A and γ_C to 1, since it reduces the number of model parameters. Hence, $\gamma_A = 1 - \gamma_C$. This does not affect the main results, since what is important for the mechanisms of the model is the ratio $\frac{\gamma_C}{\gamma_A}$.

In this paper, the R&D process is modeled as a one-shot game. This modelling choice is motivated by the fact that firm's R&D projects for development of new products often are close to irreversible. This is especially true in the biotechnology and pharmaceutical industries. As a consequence of this structure, the model has a positive probability that both firms innovate if they choose the same technology to do R&D on. It is necessary to specify the payoffs to both firms if this event occurs. Let the game be interpreted as a time period of for example five years, a period over which it is reasonable to assume that the R&D strategy cannot easily be changed. If both firms innovate during this time period, a patent will be awarded to the firm which innovated first. Suppose that innovations arrive with a hazard rate that depends on the R&D investment. Then, conditional on both innovating, the firms have the same probability of innovating at each point in time. Therefore, I assume that each firm has probability $\frac{1}{2}$ of obtaining the patent if both innovate. Further, I assume that the incumbent always chooses to invest in technology C irrespective of the entrant's technology choice. A justification for this assumption is that using a particular technology requires a fixed cost or an investment in human capital.[2] In the baseline model, both firms act simultaneously. In section 8, the model is extended to Stackelberg competition.

The patent regimes are modeled as follows. The patent scope on the state-of-the-art technology can be either narrow or broad. In the case of a narrow patent scope, the entrant can choose between the two technologies when investing in R&D, and he selects the technology which gives the highest expected

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[2] The assumption rules out an equilibrium in which the incumbent would choose to abandon his patented technology and invest in an alternative technology that is ex ante less attractive, only in order to escape competition from the entrant.

payoff. In the case of a broad patent scope, the incumbent can use his patent to block the entrant's innovation if it is based on technology C. Therefore, the entrant automatically chooses technology A in order to avoid infringement. This assumption will be relaxed in Section 8, where the model is extended to allow for license agreements between the firms.

The possibility of duplication of R&D resources can be illustrated in terms of two urns, A and C, filled with marbles. Each urn corresponds to a technology. Suppose that a firm's investment in R&D can be described as drawing a number of marbles from one of the urns and then replacing them. Drawing one marble is equivalent to conducting one experiment. Each urn has its own set of marbles, and the number of marbles is n_i, $i \in \{C, A\}$. Only one marble corresponds to a successful experiment, i.e. an innovation, and this marble is denoted 1. With probability γ_C marble number 1 is in urn C. Firm j purchases t_j, $j \in \{I, E\}$ marbles from urn i and the probability that it innovates, conditional on having chosen the right urn, is $\frac{t_j}{n_i}$. Firm j can increase this probability by buying more marbles at a cost of the per marble price. The draws of different firms are independent events. Suppose first that the incumbent and the entrant both choose urn C. The incumbent draws t_I marbles and replaces them in the urn, which gives him an innovation probability $\frac{t_I}{n_C}$. Then, the entrant draws t_E marbles, resulting in an innovation probability $\frac{t_E}{n_C}$. It is possible that both firms draw the same marble, that is, conduct the same experiment. This is a duplication of R&D resources from the point of view of society. No individual firm draws the same marble twice, and there are no duplicate experiments on the firm level. A social planner is however interested in the probability of any of the firms drawing marble number 1. For two events A and B, we can write the probability of at least one event occurring as:

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

The two events are independent, hence $P(A \cap B) = P(A)P(B)$. In our example, the probability of at least one innovation is:

$$P(no\ 1\ at\ least\ once) = \gamma_C \left(\frac{t_I}{n_C} + \frac{t_E}{n_C} - \frac{t_I}{n_C}\frac{t_E}{n_C} \right)$$

The product $\frac{t_I}{n_C}\frac{t_E}{n_C}$ represents a waste of resources due to duplication.

Now, suppose instead that the incumbent draws marbles from urn C and the entrant draws marbles from urn A. The incumbent and entrant have probabilities $\frac{t_I}{n_C}$ and $\frac{t_E}{n_A}$ respectively, of drawing marble number 1, conditional on choosing the right urn. The probability that both firms draw the same marble is zero. Hence, the probability of at least one innovation is:

$$P(no\ 1\ at\ least\ once) = \gamma_C \frac{t_I}{n_C} + (1 - \gamma_C)\frac{t_E}{n_A}$$

There is no waste of resources due to duplication. Next, I turn to the characterization of the equilibrium investments in R&D.

5 Equilibrium investments

In this model, the incumbent always invests in his patented technology when he does R&D. He invests the amount of resources, p_I, which maximizes his expected payoff Π_I, where subscript I denotes incumbent. The entrant, on the other hand, chooses both which technology to invest in, denoted i, and the level of investment, p_E, which maximizes his expected payoff Π_E, where subscript E denotes entrant. Each firm's investment translates directly into its probability of innovating. The timing of the game is as follows: First, the entrant chooses which technology to invest in. Second, given the entrant's technology choice, both firms simultaneously decide how much to invest. An equilibrium is a triplet $\{i^*, p_I^*, p_E^*\}$, $i \in \{C, A\}$ and $p_I, p_E \in [0,1]$ such that $i^*, p_E^* = \arg\max_{i,p_E} \Pi_E(i, p_I^*, p_E)$ and $p_I^* = \arg\max_{p_I} \Pi_I(i^*, p_I, p_E^*)$. I divide the equilibria into two types given the entrant's choice of i:

- If the entrant chooses C, the equilibrium is of type C
- If the entrant chooses A, the equilibrium is of type A

First, the investments in equilibrium of type C are characterized, and then investments in equilibrium of type A. In order to interpret the firms' investments as probabilities of innovation, each investment must be bounded above by 1. I focus on the case when the optimal investment levels by both firms are interior solutions. In the baseline model, this is achieved by setting both V and the marginal cost of investment equal to 1. The effects of varying V will be analyzed in Section 7.

5.1 Equilibrium of type C

The expected payoff to the incumbent when both firms choose technology C is

$$\begin{aligned}\Pi_I\left(C, p_I, p_E\right) &= \alpha V + \gamma_C p_I (1-p_E)(V-\alpha V) + \gamma_C p_E (1-p_I)(0-\alpha V) \\ &\quad + \gamma_C p_E p_I \left(\frac{1}{2}\left(V-\alpha V\right) + \frac{1}{2}(0-\alpha V)\right) - \frac{\left(p_I\right)^2}{2} \qquad (1)\end{aligned}$$

where the subscript I denotes incumbent. With probability $\gamma_C p_I(1-p_E)$ the incumbent innovates whereas the entrant does not. The gain is $V(1-\alpha)$, the value of the innovation net of current profit, since the new product replaces the old one. Following Katz and Shapiro (1987), I refer to $V(1-\alpha)$ as the incumbent's stand-alone incentive to innovate, i.e. the difference in profit after versus before he innovates if he believes his rival will not innovate. With probability $\gamma_C p_E(1-p_I)$ the entrant innovates but not the incumbent, and the latter loses his current profits. With probability $\gamma_C p_E p_I$ both firms innovate, in which case the incumbent has probability $\frac{1}{2}$ of obtaining the patent. The variable cost of R&D is $\frac{(p_I)^2}{2}$. The first order condition yields

$$p_I = \gamma_C V \left(1 - \alpha - p_E\left(\frac{1}{2} - \alpha\right)\right)$$

The incumbent's investment p_I is increasing in γ_C and in $V(1-\alpha)$. It can be increasing or decreasing in p_E, depending on the value of α. There are two opposing forces at work: A higher investment by the entrant lowers the probability that the incumbent wins the patent, given his own investment, which decreases his incentives to invest in order to win. At the same time, a higher investment by the entrant increases the probability that the entrant wins. This increases the incumbent's returns to investing in order not to lose current profit and to increase the probability that both innovate, which increases his expected payoff by $\frac{V}{2}$. This effect increases the incumbent's incentive to invest. When $\alpha > \frac{1}{2}$, current profits are high relative to the value of innovation and expected payoff from winning is low. The latter effect dominates. When, $\alpha < \frac{1}{2}$, current profits are low relative to the value of innovation, and the first effect dominates. The cutoff point is at $\alpha = \frac{1}{2}$, which follows from the assumption that if both firms innovate, each firm has probability $\frac{1}{2}$ of obtaining the patent.

The expected payoff to the entrant when both firms choose technology C is

$$\Pi_E\left(C, p_I, p_E\right) = \gamma_C p_E(1-p_I)V + \gamma_C p_E p_I \frac{1}{2}V - \frac{\left(p_E\right)^2}{2} \tag{2}$$

With probability $\gamma_C p_E(1-p_I)$ the entrant wins V. With probability $\gamma_C p_E p_I$ both firms innovate, in which case the entrant gets V with probability $\frac{1}{2}$. The first order condition yields

$$p_E = \gamma_C V\left(1 - \frac{p_I}{2}\right) \tag{3}$$

The entrant's investment is decreasing in the incumbent's, for all parameter values. Solving for Nash equilibrium investment levels, given $V = 1$, yields the following investment by the incumbent and the entrant, respectively.

$$p_I^C(\alpha, \gamma_C) = \frac{2\gamma_C\left(2(1-\alpha) + 2\alpha\gamma_C - \gamma_C\right)}{\left(4 + 2\alpha\gamma_C^2 - \gamma_C^2\right)} \tag{4}$$

$$p_E^C(\alpha, \gamma_C) = \frac{2\gamma_C\left(2 + \alpha\gamma_C - \gamma_C\right)}{\left(4 + 2\alpha\gamma_C^2 - \gamma_C^2\right)} \tag{5}$$

where the superscript C indicates that the equilibrium is of type C. The incumbent's equilibrium investment $p_I^C(\alpha, \gamma_C)$ is increasing in γ_C and decreasing in α. The entrant's equilibrium investment $p_E^C(\alpha, \gamma_C)$ is increasing in γ_C and α. An increase in γ_C implies a higher probability that technology C leads to the next innovation, which increases both firms' investments. An increase in α decreases the incumbent's stand-alone incentive to innovate, $V(1-\alpha)$, which reduces his investment. The entrant responds to this reduction by increasing his investment.

As long as $\alpha > 0$, $p_I^C(\alpha, \gamma_C) < p_E^C(\alpha, \gamma_C)$. The fact that the incumbent stands to lose current profit from innovating, while the entrant does not, implies that in equilibrium the incumbent invests less. This is the Arrow effect. When the two firms invest in the same technologies, innovation is characterized by leapfrogging, i.e. the incumbent is less likely than the entrant to be the next innovator.

5.2 Equilibrium of type A

The expected payoff to the incumbent when the entrant chooses technology A is

$$\Pi_I\left(A, p_I, p_E\right) = \alpha V + \gamma_C p_I (V - \alpha V) + (1-\gamma_C) p_E (0 - \alpha V) - \frac{(p_I)^2}{2}$$

The assumption that one of the technologies leads to innovation, but not both, implies that the incumbent's optimal investment is independent of that of the entrant's. Taking the first order condition, given $V = 1$, yields

$$p_I^A(\alpha, \gamma_C) = \gamma_C\left(1-\alpha\right)$$

where the superscript A indicates that the equilibrium is of type A. The expected payoff to the entrant when he chooses technology A is

$$\Pi_E\left(A, p_I, p_E\right) = (1-\gamma_C) p_E V - \frac{(p_E)^2}{2}$$

Taking the first order condition, given $V = 1$, yields

$$p_E^A(\gamma_C) = (1-\gamma_C)$$

As above, the entrant's optimal investment is independent of the investment by the incumbent.

In this equilibrium, the incumbent invests in a technology that is more likely to lead to the next innovation, which increases his incentives to invest relative to the entrant's. If this effect is sufficiently strong, it can dominate the Arrow effect. If the following condition holds

$$\gamma_C > \frac{1}{2-\alpha} \tag{6}$$

the incumbent is more likely to innovate than the entrant. The threshold value for γ_C defined by (6) is increasing in α and takes values in the interval $\left(\frac{1}{2}, 1\right)$. A lower stand-alone incentive for the incumbent to innovate requires a higher probability of success for technology C in order to offset it.

5.3 The entrant's choice of technology

Let us return to the entrant's decision of which technology to invest in. The entrant chooses the technology which gives the highest expected payoff, given the equilibrium investments described above. The condition for when choosing C has a higher expected payoff than choosing A is given below.

Proposition 1 *If (7) holds, then the Nash equilibrium is of type C.*

$$\alpha > \frac{4 - 8\gamma_C + \gamma_C^2 + \gamma_C^3}{2\gamma_C^3} = \bar{\alpha} \tag{7}$$

Proof. See Appendix ■

The higher is α, the lower will the incumbent's investment be, which increases the entrant's expected payoff from choosing C relative to A. The threshold in (7) is decreasing in γ_C, since a larger probability of success for technology C increases the entrant's relative expected payoff from choosing C. I assume that if indifferent, the entrant chooses technology A.

6 Patent scope

In this model, the scope of a patent can be either narrow or broad. Patent scope is defined such that if the scope of the patent connected to technology C is narrow, the entrant can choose between technology C and A and hence the possible types of equilibria are both C and A. If the patent scope is broad, the entrant has to choose technology A in order to avoid patent infringement, and the equilibrium is always of type A. Consequently, patent scope determines which strategies are available to the entrant.

I assume that the patent scope does not affect V, the private value of the innovation, or α, the incumbent's current profit relative to V. One may argue that a broad scope can increase the current profits accruing to the patent holder as it discourages development of substitutes during the patented product's life. This effect would reduce the incumbent's investment in R&D under a broad scope relative to a narrow. The assumption that α is independent of scope gives an upper bound to the incumbent's investment under a broad scope. One may also argue that a firm's expectation of patent scope affects the expected value of innovating. In a dynamic model, V would correspond to the present discounted value of future profits, and if future patents are expected to be broad in scope, that may translate into a higher V, given expectations of γ_C and α. Hence, expectations of patent scope can affect firms' investments independently of their technology choices, but to assess the magnitude of this effect a dynamic model is required. In this paper, I abstract from the potential effects of patent scope on innovation through current profit and expectations of future scope, and analyze the effect through technology choice alone. Nevertheless, as a robustness check I also allow V to take a higher, exogenously given value under a broad scope relative to a narrow, to assess the impact on the model's predictions. The result is reported in Section 7.

In the case of a narrow patent scope, the entrant will choose C if (7) holds. If not, patent scope is irrelevant for the entrant's technology choice, as he chooses technology A under a narrow patent scope as well as under a broad. Therefore, the comparison of investment and innovation probabilities under differing patent scope is meaningful only under the condition $\alpha > \bar{\alpha}$.

6.1 Narrow patent scope

I start with a characterization of the investments by the two firms and the aggregate innovation probability under a narrow patent scope. Suppose that $\alpha > \bar{\alpha}$ so that the equilibrium is C. In this type of equilibrium, the entrant is more likely to innovate than the incumbent, and there will be leapfrogging, as in the standard stochastic racing and endogenous growth models.

The aggregate innovation probability is defined as the probability of at least one firm innovating. When both the entrant and the incumbent invest in the same technology there is duplication of R&D investment, and in analogy with the example in Section 4 the innovation probability is:

$$i^N = \gamma_C \left[p_I^C(\alpha, \gamma_C) + p_E^C(\alpha, \gamma_C) - p_I^C(\alpha, \gamma_C)\, p_E^C(\alpha, \gamma_C) \right] \tag{8}$$

where the superscript N denotes narrow patent scope. The amount of duplication for a given total investment is highest when the two firms' investments are equal, and it decreases as investments become more asymmetric. It reflects the fact that no firm duplicates its own research, but the higher is the potential overlap in experiments with the other firm, the higher is the probability of duplication. The innovation probability i^N is increasing in γ_C. Inspection of $\frac{\partial i^N}{\partial \alpha}$ shows that i^N is increasing in α if

$$\alpha > \frac{(\gamma_C - 2)^2}{2\gamma_C^2}$$

and decreasing otherwise. An increase in α decreases the incumbent's investment, and increases the entrant's. The net effect is a decrease in total investment, but also a decrease in duplication as the investments become more unequal. When α is sufficiently high, the reduction in total investment is offset by the decrease in duplication.

6.2 Broad patent scope

Now, I turn to a characterization of investments and the innovation probability under a broad patent scope. A broad patent scope implies that firms are in an equilibrium of type A. If γ_C is sufficiently high so that (6) holds, the incumbent is more likely to innovate than the entrant. The fact that the entrant has a monopoly on the more promising technology, given by the broad scope of the patent, provides him with an additional incentive to invest. If the patented technology has a sufficiently large advantage relative to the alternative, the incumbent becomes more likely to innovate than the entrant. Under a narrow scope, in contrast, the entrant is always more likely to innovate, irrespective of the value of γ_C. As described above, Etro (2004) explains the empirical pattern of innovation by incumbents with a first mover advantage for the incumbent, and Segerstrom and Zolnierek (1999) among others, with a technological advantage. This paper suggests an additional source of advantage for the incumbent resulting from policy, namely the scope of his patent.

The innovation probability under a broad patent scope is

$$i^B = \gamma_C p_I^A(\alpha, \gamma_C) + (1 - \gamma_C) p_E^A(\gamma_C) \tag{9}$$

where the superscript B denotes broad patent scope. Note that there is no duplication of R&D. It follows that i^B is decreasing in α. It is increasing in γ_C if (6) holds.

7 Effects of patent scope on innovation

The previous Section characterized the economy's innovation probability under the two patent regimes; a narrow and a broad scope, respectively. The effects of differing patent scope on innovation can be analyzed by comparing the ratio of the resulting innovation probabilities

$$\frac{i^N}{i^B} = \frac{\gamma_C \left[p_I^C(\alpha, \gamma_C) + p_E^C(\alpha, \gamma_C) - p_I^C(\alpha, \gamma_C) p_E^C(\alpha, \gamma_C) \right]}{\gamma_C p_I^A(\alpha, \gamma_C) + (1 - \gamma_C) p_E^A(\gamma_C)} \tag{10}$$

First, I describe how $\frac{i^N}{i^B}$ varies with the two key parameters in the model: α and γ_C.

Proposition 2 *$\frac{i^N}{i^B}$ is increasing in α.*

Proof. See Appendix ■

If the incumbent has a low stand-alone incentive to innovate, α is high, then the benefit of introducing competition in R&D on the current technology is large. The entrant invests more in case he gets access to this technology. In addition, the small investment by the incumbent relative to that of the entrant implies a low amount of duplication.

Proposition 3 *For all $\alpha \in (0, 1)$ $\arg\max_{\gamma_C} \left(\frac{i^N}{i^B} \right) < 1$.*

Proof. See Appendix ■

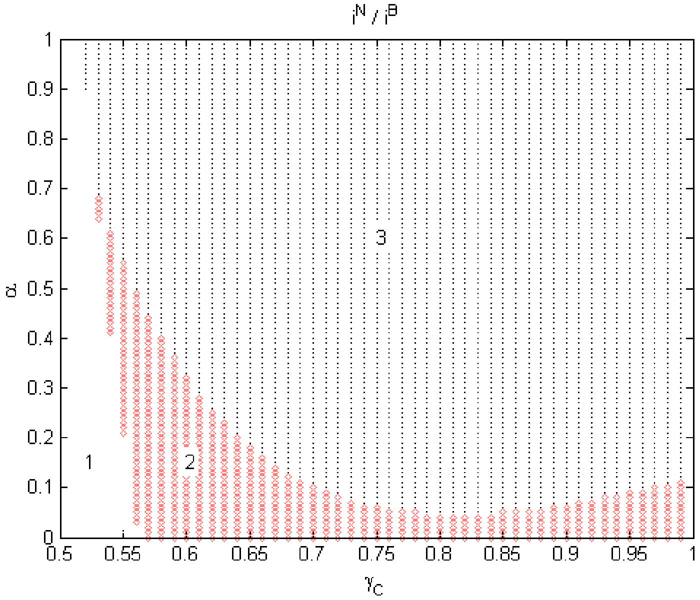
The ratio $\frac{i^N}{i^B}$ takes its highest value for $\gamma_C < 1$. The numerical solution shows that $\frac{i^N}{i^B}$ has an inverted U-shape over γ_C for all values of $\alpha \in (0, 1)$. One might have thought that the largest gain from a narrow scope would be obtained when the patented technology leads to the next innovation with probability 1, that is when there are no expected gains from doing research on an alternative technology. The intuition for this result is that for γ_C close to 1, an increase in γ_C increases total investment under both a narrow and a broad scope, but under a narrow scope there is a high degree of duplication. The duplication effect implies that $\frac{i^N}{i^B}$ decreases.

Now, I return to the assumption that both technologies cannot simultaneously lead to an innovation. This assumption is made for tractability, rather than as a description of reality. Relaxing the assumption will have the following implication for the results. Given a positive probability that both firms find an innovation when they invest in different technologies, there is now strategic interaction between the two firms in equilibrium of type A, which reduces the level of total investment in that equilibrium. Suppose both firms find an innovation. Each firm can obtain a patent, and if they can collude, each firm will earn $\frac{V}{2}$ from selling its innovation. If not, the expected gains from innovation are lower, which further reduces the level of investment in equilibrium of type A. Consequently, the assumption does not affect the the main results of the model, but introduces a level effect on the investments under a broad scope. Hence, it gives an upper bound on the benefit of a broad scope compared to a narrow scope.

7.1 Does a broad scope give a higher probability of innovation?

In order to assess the effects on innovation of an increase in patent scope, it is instructive to return to the trade-off between total investment and allocation of investment. A narrow patent scope allows both firms to do research on the most promising technology, but gives rise to duplication of R&D. This effect decreases the numerator of $\frac{i^N}{i^B}$. A broad patent scope forces the entrant to do research that is ex ante less promising, and he has a lower probability of innovation, which decreases the denominator of $\frac{i^N}{i^B}$. In order to answer the question: Does a broader scope give a higher probability of innovation?, it remains to determine which effect dominates, and under what conditions. That is, when is $i^B > i^N$ and vice versa? I solve for the innovation probabilities for all values of $\gamma_C \in [0.5, 1]$ and $\alpha \in [0, 1]$ and the result is shown in Figure 1.

Figure 1



Area 1: patent scope is inconsequential.Area 2: $i^N < i^B$.Area 3: $i^N > i^B$.

In Figure 1, the area labelled 1 is the area in which the entrant chooses equilibrium A even under a narrow scope and the patent scope has no effect on the innovation probabilities. The area labelled 2 is the one in which the broad scope gives the highest probability of innovation, whereas area 3 is the one in which a narrow scope gives the highest probability of innovation. Figure 1 shows that a broad scope gives a higher innovation probability for low values of γ_C and α, that is when the patented technology has a small advantage relative to the alternative and the incumbent's stand-alone incentive to innovate is high. When technology C has a small advantage, the entrant if forced to do R&D on technology A, does not reduce his investment very much. Consequently, a broad patent scope gives a higher probability of innovation. When the incumbent has a high stand-alone incentive to innovate, the amount of duplication under a narrow scope is high and a broad patent scope gives a higher probability of innovation. As seen in the Figure, for a lion's share of the parameter space, a narrow patent scope gives a higher probability of innovation.

7.2 Example from the biotechnology industry

The model developed in this paper can be used to assess whether granting a broad scope on a patent in a given market had a positive or negative impact on innovation in that market. As an illustration, consider an example of a specific patent in biotechnology. As noted in the introduction, biotechnology is an industry where a number of patents with broad scope have been granted.

The patent is on "Linked breast and ovarian cancer susceptibility gene", US patent [#5,709,999], which is owned by the National Institutes of Health, the University of Utah and the firm Myriad Genetics. The patented innovation is a method for diagnosing breast cancer. The technology used is certain mutations in the gene BRCA1 which have shown to increase a woman's probability of developing breast cancer. If a firm wants to find a new generation diagnostic method in this market, it can do R&D on the patented technology, that is search for an improved diagnostic method which identifies these mutations in BRCA1. Another option is to do R&D on an alternative technology, that is find an improved diagnostic method which identifies new mutations in BRCA1, or mutations in a different gene. The scope of this patent is broad; it covers all diagnostic tests identifying these mutations in BRCA1, irrespective of how the tests are performed[3]. In order to avoid infringement, all firms other than Myriad itself must do R&D on an alternative technology.

In order to apply the model to this example, it is necessary to assign values to the parameters γ_C and α. Starting with γ_C, the patented technology's advantage, the following argument can be made. The alternative technology relies on using other mutations than the ones described in the patent. However, these other mutations must first be identified, connected to the development of this form of breast cancer and be shown to be reliable indicators. Therefore, it is probable that doing R&D on the mutations in BRCA1 covered by the patent has a much higher probability of success than doing R&D on alternative mutations. In the model, this corresponds to a high γ_C. Next, what is $1-\alpha$, the incumbent's stand-alone incentive to innovate? According to Orsi and Coriat (2005), the incentive is low. Myriad has not made improvements on its own test, which uses a direct sequencing method. However, French researchers at the Institute Curie have argued that Myriad's test fails to detect 10-20 percent of mutations, and that it would be possible to develop tests with higher precision, relying on "combing" techniques. The fact that no improvements have been made, suggests a high value of α. For an industry characterized by a high γ_C and a high α, the model predicts that a narrow patent scope gives the highest probability of innovation. Hence, according to the model, assigning a broad scope rather than a narrow on the patent on "Linked breast and ovarian cancer susceptibility gene" has reduced the probability of innovation in breast cancer diagnostics for the US market.

7.3 Social surplus

The previous Section shows under what conditions a broad and a narrow patent scope, respectively, gives the highest probability of innovation. However, maximizing the probability of innovation is desirable only insofar it is also socially optimal. In addition to the duplication effect, a social planner must take two other effects of R&D into account when choosing patent scope. The first effect is the social value of innovation, which is typically considered to be larger

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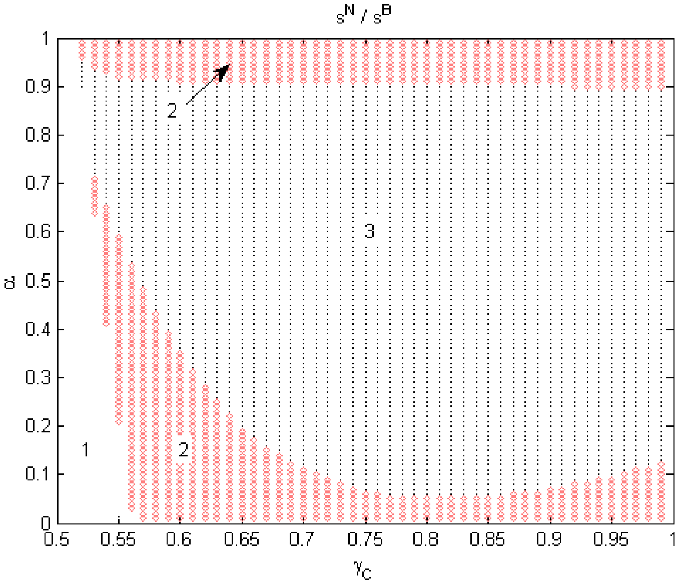
[3] See Nature, Vol. 418, July 2002

than the private value. One reason is that creation of new knowledge generates spillovers across sectors in the economy and across time. The second effect is the business stealing effect; entrant firms do not take into account the fact that as they innovate, the incumbent's profit is lost. In order to analyze which patent scope is socially optimal in this model, I define the social surplus as s^k where $k \in \{N, B\}$ denotes the patent scope. I assume that the private value of innovation is proportional to the social value. In addition, the social value of the new innovation is S and the social value of the current innovation is αS. The increase in social value from innovation is then $S(1-\alpha)$, when accounting for the business stealing effect, and it comes at a cost equal to the sum of the two firms' investment costs. The ratio of social surpluses is

$$\frac{s^N}{s^B} = \frac{i^N S(1-\alpha) - \frac{\left(p_I^C(\alpha,\gamma_C)\right)^2 + \left(p_E^C(\alpha,\gamma_C)\right)^2}{2}}{i^B S(1-\alpha) - \frac{\left(p_I^A(\alpha,\gamma_C)\right)^2 + \left(p_E^A(\gamma_C)\right)^2}{2}}$$

Suppose that the social value is 5 times larger than the private value of innovation, $S = 5V$. I solve numerically for the social surpluses to see when $\frac{s^N}{s^B} > 1$. The result is shown in Figure 2.

Figure 2



Area 1: patent scope is inconsequential.Area 2: $s^N < s^B$.Area 3: $s^N > s^B$.

In the comparison of social surpluses in Figure 2, it is notable that for most values of α, the patent scope which maximizes the probability of innovation is also the scope that is socially optimal. However, when α is close to 1, a broad scope, which gives the lowest probability of innovation in this parameter range, gives the highest surplus. The reason is that the innovation generates such a small increase in social value that it is optimal to restrict the investments in R&D. The level of α above which restricting investments is optimal depends on the ratio of social to private value of innovation, which in this example was set to 5. If the ratio is large enough, restricting investment will never be optimal. The tentative conclusion is that the socially optimal patent scope is that which maximizes the probability of innovation, except when the increase in social value from the innovation is small.

7.4 Effects of varying the private value of innovation

In the baseline model, I have set $V = 1$ in order to assure that equilibrium investments are bounded above by 1. This precludes any analysis of the effects of varying the private value of innovation. Now, I allow for corner solutions where $p_I, p_E = 1$, and analyze the effects of an increase in V. It is still assumed that both technologies give rise to innovations of equal value. The result is that an increase in the value of innovation has two effects. First, compared to Figure 1 it increases the area of parameter space for which patent scope is inconsequential. The intuition for this result is that an increase in V increases the incumbent's investment, which decreases the entrant's payoff in equilibrium of type C but not A. Second, it increases the area of parameter space for which a broad scope gives a higher innovation probability than a narrow scope. The reason is that an increase in V increases the investment by both firms, but under a narrow scope there is also an increase in the amount of duplication.

As a robustness check, I also allow V to take a higher, exogenously given value under a broad patent scope relative to a narrow. If firms expect the value of innovation to be higher under a broad scope, that increases incentives to invest under a broad scope relative to a narrow, and one may expect a decrease in $\frac{i^N}{i^B}$. Let $V^B = \theta V^N, \theta > 1$. First, the model is solved for $\theta = 1.5$; firms expect that obtaining a broad patent scope increases the value of innovation by 50 percent. The result is an increase in the area of parameter space for which a broad scope gives a higher innovation probability than a narrow scope, as compared to Figure 1. However, it is still the case that a broad patent scope gives the highest innovation probability for *less* than half of the total area of parameter space spanned by α and γ_C. The model is also solved for $\theta = 2$; firms expect the broad patent scope to double the value of innovation, which should be an upper bound on the differences in V caused by patent scope. Nevertheless, a broad patent scope gives the highest innovation probability only for *less* than two thirds of the total area of the parameter space.

8 Extensions of the model

Until now, it has been assumed that both firms simultaneously decide how much to invest. In addition, it has been assumed that the entrant cannot enter into a licensing agreement with the incumbent in case of infringement on the incumbent's patent. However, many industries are characterized by precommitment in R&D investment or licensing agreements among firms. Therefore, it is important to investigate if, and how the effects of an increase in scope depend on these assumptions. In this section, each of the two assumptions will be relaxed in turn.

8.1 Stackelberg competition

Suppose that the incumbent can commit to an investment in R&D. For example, he builds a new research lab or employs researchers. The incumbent then acts as a Stackelberg leader. The entrant observes the incumbent's investment, and then decides which technology to invest in, and how much to invest. In the equilibrium of type C, the firms' optimal investments are dependent on each other. If the incumbent is a Stackelberg leader, he can affect the entrant's optimal investment level. In addition, the incumbent can affect the entrant's technology choice. If the incumbent's investment is sufficiently large, the entrant will get a higher expected payoff from choosing technology A than from choosing C. Hence, by sufficient overinvestment, the incumbent can keep the entrant out of technology C. When the equilibrium is of type A, the firms' investments are independent of each other. Hence, unlike in equilibrium of type C, the incumbent is not able to affect the entrant's optimal investment level in this equilibrium by moving first. The entrant optimally invests $p_E^A(\gamma_C)$ under both Stackelberg competition and simultaneous moves.

8.1.1 Investments in equilibrium of type C

When the incumbent invests first, he takes into account the entrant's optimal response to his investment. Since the entrant's investment is no longer taken as given, there is an additional effect of the incumbent's investment on his expected payoff, through the entrant's investment. As shown in (3), the entrant's reaction function is decreasing in the investment by the incumbent. This implies that by investing more, the incumbent not only increases his probability of winning, but also indirectly decreases the entrant's probability of winning as the entrant is induced to invest less.

Let the optimal investments by the two firms in equilibrium of type C be $p_{I,S}$ and $p_{E,S}$ where subscript S denotes Stackelberg competition. In order to find the optimal investment by the incumbent, I insert (3) into (1). Taking the first order condition yields

$$p_{I,S}(\alpha,\gamma_C)=\frac{\gamma_C\left(1-\alpha-\frac{1}{2}\gamma_C+\frac{3}{2}\alpha\gamma_C\right)}{\left(1-\frac{1}{2}\gamma_C^2+\alpha\gamma_C^2\right)} \tag{11}$$

The optimal investment by the entrant is (as given by (11) and (3))

$$p_{E,S}(\alpha,\gamma_C)=\frac{\gamma_C\left(2\alpha\gamma_C-2\gamma_C-\gamma_C^2+\alpha\gamma_C^2+4\right)}{2\left(2\alpha\gamma_C^2-\gamma_C^2+2\right)}$$

Since the entrant's reaction function is decreasing in the incumbent's investment, the following holds.

Proposition 4 *For all* $\alpha \in [0,1]$ *and all* $\gamma_C \in \left[\frac{1}{2}, 1\right]$, $p_{I,S}(\alpha, \gamma_C) > p_I^C(\alpha, \gamma_C)$

Proof. See Appendix. ■

In an equilibrium of type C, if the incumbent is a Stackelberg leader, he always invests more than when the two firms move simultaneously.

8.1.2 The entrant's choice of technology

The level of investment by the incumbent which induces the entrant to choose technology A is denoted $\bar{p}_I$ and can be expressed as

$$\bar{p}_I(\gamma_C) = \frac{2\,(2\gamma_C - 1)}{\gamma_C} \tag{12}$$

The investment level $\bar{p}_I(\gamma_C)$ is increasing in γ_C. The higher is the relative advantage of technology C, the larger is the investment required to keep the entrant out of it. Note that if $\gamma_C > \frac{2}{3}$ not even the maximal investment by the incumbent, $\bar{p}_I(\gamma_C) = 1$, can prevent the entrant from choosing technology C under a narrow patent scope, and the equilibrium is always C.

8.1.3 Equilibria under narrow patent scope

Suppose that the patent scope is narrow. In order to establish which equilibrium arises under Stackelberg competition, it is necessary to determine which investment level by the incumbent gives him the highest expected payoff $\Pi_I(i, p_I, p_E)$, given the entrant's optimal response to that investment level, both as regards the latter's technology choice and investment level.

I define a threshold $\bar{\alpha}_S \in (0,1)$, where S denotes Stackelberg competition, such that the incumbent's payoff in the two types of equilibria are equal:

$$\Pi_I(A, p_I(\bar{\alpha}_S, \gamma_C), p_E(\gamma_C)) = \Pi_I(C, p_{I,S}(\bar{\alpha}_S, \gamma_C), p_{E,S}(\bar{\alpha}_S, \gamma_C))$$

Proposition 5 *If* $\alpha < \bar{\alpha}_S$ *the equilibrium is of type* A*, and if* $\alpha \geq \bar{\alpha}_S$ *the equilibrium is of type* C*.*

Proof. See Appendix ■

If $\alpha < \bar{\alpha}_S$ the incumbent will choose to strategically overinvest, and thereby he induces the entrant to choose to do R&D on technology A. If $\alpha \geq \bar{\alpha}_S$ the incumbent finds it optimal to not to strategically overinvest, and the entrant chooses technology C. The incumbent's payoff functions for different levels of α are shown in Figure 3 a and 3 b.

Figure 3 a

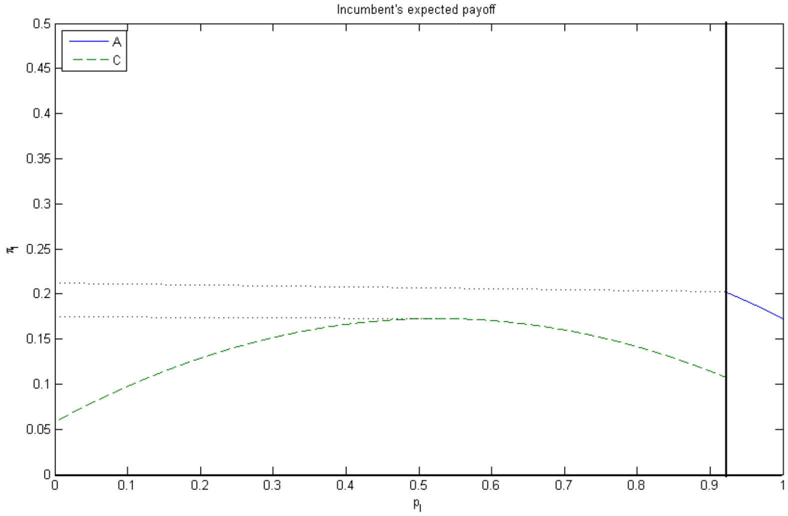
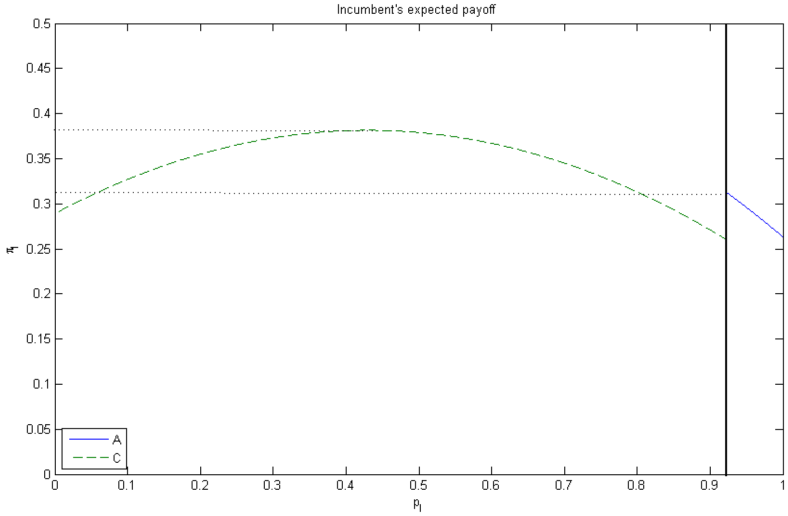


Figure 3 b



Both Figures 3 a and 3 b depict the incumbent's expected payoff Π_I as a function of his investment in equilibrium candidates C and A. The vertical line indicates the threshold level of investment $\bar{p}_I(\gamma_C)$, at which the entrant chooses technology A. Note that the incumbent's investment in equilibrium candidate A is constrained to $\bar{p}_I(\gamma_C)$ whereas in equilibrium candidate C he can invest the optimal level; $p_{I,S}(\alpha, \gamma_C)$. Figure 3a displays the case when $\alpha < \bar{\alpha}_S$. Even though investment is not at its optimal level in A, the expected payoff in A is larger than in C and the incumbent prefers A. Consequently he will strategically overinvest such that the entrant chooses technology A. Figure 3b displays the case when $\alpha > \bar{\alpha}_S$. As α increases, the incumbent's incentives for innovation decrease, and he prefers to invest less. However, it is only in equilibrium of type C that he can reduce his investment, since in equilibrium of type A he must invest at least $\bar{p}_I(\gamma_C)$. Hence, the payoff of choosing A relative to C decreases. For α above the threshold $\bar{\alpha}_S$ the incumbent has a higher expected payoff in equilibrium of type C and will induce the entrant to choose C.

8.1.4 Effects of patent scope

If the patent scope is broad, the Stackelberg competition has no effect on equilibrium investments, since the equilibrium is of type A. The innovation probability is identical to that under a broad scope with simultaneous moves, given by (9).

If the patent scope is narrow, the probability of innovation depends on which type of equilibrium firms are in. Let $i^{N,S}$ denote the innovation probability under a narrow scope. If the equilibrium is of type A, there is no duplication of R&D, and hence the only difference between the patent regimes is that under a narrow scope, the incumbent strategically overinvests, and $\bar{p}_I(\gamma_C) > p_I^A(\alpha, \gamma_C)$.[4] Hence, total investment in R&D is higher under a narrow scope, and it follows that $i^{N,S} > i^B$. If the equilibrium is of type C, the innovation probability is

$$i^{N,S} = \gamma_C \left[p_{I,S}(\alpha, \gamma_C) + p_{E,S}(\alpha, \gamma_C) - p_{I,S}(\alpha, \gamma_C) p_{E,S}(\alpha, \gamma_C) \right]$$

In this equilibrium, there is duplication of R&D, as under simultaneous moves. Which patent scope gives the highest innovation probability depends on α and γ_C, as shown in Figure 4.

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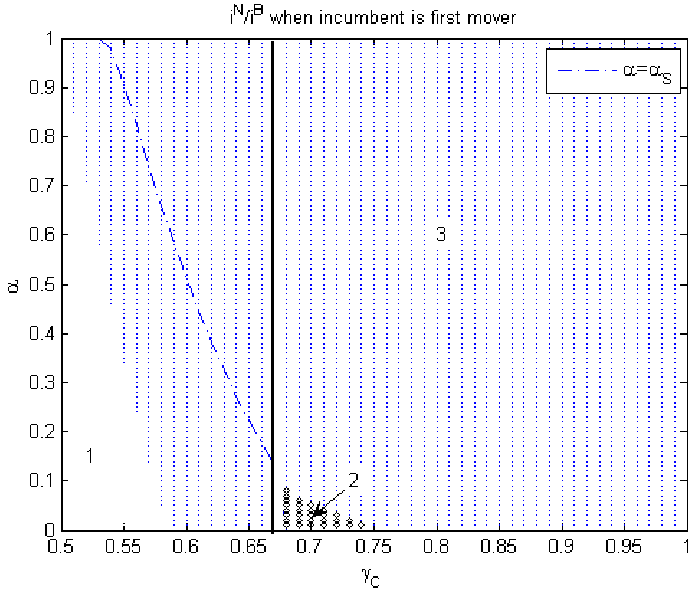
[4] If $\bar{p}_I(\gamma_C) \leq p_I^A(\alpha, \gamma_C)$, then the entrant would choose technology A even under a narrow patent scope, and patent scope has no effect on innovation probabilities.

Figure 4



Area 1: patent scope is inconsequential.Area 2: $i^{N,S} < i^B$.Area 3: $i^{N,S} > i^B$.

Figure 4 shows that a broad scope gives a higher probability of innovation for a small subset of parameter space, denoted area 2. This holds for values of α close to zero, and values of γ_C close to 0.7. In this area, the incumbent is not able to overinvest and keep the entrant out, since $\gamma_C > \frac{2}{3}$, and the equilibrium is C. However, the incumbent can still affect the entrant's optimal investment level, and the first mover advantage implies that the incumbent invests more, and the entrant less, relative to under simultaneous moves. Now, the negative effects of duplication are sufficiently large that a broad scope gives a higher probability of innovation. To the left of area 2, the equilibrium under a narrow scope is of type A, as the incumbent chooses to overinvest sufficiently to keep the entrant out of technology C. There is no duplication, and a narrow scope gives a higher probability of innovation. To the right of area 2, a higher value of γ_C increases total investments under a narrow scope sufficiently to render it a higher innovation probability than a broad.

If we compare Figures 1 and 4 it is clear that the subset of parameter space for which a broad patent scope gives a higher innovation probability is now substantially smaller. The conclusion is that the effect of patent scope on the innovation probability depends on whether the incumbent can commit to investing or not. If commitment is possible, the potential benefit of a broad scope is substantially smaller.

8.2 Licensing

Until now, any licensing agreement between the two firms has been precluded. It has been assumed that the incumbent always chooses to block the entrant's innovation, if it infringes on his patent. However, if the two firms can write a license agreement, the incumbent may choose to license its technology to the entrant, in return for a license fee. Suppose that the patent on technology C is broad in scope, but the entrant nevertheless chooses to do R&D on technology C. If he innovates and the incumbent does not, the incumbent has two options: he can block the entrant's innovation, and earn his current monopoly profit, αV, or he can license his technology to the entrant, lose current profit but earn a license revenue in form of a fixed fee, F. I assume that the agreement is written ex post, after the entrant has innovated. If the incumbent agrees to license, it implies that the entrant has two strategies available under a broad patent scope. Either he chooses technology A, which gives him V if he innovates, or he chooses technology C which gives him V less the license fee F if he innovates.

The license fee will be determined by bargaining between the licensor and the licensee. The share of surplus from the licensing agreement that goes to each firm depends on its outside option and its relative bargaining power. The incumbent's outside option is to continue selling his patented product, with profit αV. The entrant's outside option is his expected payoff from choosing to do R&D on technology A instead. First, suppose that the incumbent has all the bargaining power. Then he will demand a license fee such that the entrant receives only his outside option, and the entrant always chooses to do R&D on technology A. This implies that if the incumbent has all bargaining power, allowing for license agreements has no effect on equilibrium investments nor innovation probabilities. This maximum fee gives the lower bound on the effects of licensing agreements on investments, which is zero. If, on the other hand, the entrant has all bargaining power, the incumbent will receive a fee equal to his outside option, $F = \alpha V$. The lower is the license fee, the more likely is it that the entrant will choose technology C. Hence, the minimum license fee gives the upper bound on the effects of licensing agreements. If the bargaining powers lie in between these two extremes, the effect of licensing on investments and innovation falls between zero and the upper bound. In order to find the upper bound, I determine the effect of licensing on equilibrium outcomes for the minimum license fee $F = \alpha V$. [5]

8.2.1 Equilibrium of type C

The expected payoff to the incumbent when both firms choose technology C and the entrant obtains a license in case he innovates is

$$\begin{aligned}\Pi_{I,L}(C, p_I, p_E) &= \alpha V + \gamma_C p_I(1-p_E)(V-\alpha V) + \gamma_C p_E(1-p_I)\,(0) \\ &\quad + \gamma_C p_E p_I \left(\frac{1}{2}\,(V-\alpha V) + \frac{1}{2}\,(0)\right) - \frac{(p_I)^2}{2}\end{aligned}$$

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[5] As in the baseline model, I assume that if indifferent, the entrant chooses technology A.

where the subscript L denotes licensing. The difference between this expected payoff and (1) is that in case the entrant wins, the incumbent licenses the technology, gets license fee αV and loses current profit αV. The net gain is zero. In case both innovate and the entrant gets the patent, the net gain is again zero.

The expected payoff to the entrant when both firms choose technology C and the entrant obtains a license in case he innovates is

$$\Pi_{E,L}(C, p_I, p_E) = \gamma_C p_E (1 - p_I)(V - \alpha V) + \gamma_C p_E p_I \frac{1}{2}(V - \alpha V) - \frac{(p_E)^2}{2}$$

The difference between this expected payoff and (2) is that the entrant, in case he wins must pay a license fee, and the net gain is $V - \alpha V$. Solving for the Nash equilibrium yields:

$$p_{I,L}(\alpha, \gamma_C) = p_{E,L}(\alpha, \gamma_C) = \frac{2\gamma_C(1-\alpha)}{2 + \gamma_C(1-\alpha)}$$

The optimal investments for the entrant and the incumbent are identical. The reason is that through the license fee, the entrant indirectly takes into account the incumbent's profit loss. In addition, the incumbent's expected payoff from not innovating when the entrant does is zero since the license revenue compensates him for the loss of current profit. Comparing these investments to their counterparts in equilibrium C in the baseline model, (4) and (5), I find that for all $\alpha > 0$,

$$p_{I,L}(\alpha, \gamma_C) < p_I^C(\alpha, \gamma_C) \quad (13)$$

$$p_{E,L}(\alpha, \gamma_C) < p_E^C(\alpha, \gamma_C) \quad (14)$$

The entrant invests less under licensing because the net reward to innovation is lower, and the incumbent invests less because he has less to lose from not innovating.

8.2.2 The entrant's choice of technology

Under licensing, the entrant chooses between doing R&D on technology C which has a higher probability of success, but where the payoff is reduced to $V - \alpha V$ or technology A which has a lower probability of success but yields a payoff of V. It is possible to derive a condition for when the entrant chooses technology C over A.

Proposition 6 *Let the licensing fee be αV. The entrant chooses technology C even under a broad patent scope if*

$$\alpha < \frac{3\gamma_C - 2 + \gamma_C^2}{\gamma_C + \gamma_C^2} = \bar{\alpha}_L \quad (15)$$

Proof. See Appendix ■

The entrant chooses technology C for sufficiently low α, that is when the license fee is sufficiently low. The threshold $\bar{\alpha}_L$, where L denotes licensing, is increasing in γ_C. A higher advantage for technology C relative to A increases the payoff to the entrant from choosing C.

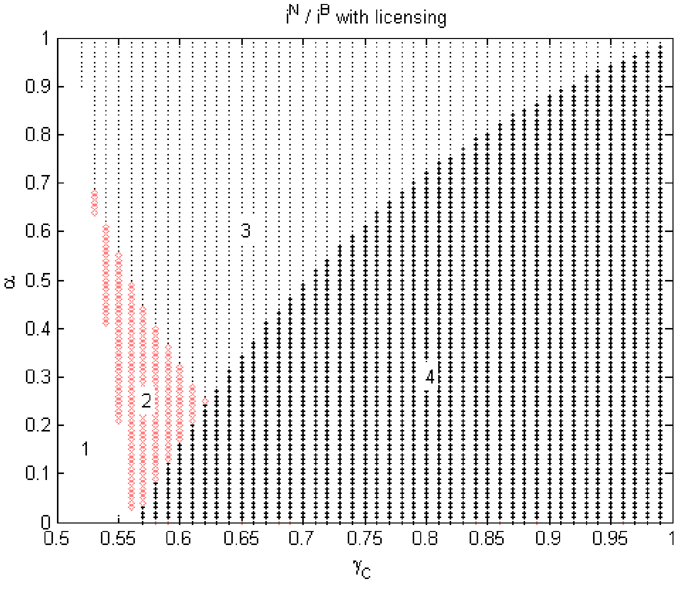
8.2.3 Effects of patent scope

When licensing is allowed, a broad patent scope does not necessarily reduce duplication. When (15) holds, the entrant chooses technology C even though a new innovation would infringe on the patent. Hence, the two firms invest in the same technology even under a broad patent scope. The probability of innovation is:

$$i^{B,L} = \gamma_C \left[p_{I,L}(\alpha, \gamma_C) + p_{E,L}(\alpha, \gamma_C) - p_{I,L}(\alpha, \gamma_C) \, p_{E,L}(\alpha, \gamma_C) \right]$$

where superscript L denotes licensing. Under a narrow scope, no license is required and the innovation probability is identical to that under no licensing; as given by (8). The subset of parameter space where the entrant chooses to do R&D on technology C and obtain a license is shown in Figure 5.

Figure 5



Area 1: patent scope is inconsequential.Area 2: $i^N < i^B$.Area 3: $i^N > i^B$.Area 4: (15) holds and $i^N > i^{B,L}$.

In Figure 5, the areas 1, 2 and 3 are the subsets of parameter space where under a broad scope, the entrant chooses technology A even when he has the option to get a license. The innovation probabilities are unaffected by the licensing option. In area 4, the entrant finds it profitable to use the licensing option and chooses C. For this subset of parameter space, the innovation probability is higher under a narrow scope. The reason is that there is now duplication of R&D under both narrow and broad scope and in addition, the incumbent and entrant both invest less under a broad scope, as shown by (13) and (14). [6]

Comparing Figures 1 and 5, one can conclude that the area of the parameter space where a broad scope gives a higher probability of innovation is smaller with licensing than without. If licensing is possible and the entrant has some bargaining power, the benefit of a broad patent scope is smaller.

9 Concluding comments

The model developed in this paper is motivated by the perceived increase in patent scope in the US in the last two decades. The model predicts the level of investment in R&D and the innovation probability resulting from a narrow and broad patent scope respectively. It suggests a new explanation for the empirical fact that incumbent firms have high innovation rates relative to entrant firms. An incumbent firm can be more likely to innovate even in absence of any technological or cost advantage, if the firm has an advantage originating from policy, namely a broad scope on the patent he owns.

The main finding is that if the incumbent has a high stand-alone incentive to innovate and the patented technology has a small advantage relative to alternative technologies, a broad patent scope gives a higher probability of innovation than a narrow. Consequently, the negative effects of duplication of R&D investments are under some conditions large enough to warrant a broad patent scope. Conversely, when the incumbent's stand-alone incentive is low or the patented technology has a large advantage, a narrow patent scope gives a higher probability of innovation. When the incumbent can commit to an investment level, or when license agreements can be made, the first result is partly reversed; in instances where previously the highest innovation probability was given by a broad scope, it is now obtained under a narrow scope. Consequently, the benefit of a broad patent scope largely relies on the assumptions that the firms act simultaneously and that there is no possibility for licensing agreements.

This paper shows that the effects of an increase in patent scope depends on innovation and industry characteristics. It is possible that an increase in patent scope increases the probability of innovation in a given industry. However, it requires that specific conditions on the form of competition, the technological

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[6] Figure 5 depicts the maximal effect of licensing agreements, which is when the entrant has all the bargaining power. If the incumbent has some bargaining power, that increases the license fee, which shifts area 4 to the right. If the incumbent has all the bargaining power, area 4 disappears completely and licensing has no effect on innovation probabilities.

alternatives, the expected profits and the opportunities for license agreements are met. If not, the result is a reduction in the probability of innovation. A uniform increase in patent scope, such as awarding patent holders larger powers in infringement lawsuits, cannot be an optimal policy.

The conclusion raises a new question: is the optimal policy implementable? In order to set the optimal scope ex ante, the Patent Office must make predictions of for example the technology's advantage relative to alternatives and the patent holder's incentive for further improvement of the innovation he seeks to patent. This might seem as an inherently difficult task for the patent examiner. However, the patent scope is also determined ex post, if the patent holder sues another party for infringement. At this point in time, the industry characteristics are observed rather than predicted. The court, deciding whether a product infringes on the patent or not, can at least in principle obtain information on alternative technologies and the incumbent's stand-alone incentive for innovation. If the court finds that a narrow scope would have generated a higher rate of innovation, it should decide that the product was not infringing on the patent. If entrant firms anticipate such a decision by the court, they will make the desirable technology choice.

A direction for future research is to increase the realism of the model by extending it to a dynamic framework, where the effects of expectations and the dynamics of technology development can be analyzed.

Appendix

Proof of proposition 1

To compute the expected payoff to the entrant in equilibrium of type C I insert the equilibrium investments $p_I^C(\alpha,\gamma_C) = \frac{2\gamma_C(2(1-\alpha)+2\alpha\gamma_C-\gamma_C)}{\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)}$, $p_E^C(\alpha,\gamma_C) = \frac{2\gamma_C(2+\alpha\gamma_C-\gamma_C)}{\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)}$ into

$$\Pi_E\left(C,p_I,p_E\right) = \gamma_C p_E(1-p_I)V + \gamma_C p_E p_I \frac{1}{2}V - b\frac{(p_E)^2}{2}$$

Given $V=1$,the expression can be simplified to

$$\Pi_E\left(C,p_I^C(\alpha,\gamma_C),p_E^C(\alpha,\gamma_C)\right) = \frac{2\gamma_C^2\left(2+\alpha\gamma_C-\gamma_C\right)^2}{\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)^2}$$

To compute the expected payoff to the entrant in equilibrium of type A, I insert $p_E^A\left(\gamma_C\right) = (1-\gamma_C)$ into

$$\Pi_E\left(A,p_I,p_E\right) = (1-\gamma_C)p_E V - \frac{(p_E)^2}{2}$$

Given $V=1$,the expression can be simplified to

$$\Pi_E\left(A,p_I,p_E^A\left(\gamma_C\right)\right) = \frac{1}{2}\left(1-\gamma_C\right)^2$$

The entrant chooses technology C if

$$\begin{aligned}\Pi_E\left(C,p_I^C(\alpha,\gamma_C),p_E^C(\alpha,\gamma_C)\right) &> \Pi_E\left(A,p_I,p_E^A\left(\gamma_C\right)\right)\\ \frac{2\gamma_C^2\left(2+\alpha\gamma_C-\gamma_C\right)^2}{\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)^2} &> \frac{1}{2}\left(1-\gamma_C\right)^2\end{aligned}$$

which can be simplified to

$$\alpha > \frac{4-8\gamma_C+\gamma_C^2+\gamma_C^3}{2\gamma_C^3}$$

Proof of proposition 2

$$\frac{i^N}{i^B} = \frac{2\gamma_C^2\left(20\alpha\gamma_C-16\gamma_C-8\alpha+4\gamma_C^2-6\alpha\gamma_C^2-\alpha\gamma_C^3+2\alpha^2\gamma_C^3+16\right)}{\left(\gamma_C^2\left(1-\alpha\right)+\left(1-\gamma_C\right)^2\right)\left(4+2\alpha\gamma_C^2-\gamma_C^2\right)^2}$$

The derivative of $\frac{i^N}{i^B}$ with respect to α is

$$\frac{\partial\left(\frac{i^N}{i^B}\right)}{\partial\alpha} = 2\gamma_C^2\frac{\begin{pmatrix}144\gamma_C-240\gamma_C^2+296\gamma_C^3-250\gamma_C^4+117\gamma_C^5-26\gamma_C^6+2\gamma_C^7\\ +16\alpha\gamma_C^2-56\alpha\gamma_C^3+188\alpha\gamma_C^4-170\alpha\gamma_C^5+52\alpha\gamma_C^6-4\alpha\gamma_C^7\\ -32\alpha^2\gamma_C^4+72\alpha^2\gamma_C^5-24\alpha^2\gamma_C^6-2\alpha^2\gamma_C^7+4\alpha^3\gamma_C^7-32\end{pmatrix}}{\left(2\alpha\gamma_C^2-\gamma_C^2+4\right)^3\left(2\gamma_C-2\gamma_C^2+\alpha\gamma_C^2-1\right)^2}$$

The denominator of the expression above is positive, since $4 > \gamma_C^2$. Let

$$\begin{aligned}
F(\gamma_C, \alpha) \;\; = \;\; & 144\gamma_C - 240\gamma_C^2 + 296\gamma_C^3 - 250\gamma_C^4 + 117\gamma_C^5 - 26\gamma_C^6 + 2\gamma_C^7 + 16\alpha\gamma_C^2 \\
& -56\alpha\gamma_C^3 + 188\alpha\gamma_C^4 - 170\alpha\gamma_C^5 + 52\alpha\gamma_C^6 - 4\alpha\gamma_C^7 - 32\alpha^2\gamma_C^4 + 72\alpha^2\gamma_C^5 \\
& -24\alpha^2\gamma_C^6 - 2\alpha^2\gamma_C^7 + 4\alpha^3\gamma_C^7 - 32
\end{aligned}$$

$\frac{\partial\left(\frac{i^N}{i^B}\right)}{\partial\alpha}$ is positive if $F(\gamma_C, \alpha) > 0$. Applying constrained optimization, the problem can be formulated as

$$\min_{\gamma_C, \alpha} F(\gamma_C, \alpha) \quad \textit{subject to} \quad 0 \leqslant \alpha \leqslant 1 \quad 0.5 \leqslant \gamma_C \leqslant 1$$

where $F(\gamma_C, \alpha)$ is continuously differentiable. The global minimum of $F(\gamma_C, \alpha)$ is $F(0.5, 0) = 4.6$. Hence, for $\gamma_C \in [0.5, 1]$ and $\alpha \in [0, 1]$ we have that $\frac{\partial\left(\frac{i^N}{i^B}\right)}{\partial\alpha} > 0$.

Proof of proposition 3

The derivative of $\frac{i^N}{i^B}$ with respect to γ_C is

$$\frac{\partial\left(\frac{i^N}{i^B}\right)}{\partial\gamma_C} = 2\gamma_C \frac{\left(\begin{array}{c}
304\alpha\gamma_C - 320\gamma_C - 64\alpha + 352\gamma_C^2 - 336\gamma_C^3 + 256\gamma_C^4 - 104\gamma_C^5 + 16\gamma_C^6 \\
-496\alpha\gamma_C^2 + 640\alpha\gamma_C^3 - 688\alpha\gamma_C^4 + 365\alpha\gamma_C^5 - 64\alpha\gamma_C^6 - 2\alpha\gamma_C^7 + 32\alpha^2\gamma_C^2 \\
-176\alpha^2\gamma_C^3 + 432\alpha^2\gamma_C^4 - 364\alpha^2\gamma_C^5 - 64\alpha^3\gamma_C^4 + 76\alpha^2\gamma_C^6 + 100\alpha^3\gamma_C^5 \\
+9\alpha^2\gamma_C^7 - 24\alpha^3\gamma_C^6 - 12\alpha^3\gamma_C^7 + 4\alpha^4\gamma_C^7 + 128
\end{array}\right)}{\left(2\alpha\gamma_C - \gamma_C^2 + 4\right)^3 \left(2\gamma_C - 2\gamma_C^2 + \alpha\gamma_C^2 - 1\right)^2}$$

The denominator of this expression is positive since $4 > \gamma_C^2$. Let

$$\begin{aligned}
G(\gamma_C, \alpha) \;\; = \;\; & 304\alpha\gamma_C - 320\gamma_C - 64\alpha + 352\gamma_C^2 - 336\gamma_C^3 + 256\gamma_C^4 - 104\gamma_C^5 + 16\gamma_C^6 \\
& -496\alpha\gamma_C^2 + 640\alpha\gamma_C^3 - 688\alpha\gamma_C^4 + 365\alpha\gamma_C^5 - 64\alpha\gamma_C^6 - 2\alpha\gamma_C^7 \\
& +32\alpha^2\gamma_C^2 - 176\alpha^2\gamma_C^3 + 432\alpha^2\gamma_C^4 - 364\alpha^2\gamma_C^5 - 64\alpha^3\gamma_C^4 + 76\alpha^2\gamma_C^6 \\
& +100\alpha^3\gamma_C^5 + 9\alpha^2\gamma_C^7 - 24\alpha^3\gamma_C^6 - 12\alpha^3\gamma_C^7 + 4\alpha^4\gamma_C^7 + 128
\end{aligned}$$

At $\gamma_C = 0$ the expression reduces to

$$G(\gamma_C, \alpha) = 128 - 64\alpha$$

which is positive for all $\alpha \in [0, 1]$. At $\gamma_C = 1$ the expression reduces to

$$G(\gamma_C, \alpha) = 9\alpha^2 - 5\alpha + 4\alpha^4 - 8$$

which is negative for all $\alpha \in [0, 1)$. $G(\gamma_C, \alpha)$ is continuous, and the intermediate value theorem can be applied. Hence, for $\alpha \in [0, 1)$ there exists at least one maximum of the function $\frac{i^N}{i^B}$ in the interval $\gamma_C \in (0, 1)$.

Proof of proposition 4

$$\begin{aligned}
p_{I,S}(\alpha, \gamma_C) &= \frac{\gamma_C\left(1 - \alpha - \frac{1}{2}\gamma_C + \frac{3}{2}\alpha\gamma_C\right)}{\left(1 - \frac{1}{2}\gamma_C^2 + \alpha\gamma_C^2\right)} \\
p_I^C(\alpha, \gamma_C) &= \frac{2\gamma_C\left(2(1 - \alpha) + 2\alpha\gamma_C - \gamma_C\right)}{\left(4 + 2\alpha\gamma_C^2 - \gamma_C^2\right)}
\end{aligned}$$

$$
\begin{aligned}
p_{I,S}(\alpha,\gamma_C) &> p_I^C(\alpha,\gamma_C) \Leftrightarrow \\
0 &> \frac{1}{2}\gamma_C\left(6\alpha\gamma_C - 2\gamma_C - 4\alpha + \gamma_C^2 - 3\alpha\gamma_C^2 - 4\alpha^2\gamma_C + 2\alpha^2\gamma_C^2\right)
\end{aligned}
$$

Let

$$J(\gamma_C,\alpha) = 6\alpha\gamma_C - 2\gamma_C - 4\alpha + \gamma_C^2 - 3\alpha\gamma_C^2 - 4\alpha^2\gamma_C + 2\alpha^2\gamma_C^2$$

Applying constrained optimization, the problem can be formulated as

$$\max_{\gamma_C,\alpha} J(\gamma_C,\alpha) \quad \textit{subject to} \quad 0 \leqslant \alpha \leqslant 1 \quad \tfrac{1}{2} \leqslant \gamma_C \leqslant 1$$

where $J(\gamma_C,\alpha)$ is continuously differentiable. The optimization yields a global maximum of $J(\gamma_C,\alpha)$ at $J(0.5,0) = -0.75 < 0$. It implies that $p_{I,S}(\alpha,\gamma_C) > p_I^C(\alpha,\gamma_C)$.

Proof of proposition 5

In equilibrium candidate of type C, the incumbent invests

$$p_{I,S}^C(\alpha,\gamma_C) = \min(p_{I,S}(\alpha,\gamma_C), \bar{p}_I(\gamma_C))$$

If

$$\alpha > \frac{3\gamma_C^3 - 8\gamma_C + 4}{\gamma_C^2(5\gamma_C - 2)} = \hat{\alpha}_1$$

then $p_{I,S}^C(\alpha,\gamma_C) = p_{I,S}(\alpha,\gamma_C)$.

In equilibrium candidate of type A the incumbent invests

$$p_{I,S}^A(\alpha,\gamma_C) = \max(p_I^A(\alpha,\gamma_C), \bar{p}_I(\gamma_C))$$

If

$$\alpha > \frac{\gamma_C^2 - 4\gamma_C + 2}{\gamma_C^2} = \hat{\alpha}_2$$

then $p_{I,S}^A(\alpha,\gamma_C) = \bar{p}_I(\gamma_C)$

There are 4 cases to consider:

Case	$p_{I,S}^C(\alpha,\gamma_C)$	$p_{I,S}^A(\alpha,\gamma_C)$
1	$\alpha < \hat{\alpha}_1$	$\alpha < \hat{\alpha}_2$
2	$\alpha > \hat{\alpha}_1$	$\alpha < \hat{\alpha}_2$
3	$\alpha < \hat{\alpha}_1$	$\alpha > \hat{\alpha}_2$
4	$\alpha > \hat{\alpha}_1$	$\alpha > \hat{\alpha}_2$

I start with case 3, and then proceed to cases 1,2 and 4.

Case 3. Compare $\Pi_I(C, \bar{p}_I(\gamma_C), p_E)$ and $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right)$. In equilibrium of type $C : p_E = \gamma_C\left(1 - \frac{\bar{p}_I(\gamma_C)}{2}\right)$

$$\begin{aligned}
\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) &= \frac{\left(-10\gamma_C^2 + 8\gamma_C + 4\gamma_C^3 + 2\alpha\gamma_C^2 - 2\alpha\gamma_C^3 - \alpha\gamma_C^4 - 2\right)}{\gamma_C^2} \\
\Pi_I(C, \bar{p}_I(\gamma_C), p_E) &= \frac{\left(-9\gamma_C^2 + 8\gamma_C + \gamma_C^3 + 2\gamma_C^4 + \alpha\gamma_C^2 + \alpha\gamma_C^3 - 3\alpha\gamma_C^4 - 2\right)}{\gamma_C^2}
\end{aligned}$$

$$\begin{aligned}
\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) &> \Pi_I(C, \bar{p}_I(\gamma_C), p_E) \Leftrightarrow \\
&\frac{\left(-10\gamma_C^2 + 8\gamma_C + 4\gamma_C^3 + 2\alpha\gamma_C^2 - 2\alpha\gamma_C^3 - \alpha\gamma_C^4 - 2\right)}{\gamma_C^2} \\
&> \frac{\left(-9\gamma_C^2 + 8\gamma_C + \gamma_C^3 + 2\gamma_C^4 + \alpha\gamma_C^2 + \alpha\gamma_C^3 - 3\alpha\gamma_C^4 - 2\right)}{\gamma_C^2}
\end{aligned}$$

which can be simplified to

$$\gamma_C^2\left(2\gamma_C - 1\right)\left(1 - \gamma_C\right)\left(1 - \alpha\right) > 0$$

For $\gamma_C > \frac{1}{2}$ and $\alpha < 1 : \gamma_C^2\left(2\gamma_C - 1\right)\left(1 - \gamma_C\right)\left(1 - \alpha\right) > 0$.The incumbent prefers A.

Case 1. Compare $\Pi_I(C, \bar{p}_I(\gamma_C), p_E)$ and $\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right)$

From case 3 it is clear that $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) > \Pi_I(C, \bar{p}_I(\gamma_C), p_E)$. In addition, $\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right) > \Pi_I(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C))$ since $p_I^A(\alpha, \gamma_C) = \arg\max_{p_I} \Pi_I(A, p_I, p_E)$. Hence, $\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right) > \Pi_I(C, \bar{p}_I(\gamma_C), p_E)$ and the incumbent prefers A.

Case 2. Compare $\Pi_I\left(C, p_{I,S}(\alpha, \gamma_C), p_{E,S}(\alpha, \gamma_C)\right)$ and $\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right)$.

$$\begin{aligned}
\Pi_I\left(C, p_{I,S}(\alpha, \gamma_C), p_{E,S}(\alpha, \gamma_C)\right) &= \frac{\left(\begin{array}{c} 8\alpha + 4\gamma_C^2 - 4\gamma_C^3 + \gamma_C^4 - 20\alpha\gamma_C^2 + 16\alpha\gamma_C^3 - 2\alpha\gamma_C^4 \\ +12\alpha^2\gamma_C^2 - 12\alpha^2\gamma_C^3 + \alpha^2\gamma_C^4 \end{array}\right)}{4\left(2\alpha\gamma_C^2 - \gamma_C^2 + 2\right)} \\
\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right) &= \frac{1}{2}\gamma_C\left(4\alpha + \gamma_C - 4\alpha\gamma_C + \alpha^2\gamma_C\right)
\end{aligned}$$

$$\Pi_I\left(A, p_I^A(\alpha, \gamma_C), p_E^A(\gamma_C)\right) > \Pi_I\left(C, p_{I,S}(\alpha, \gamma_C), p_{E,S}(\alpha, \gamma_C)\right) \Leftrightarrow$$

$$\begin{aligned}
0 &> \\
&\frac{\left(8\alpha + 4\gamma_C^2 - 4\gamma_C^3 + \gamma_C^4 - 20\alpha\gamma_C^2 + 16\alpha\gamma_C^3 - 2\alpha\gamma_C^4 + 12\alpha^2\gamma_C^2 - 12\alpha^2\gamma_C^3 + \alpha^2\gamma_C^4\right)}{4\left(2\alpha\gamma_C^2 - \gamma_C^2 + 2\right)} \\
&-\frac{1}{2}\gamma_C\left(4\alpha + \gamma_C - 4\alpha\gamma_C + \alpha^2\gamma_C\right)
\end{aligned}$$

Let

$$K(\gamma_C,\alpha) = \frac{\left(\begin{array}{c} 8\alpha + 4\gamma_C^2 - 4\gamma_C^3 + \gamma_C^4 - 20\alpha\gamma_C^2 + 16\alpha\gamma_C^3 - 2\alpha\gamma_C^4 + 12\alpha^2\gamma_C^2 \\ -12\alpha^2\gamma_C^3 + \alpha^2\gamma_C^4 \end{array}\right)}{4\left(2\alpha\gamma_C^2 - \gamma_C^2 + 2\right)} - \frac{1}{2}\gamma_C\left(4\alpha + \gamma_C - 4\alpha\gamma_C + \alpha^2\gamma_C\right)$$

I want to find the maximum value of $K(\gamma_C,\alpha)$. Applying constrained optimization, the problem can be formulated as

$$\max_{\gamma_C,\alpha} K(\gamma_C,\alpha) \quad \textit{subject to} \quad 0 \leqslant \alpha \leqslant 0.28 \quad 0.55 \leqslant \gamma_C \leqslant 0.59$$

where $K(\gamma_C,\alpha)$ is continuously differentiable. The optimization yields a global maximum of $K(\gamma_C,\alpha)$ at $K(0.55,0.28) = -0.03 < 0$. It implies that $\Pi_I\left(A, p_I^A(\alpha,\gamma_C), p_E^A(\gamma_C)\right) > \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right)$ and the incumbent prefers A.

Case 4. Compare $\Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right)$ and $\Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right)$

$$\Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) > \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) \Leftrightarrow$$

$$\begin{aligned} & \frac{\left(8\alpha + 4\gamma_C^2 - 4\gamma_C^3 + \gamma_C^4 - 20\alpha\gamma_C^2 + 16\alpha\gamma_C^3 - 2\alpha\gamma_C^4 + 12\alpha^2\gamma_C^2 - 12\alpha^2\gamma_C^3 + \alpha^2\gamma_C^4\right)}{4\left(2\alpha\gamma_C^2 - \gamma_C^2 + 2\right)} \\ > \; & \frac{\left(-10\gamma_C^2 + 8\gamma_C + 4\gamma_C^3 + 2\alpha\gamma_C^2 - 2\alpha\gamma_C^3 - \alpha\gamma_C^4 - 2\right)}{\gamma_C^2} \end{aligned}$$

Let

$$\bar{\alpha}_S = \frac{\left(\begin{array}{c} -4\gamma_C^2 + 24\gamma_C^3 - 38\gamma_C^4 + 12\gamma_C^5 + 3\gamma_C^6 \\ +2\sqrt{20\gamma_C^4 - 128\gamma_C^5 + 320\gamma_C^6 - 408\gamma_C^7 + 301\gamma_C^8 - 144\gamma_C^9 + 49\gamma_C^{10} - 10\gamma_C^{11}} \end{array}\right)}{-4\gamma_C^4 + 4\gamma_C^5 + 9\gamma_C^6}$$

For

$$\begin{aligned} \alpha & \geq \bar{\alpha}_S : \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) > \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) \\ \alpha & < \bar{\alpha}_S : \Pi_I\left(C, p_{I,S}(\alpha,\gamma_C), p_{E,S}(\alpha,\gamma_C)\right) \leq \Pi_I\left(A, \bar{p}_I(\gamma_C), p_E^A(\gamma_C)\right) \end{aligned}$$

I assume that if indifferent, the incumbent chooses C.

Show that $\alpha_1 < \bar{\alpha}_S$ for $\gamma_C \in [0.5332, 0.667]$

$$\begin{aligned} \alpha_1 &< \bar{\alpha}_S \Leftrightarrow \\ \frac{3\gamma_C^3-8\gamma_C+4}{\gamma_C^2\left(5\gamma_C-2\right)} &< \frac{\left(\begin{array}{c} -4\gamma_C^2+24\gamma_C^3-38\gamma_C^4+12\gamma_C^5+3\gamma_C^6 \\ +2\sqrt{\begin{array}{c}20\gamma_C^4-128\gamma_C^5+320\gamma_C^6-408\gamma_C^7+301\gamma_C^8\\ -144\gamma_C^9+49\gamma_C^{10}-10\gamma_C^{11}\end{array}}\end{array}\right)}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6} \end{aligned}$$

the expression can be simplified to

$$0 < 8\gamma_C^4\left(1-\gamma_C\right)\left(2\gamma_C-1\right)\left(4\gamma_C+9\gamma_C^2-4\right)\left(4\gamma_C-\gamma_C^2+\gamma_C^3-2\right)\left(2\gamma_C^2-6\gamma_C+\gamma_C^3+4\right)$$

which holds for $\gamma_C \in [0.5332, 0.6667]$.

Show that $\alpha_2 < \bar{\alpha}_S$ for $\gamma_C \in [0.5332, 0.6667]$:

$$\begin{aligned} \alpha_2 &> \bar{\alpha}_S \Leftrightarrow \\ \frac{\gamma_C^2-4\gamma_C+2}{\gamma_C^2} &< \frac{\left(\begin{array}{c} -4\gamma_C^2+24\gamma_C^3-38\gamma_C^4+12\gamma_C^5+3\gamma_C^6 \\ +2\sqrt{\begin{array}{c}20\gamma_C^4-128\gamma_C^5+320\gamma_C^6-408\gamma_C^7+301\gamma_C^8\\ -144\gamma_C^9+49\gamma_C^{10}-10\gamma_C^{11}\end{array}}\end{array}\right)}{-4\gamma_C^4+4\gamma_C^5+9\gamma_C^6} \end{aligned}$$

The expression can be simplified to

$$392\gamma_C^2-128\gamma_C-496\gamma_C^3-11\gamma_C^4+648\gamma_C^5-543\gamma_C^6+122\gamma_C^7-9\gamma_C^8+16 > 0 \quad (16)$$

Let

$$f_{\alpha_2}(\gamma_C) = 392\gamma_C^2-128\gamma_C-496\gamma_C^3-11\gamma_C^4+648\gamma_C^5-543\gamma_C^6+122\gamma_C^7-9\gamma_C^8+16$$

$\frac{\partial f_{\alpha_2}(\gamma_C)}{\partial \gamma_C} > 0 \ for \ \gamma_C \in [0.5332, 0.6667]$ and $f_{\alpha_2}(0.5332) = 4.39\times 10^{-2} > 0$. It follows that for $\alpha < \bar{\alpha}_S$, the equilibrium is of type A and for $\alpha \geq \bar{\alpha}_S$ the equilibrium is of type C.

Proof of proposition 6

The expected payoff to the entrant in equilibrium A is

$$\Pi_E\left(A, p_I, p_E^A(\gamma_C)\right) = \frac{1}{2}\left(1-\gamma_C\right)^2$$

The expected payoff to the entrant from choosing technology C when the patent scope is broad and the incumbent demands a license fee αV is obtained by inserting $p_{E,L} = \frac{2\gamma_C(1-\alpha)}{2+\gamma_C(1-\alpha)}$ and $p_{I,L} = \frac{2\gamma_C(1-\alpha)}{2+\gamma_C(1-\alpha)}$ into

$$\Pi_{E,L}\left(C, p_I, p_E\right) = \gamma_C p_E(1-p_I)(V-\alpha V) + \gamma_C p_E p_I \frac{1}{2}(V-\alpha V) - \frac{\left(p_E\right)^2}{2}$$

which can be simplified to

$$\Pi_{E,L}\left(C, p_{E,L}, p_{I,L}\right) = \frac{2\gamma_C^2\left(1-\alpha\right)^2}{\left(2+\gamma_C(1-\alpha)\right)^2}$$

The entrant chooses technology C if

$$\begin{aligned}\Pi_{E,L}\left(C, p_{E,L}, p_{I,L}\right) &> \Pi_E\left(A, p_I, p_E^A(\gamma_C)\right)\\ \frac{2\gamma_C^2\left(1-\alpha\right)^2}{\left(2+\gamma_C(1-\alpha)\right)^2} &> \frac{1}{2}\left(1-\gamma_C\right)^2\end{aligned}$$

which can be simplified to

$$\alpha < \frac{3\gamma_C - 2 + \gamma_C^2}{\gamma_C + \gamma_C^2}$$

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The nature of collaborative innovative activities

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This draft: September 2007
Paper to be presentd at:
2nd Annual Conference of the EPIP Association

CIRCLE/Lund University – Sweden
September 20-21, 2007

Abstract
We investigate the determinants of governance for a sample of successful collaborative inventive activities. We find that firm size and incoming spillovers have a positive impact on the probability to co-operate. We then extend the analysis to four possible modes of governance: co-assignment, co-invention, formal agreement, and informal agreement. We find that higher project complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes.

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1. Introduction

Innovative activity often involves the formation of partnerships that span across a wide range of institutions (Chesborough, 2002), from firms to Universities and public and private research organizations (Poyago-Theotoky *et al.*, 2002). This is both a consequence of the fact that complex R&D activities in multi product firms demand the integration of different bodies of knowledge (Granstrand *et al.*, 1997) and the recognition by firms that the relevant knowledge should be found outside their own boundaries. During the last decade, collaborative innovative activity has become crucial within the wider context of research collaborations and the subject of extensive academic debate.

There is a very large theoretical and empirical literature examining R&D co-operation. This literature can be organized around three main approaches. First, there are the game-theoretical models developed following the seminal work of d'Aspremont and Jacquemin (1988). Second, there is the transaction const framework that emphasises the mix characteristics of co-operations (Williamson, 1996). Third, there are the strategic management approaches (or resource based theories of the firms) that study the reasons for the rapid development of this new from of company interaction since they started to be formed after the mid 1970s (Mowery, Oxley & Silverman, 1996). Parallel to the theoretical analysis, the field has also seen the development of a large number of empirical studies based on large databases of R&D co-operations (see Caloghirou *et al.*, 2003 for a review of this body of literature) and, most recently, econometric studies based on innovation surveys (see Cassiman and Veugelers, 2002 among others) and patents.

Collaborative innovative researches leading to patents may be of different nature depending on the different modes of governance employed (i.e. co-invention or co-assignment). While these alternative modes have become increasingly relevant (Hicks and Narin, 2001; Hagedoorn, 2003), little is known about why and when they are chosen. This paper aims at providing a first exploratory investigation of what drives their choice within the context of R&D co-operation. Our research question is the following: How do we explain that R&D cooperation agreements may entail different governance structure even within a regime of strong Intellectual Property Right (IPR) protection warranted by a patent? In other words, why do firms that engage in successful R&D cooperation (i.e. the outcome of the cooperation is a patent) may also choose to establish strict modes of governance such as co-invention or co-assignment in alternative to a more informal contractual agreements? In this paper we argue that the choice of a mode of governance is the consequence of the presence of a specific level of appropriability hazard underlying the R&D partnership. The higher the level of appropriability hazard is the higher the probability to choose a tighter (i.e. more hierarchical) mode of governance. Existing contributions (Oaxley, 1997; 1999) have mainly stressed the impact of project level attributes on the choice. We will consider both the role of project specific attributes and the impact of individual (i.e. inventor specific), and organizational (i.e. environment specific) attributes.

Our investigation is based on data from the PatVal database, a sample of 9017 European inventors and their associated patents registered at the European Patent Office (EPO) between 1993 and 1997 (Giuri, Mariani *et al.*, 2006). Relying upon this dataset, we select those patents that are the outcome of a collaborative research project, identify four possible modes of governance (ranked from the more to the less hierarchical): co-assignment, co-invention, formal agreement, and informal agreement and we run Ordered Probit analysis and a Multivariate Probit analysis with sample selection to study the choice of a governance mode conditional on the patent being the outcome of an innovative collaborative project. We find that firm size and incoming spillovers have a positive impact on the probability to co-operate and that project related characteristics impact instead on the choice of the governance mode. Higher complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes. The structure of the paper is as follows. Section 2 reviews the existing literature on the determinants of R&D cooperation and the mode of governance of R&D collaborative projects. Section 3 introduces the data, the variables and the econometric model that will be used in the empirical analysis. Section 4 presents the results and Section 5 concludes.

2. Background Literature

Within the context of R&D cooperation, patents are usually found to be the most frequently used mechanism for IPRs protection (Hertzfeld *et al.,* 2006). However, simple patenting by itself is far from being the only mechanism to share IPRs. Hagedoorn (2003) provides empirical evidence that other forms of governance such as co-assignment has increased in last couple of decades. Hagedoorn *et al.* (2003) distinguish co-assignment from other types of patent agreements such as cross-licenses and pooled patents. Their analysis provides evidence that the probability of co-assignment increases with previous engagement in collaboration activity. To the extent to what co-assignment entails joint ownership of an invention, they argue that it is based on mutual relational trust between separate companies. Contrary to the empirical evidence on the determinants of R&D cooperation, they do not find any significant positive correlation between firm size and co-patenting. The issues of the reason why firms and other types of organization such as universities and research organizations that engage in successful R&D cooperation (i.e. the outcome of the cooperation is a patent) may also choose to establish alternative modes of governance such as co-invention or co-assignment in alternative to a more informal contractual agreements is important and deserves close scrutiny.

One way of tackling the issue is by taking a transaction cost perspective. Transaction cost theory predicts that, in the context of R&D co-operation, the choice of a governance mode is mainly a function of the appropriability hazard of the R&D project which is, in turn, an inverse function of three dimensions: the extent of IPRs specification, contract monitoring, and enforcement. Better property right specification, better monitoring and better enforcement reduce the appropriability hazard level and decrease the probability of choosing a more hierarchical mode of governance. By devising suitable indicators for these dimensions it is possible to understand the determinants of the choice of a specific firm of governance through their impact on appropriability hazard level. Transaction cost theory claims that suitable indicators should be related only to the transaction (i.e. they should mainly be characteristics of the research project underlying the transaction). As argued by Teece (1986) definition of IPRs appears problematic when project entails a large change in the underlying technology (i.e. complexity is high), uncertainty on the outcome is high (i.e. incrementality is low), the technological know how that result from the underlying research is highly tacit (i.e. scope is large), and the underlying research project does not entail a prior licensing agreement. High complexity, low incrementality, large scope, absence of prior licensing agreement should therefore be associated with more hierarchical forms of governance. IPRs definition is also sectoral and country specific (Oaxley, 1999). Thus cross sectoral differences in the propensity to patent may also reflect in the choice of the form of governance with sectors more inclined to patent are also more likely to be associated to choose tighter forms of governance. Country differences in patent legislation or in the propensity to engage in R&D collaboration may also affect the choice. Concerning monitoring, existing empirical studies have highlighted that monitoring is problematic when the number of products or technologies characterizing the research project is large and geographical dispersion is high (Oaxley, 1997). The presence of these characteristic is therefore associated to tighter forms of governance

In this paper we consider project level attributes, as well as other determinants related to both the individual (i.e. the inventor) and the characteristics of the organization involved in the transaction. Concerning the role of individual characteristics, it has to be noted that few contributions have looked at the determinants of R&D collaborations from the viewpoint of the individual inventor actually involved in the collaborative project (Audretsch and Stephan, 1996; D'Este and Patel, 2007). Even fewer, to our knowledge, are the empirical works that have explicitly considered the connection between the inventors' background (i.e. education, experience, reputation, mobility) on the choice of the governance mode. This paucity of empirical works notwithstanding, the importance of the background can be grasped by relying on the idea that individuals, their social networks and mobility are the main responsible for the flow of innovative knowledge and that the size of the network in turn is affected by the ability and experience of the inventors (Breschi and Lissoni, 2001; Singh, 2005).

Concerning the role of social networks, Audretsch and Stephan (1996) for instance argue that more experienced researchers have a higher propensity to interact outside the boundaries of their firm and provide empirical evidence on the presence of a positive relationship between inventors' experience and the size of their network. Giuri and Mariani (2007) argue that better educated researchers have higher opportunities to enter larger networks and signal their ability to rely upon connections to establish interactions in their career. They find the presence of a positive relationship between educational background of the inventor and the size of their network. Individuals embedded in a dense network of relationships and interactions are more likely to increase monitoring problems. Thus we should expect better educated inventors to be associated to a tighter mode of governance.

Concerning mobility, it has been shown that labor mobility depends on a series of individual characteristics. Crespi *et al.* (2006) for instance consider a sample of academic researchers and look at the determinants of mobility from academia to the private sector. They find that, controlling for their productivity, younger and less experienced inventors are more likely to leave academia and move to the private sector. The positive role of experience for mobility is also stressed by Lenzi (2006) who works on a sample of Italian inventors in the pharmaceutical sector. She also finds that gender is important with male workers being more mobile than female. Finally better educational background has been found to increase mobility (Hoisl, 2007). Mobility is likely to increase potential geographical dispersion thus making monitoring more problematic. Again we should expect better educated and young inventors to be associated to a tighter mode of governance.

In this paper we account for education, experience, individual mobility and control for organization and project level characteristics such as complexity, scope, and licensing. First, we expect better education and mobility to be associated to tighter modes of governance. Looser modes of governance should instead be associated to previous experience. Second, we expect complexity and scope to be associated to tighter modes of governance. The presence of alternative mechanisms of compensation and/or IPR management such as licensing instead should lead to less hierarchical modes.

3. Empirical Analysis

The data used in this paper come from the PatVal database, a sample of 9017 European inventors and their associated patents registered at EPO between 1993 and 1997. Inventors are from six European countries (Germany, UK, France, Spain, Italy, and The Netherlands) and five sectors (electrical engineering, instruments, chemistry and pharmaceuticals, process engineering, and mechanical engineering). These six countries account for about 80% of patents whose first inventor has and address in EU-15 countries. Our main focus is whether the patent was the outcome of a collaborative innovative effort and whether the patent was associated to a specific mode of governance. We identify four main governance modes from the tighter 8i.e. more hierarchical) to the looser: Co-assignment, Co-Inventorship, Formal Agreements, and Informal Agreements.

3.1. Sample and Dependent Variable

In our sample, there are 553 patents that were co-assigned, of these only 323 are assigned to companies belonging to different groups. They represent 3.6% of our sample. There are 3261 patents with only one inventor, while 5756 have multiple inventors. 1309 patents are co-invented collaborative patents (i.e. they include inventors with employers from different companies). They represent 15% of our sample. It has to be noted that the two sets are partially overlapping. Indeed, 119 co-invented collaborative patents have a co-assignment from the employers of the inventors. 57 have a co-assignment from employers who differ from the one of the inventor. No information is available on the others. 1745 patents (20.5% of the sample) involved other forms of collaborative agreements either formal or informal. From the interplay of these categories we identify two other groups of patents. The first category is made of patents that involved a formal collaborative agreement but were neither co-invented nor co-assigned (no co-inventor or co-assignee from the same or different company group). 246 patents belong to this category. The second category includes patents that involved an informal collaborative agreement but were neither co-invented nor co-assigned (no co-inventor or co-assignee from the same or different company group) and zero otherwise. 102 patents belong to this category. Table 1 below summarizes the frequencies of patents in our sample.

[Table 1 approximately here]

To these categories we associate four possible governance modes: CO-ASSIGNMENT, CO-INVENTION, FORMAL AGREEMENT, INFORMAL AGREEMENT. Using this classification we create the variable MODE$_J$ taking the value of (MODE$_3$= 3) if the patent has been co-assigned, (MODE$_2$= 2) if the patent has been co-invented, (MODE$_1$= 1) if the patent involved also a formal agreement, (MODE$_0$= 0) if the patent involved also an informal agreement.

The variable MODE$_J$ takes on one of four values depending on the specific mode of governance associable to the patent. Each mode of governance is ranked on the basis of the degree of additional protection it warrants, from the tightest (i.e. co-assignment) to the loosest (i.e. only informal). The choice of a specific mode of governance is the consequence of the level of appropriability hazard associable to an innovative collaborative research project (and ultimately to its outcome: the patent). The assumption is that a tighter mode of governance derives from the need to protect against a higher level appropriability hazard. Thus, by looking at how each covariate influences the level of appropriability, we will gain a better understanding of the likelihood to observe a specific mode of governance.

3.2. Independent Variables

We consider two sets of covariates: a set of variables that influence the probability of engaging in R&D co-operation and a set of variables that influence the choice of the governance mode. More in general our covariates can be classified into three groups. First, we consider a set of variables related to the type of project underlying the specific patent. Second, we control for the influence of individual characteristics of the inventor as well as of the motivation to patent. We expect these two sets of covariates to influence the choice of a mode of governance mainly by impacting on the extent of property rights definition and contract monitoring. Third, we consider a set of 'environmental' characteristics associated with the organizational affiliation (i.e. firm and/or university) of the inventor and the presence of subsidies. We expect these covariates to impact on the probability of choosing a governance mode mainly through the propensity to patent. Finally we control for country and sector fixed effect. The country effect is likely to impact on the choice of a governance mode by influencing the extent patent enforcement. Sectoral dummies instead account for the role of property right specification.

Project related characteristics

The choice of a governance mode is affected by project related characteristics such as: complexity, breadth, R&D cost and the decision to license or not the patent to a third party. The PatVaL survey asked respondents to give an estimate of the time (measured in person months) required by the research leading to the patent. Responses were structured in eight asymmetric intervals ranging from less than one person month to more than seventy two person months. COMPLEXITY is constructed as the natural logarithm of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval. Longer and larger projects usually bring about a large change in the underlying technology and are more likely to be associated to uncertain outcome. Thus we expect the more complex the project, the higher the probability that a tighter mode of governance is chosen.

The scope of the project is also likely to impact on the choice of a specific governance mode. Indeed, research projects demanding the integration of different bodies of knowledge are more uncertain and IPRs are more difficult to specify clearly at the start of co-operation activity. Higher uncertainty also makes monitoring more difficult and generally increases the probability of opportunistic behavior in the underlying R&D collaboration. The scope of the research is captured by the variable BREADTH which is constructed as the natural logarithm of the number of 4-digit technological classes (IPC) in which the patent was classified. We expect that the higher the breadth the higher the probability of choosing a tighter mode of governance.

The choice of the governance mode also depends on whether other alternative arrangements, such as economic rewards, concerning the individual returns from and/or the ownership of the patent are present. COMPENSATION is a dummy variable equal to 1 if the inventor received any personal monetary compensation expressly offered because of the production of the patent. We expect the presence of such monetary reward to be associated to the choice of a relatively less tight governance mode. Finally, the choice of the governance mode also depends on whether the patent has been licensed or not. LICENSING is a dummy variable that takes the value of 1 if the patent has been licensed, by one of the patent holders, to a third party. To the extent to what licensing is possible only when a clear definition of IPRs exist and/or the knowledge content of the underlying research project can be easily codified, we expect less hierarchical modes of governance to be associated to patents that have been licensed.

Individual characteristics and the motivations to patent

We control for the influence of individual characteristics of the inventor, such as age at time of application, level of education, mobility (i.e. whether the inventor has been previously employed in other organizations), work location and 'openness' as measured by the relative importance given to external sources of information both public (University laboratories and faculties, PROs, technical conferences, and scientific literature) and private (patent literature, customers, suppliers, and competitors) for the research activity leading to the patent.

AGE is the natural logarithm of the age of the inventor at the time of patent application. This is our proxy for experience. To the extent to what more previous experience leads to trust, it should be associated to the choice of less hierarchical modes of governance for co-operation. PHD is a dummy variable equal to 1 if the inventor's highest academic degree is a PhD. This is our measure of education. We expect better educated inventors to demand tighter modes of governance. MOBILITY is a dummy variable equal to 1 if the inventor moved organization in the year before the patent was taken. Mobility is associated to the establishment of a large network of colleagues as a result also of a higher probability of being involved in co-operative research. To the extent to what high mobility generally entails higher dynamism and job searching, it may increase monitoring problems therefore leading to the choice of more hierarchical modes of governance for the co-operation. Finally, CITY is a dummy variable equal to 1 if the inventor worked in a city of more than 100,000 inhabitants when the research leading to the patent was carried out. This variable can be considered a proxy, admittedly a coarse one, for geographic dispersion. High geographic dispersion is likely to increase monitoring problems therefore increasing the probability of choosing tighter modes of governance.

Particular attention is devoted to the relative importance of sources of knowledge (i.e. incoming spillovers) as a factor influencing the probability to co-operate. A question in the PatVal survey asked inventors to rank on a five-point scale from not important to very important external sources of knowledge relate to the innovation included in the patent. Following Cassiman and Veugelers (2002), PRIVATE (PUBLIC) SPILLOVERS is constructed by summing the scores of each type of information sources (University laboratories and faculties, PROs, technical conferences, and scientific literature for public; patent literature, customers, suppliers, and competitors for private) and re-scaling the total scores to a number between 0 and 1. We expect the presence of incoming spillovers to positively affect the probability of engaging in R&D collaboration.

Environmental characteristics

Further controls include ‘environmental’ characteristics related to the organizational affiliation (i.e. firm and/or university) of the inventor. A question in the PATVAL survey asked the respondent to state the nature of the employer when the researcher leading to the patent was performed. Five types of organizations were identified: firms, private research organizations (including hospitals and foundations), PROs (including government research organizations), universities, others. FIRM and UNIVERSITY are two dummy variables equal to 1 if the inventor was employed by a firm or a university respectively. Extensive evidence exists on the increasing involvement of Universities in the formation of research partnerships (Poyago-Theotoky *et al.*, 2002), thus we expect Universities to have a positive probability to team up with other organizations for carrying out the research leading to a patent. However, recent empirical analyses of the motivations underlying IPRs protection mechanism within research co-operation have found that partnerships involving universities are generally more problematic with respect to the negotiation of IPR agreements (Hertzfeld *et al.*, 2006). In line with these findings, and taking public and private research organizations as a reference category, we expect universities to have a relatively lower probability to choose a more hierarchical mode of governance.

The existing literature has found a positive relationship between firm size and the probability to cooperate (Tether, 2002; Leiponen, 2001). Further evidence has highlighted the non linear nature of the relationship (Cassiman and Veugelers, 2002). For those inventors who were employed by a firm, the survey asked whether the firm was large, medium, or small.[1] We use information on the boundaries of size intervals defined in

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[1] Large firm are organizations with more than 250 employees. Medium firms (100-250 employees). Small firms (less than 100 employees).

terms of number of employees to construct our proxy for firm size. SIZE (and SIZE^2) are constructed as the natural logarithms (square of the logarithm) of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval.

Finally we take into consideration the role of R&D subsidies. Co-operative research projects may and may or not have benefited from the allowance of monetary support from national governments and/or supranational institutions such as the European Union. As argued by Belderbos *et al.* (2004), the presence of subsidies may have a double impact on the probability to engage in R&D co-operation. On the one hand, they may stimulate firms to engage in co-operation of any kind especially when their availability is conditional on the establishment of the co-operation. On the other hand, their presence may ease financial bottlenecks and therefore reduce the propensity to engage in co-operation tout-court. This is more likely to occur when co-operations are created with the explicit intent of reducing costs. GOVFUNDS is a dummy equal to 1 if the research leading to the patent has benefited from government research programmes and/or other government funds. We expect this variable to impact positively on the probability to co-operate.

Technology fixed effects are included in the model. We expect that technological factors are most important as technologies (and sectoral innovation systems) are characterised by different propensities to rely upon collaborative innovative processes, and specific modes of governance depending on project related characteristics not captured by our covariates (i.e. for example we think that technologies in the pre-paradigmatic phase depends more on collaborative innovative agreements and tighter modes of governance). Country fixed effects are included too. We expect that certain national systems of innovations are more conducive to co-operation in research than others due to cultural and institutional reasons. Moreover, we also expect different institutional settings to influence the choice of the mode of governance through their support and provision of IPRs enforcement mechanisms. Descriptive statistics for the variables used in the regression are listed in Table 2. In the remaining of this Section we will present the econometric models that will be estimated.

[Table 2 approximately here]

3.3 Econometric Models

To study the determinants of the choice of a specific governance mode we carry out two types of analysis. First we estimate an Ordered Probit model. Second we apply a Multivariate Probit model to account for the possible presence of correlation between the governance modes. In both cases the choice of a governance mode is conditional on the probability of having been engaged in a collaborative innovative project.

Using only information on the sub-sample of patents resulting from a collaborative agreement may introduce a sample selection bias. To eliminate this potential source of misspecification we proceed in two-step. In the first step, we use a binary response model to explain the probability of engaging in collaboration as a function of a series of independent variables. In the second step, we focus only on collaborative patents and investigate the determinants of the choice of a specific governance mode as described by MODE$_J$ and correct for selection bias. Our model can be specified as follows:

$$Mode_j^* = Z_j^{'}\gamma + \eta_j \qquad (1),$$

where MODE$_J$* is the latent variable associated to the ordered variable MODE$_J$, Z contains the covariates, γ are the coefficients to be estimated, and η is a random error term.

MODE$_J$* is not directly observed. We observe instead the following intervals in its realization:

$$\begin{array}{lllll}
Mode_0 = 0 & if & Coll = 1 & and & Mode_j^* \le \mu_1 \\
Mode_1 = 1 & if & Coll = 1 & and & \mu_1 < Mode_j^* \le \mu_2 \\
Mode_2 = 2 & if & Coll = 1 & and & \mu_2 < Mode_j^* \le \mu_3 \\
Mode_3 = 3 & if & Coll = 1 & and & \mu_3 < Mode_j^*
\end{array} \qquad (2)$$

where μ are unknown parameters to be estimated together with γ.

This is the model estimated among others by Oaxley (1997; 1999). It has to be noted that in our case, the probabilities of falling into one of these intervals can be estimated only for that part of the sample for which the patent is the outcome of a collaborative engagement. To account for this we follow Heckman (1979), who suggests a two stage procedure that relies on a first estimation of a selection equation for the entire sample of patents

Let us call COLL$_J$ a binary variable describing whether the patent is the outcome of a collaboration. A latent variable COLL$_J$* is associated to this binary variable:

$$Coll_j^* = X_j\beta + \varepsilon_j \qquad (3)$$

in which X is a set of determinants of the probability to collaborate, β are the coefficients to be estimated, and ε is a random error term. The parameter β can be estimated by replacing COLL$_J$* with a dummy variable COLL$_J$ which is equal to zero when no collaboration has occurred (i.e. COLL$_J$* is zero) and it is equal to one when a collaboration has occurred (i.e. COLL$_J$* is positive).

The selection equation is then treated as a binary probit model and estimated by maximum likelihood $\left(\hat{\beta}\right)$. For all our sample we estimate the probability to collaborate $\Pr\left(Coll_j = 1\right)$ that can be computed as $\Phi\left(X_j^{'}\hat{\beta}\right)$ where Φ is the cumulative distribution function of a standard normal. In the second stage we then estimate a regression model augmented by the selection variable $\hat{\lambda}_j = \varphi\left(X_j^{'}\hat{\beta}\right) / \Phi\left(X_j^{'}\hat{\beta}\right)$ where $\varphi(\cdot)$ is the standard normal density function restricted to those firms who have adopted. In other words we estimate the following:

$$Mode_j^* = Z_j^{'}\gamma + \gamma_\lambda \hat{\lambda}_j + \eta_j \tag{4}$$

for all j with COLL$_j$* > 0.

It has to be noted that $\hat{\lambda}_j$ results from the estimation of the selection equation in the first stage. If parameters are estimated simultaneously the second stage estimation provides correct standard errors. While this is a standard estimation strategy (Mohnen and Horeau, 2003), it has to be noted that the results depend on the starting solution of the Ordered Probit model without sample selection. We therefore choose to compute the second stage separately and correct the estimation in the second stage via bootstrapping. Bootstrapping allows for re-sampling with replacement from the whole sample and carries out the whole two stage procedure for each resample (Efron and Tibshirani, 1993). We iterate this procedure for 1000 times to obtain different estimates of the parameters from which the correct standard errors can be calculated.

In the second set of estimations, we account for the likely presence of correlations between the modes of governance by carrying out a Multivariate Probit estimation. The Multivariate Probit is a generalization of the Probit approach that allows the estimation of more than one binary equation with correlated disturbances. Not accounting for the presence of likely correlation, by estimating for example separate Probit equations, would produce inefficient estimators. In our case, we include four equations in which each one of four modes of governance identified (CO-ASSIGNMENT, CO-INVENTION, FORMAL AGREEMENT, INFORMAL AGREEMENT) is modeled as a latent variable by a standard Probit model:

$$y_{ij}^* = \alpha_j + v_j^{'} x_{ij} + u_{ij} \tag{5}$$

where:

$$y_{ij} = \begin{cases} 1 & if \qquad y_{ij}^* > 0 \\ 0 & otherwise \end{cases} \tag{6}$$

with: $i = 1,\dots,n$ and $j = 1,\dots, 4$ are the observations and the modes of governance respectively. The disturbances u_{ij} are distributed according to a multivariate normal distribution with mean 0 and covariance matrix with diagonal elements equal to 1 (Greene, 2003).

4. Empirical Analysis

To investigate the determinants of the choice of a governance mode for collaborative innovative research projects we have proceeded in several steps. First we have used a Probit model to estimate the probability that the patent resulted from an innovative collaborative activity. This estimate is our selection equation. Then we have used an

Ordered Probit model to estimate the probability to choose a specific governance mode. This equation includes the Inverse Mills Ratio from the selection equation to correct for possible selection bias and the corrected (i.e. bootstrapped) standard errors. Finally we have extended the analysis to account for correlation across the governance modes by estimating a Multivariate Probit model.

4.1. Preliminary Results

Preliminary results are reported in Table 3. Column (1) presents the estimates for the selection equation.

[Table 3 approximately here]

We observe a positive dependence on SIZE indicating that large firms are more likely to cooperate. However, the negative and significant coefficient of the squared value indicates that the relationship is not linear. Both results are consistent with previous works on the determinants of R&D cooperation (Cassiman and Veugelers, 2002). Coefficients for INCOMING SPILLOVERS are significant suggesting that innovators used to tap external sources for information are more likely to engage in cooperative R&D projects. Interestingly both coefficients are positive indicating that the different types of information seem to complement rather than substitute for each other. Again this result confirms previous works for Europe based on CIS surveys (Cassiman and Veugelers, 2002; Abramovsky *et al.*, 2005). Additional controls for the type of organization and the presence of funds are also positive and significant. Patents resulting from research funded by public funds are more likely to be the outcome of collaborative projects as indicated by the positive and significant coefficient of GOVFUNDS. Moreover, Universities are relatively more likely than other organizations (i.e. Firms, Private Research Organizations, Government Research Organisations) to engage in a collaborative project leading to a patent. Marginal effects are reported in column (2).

Results for the Ordered Probit model, conditional on the engagement in a collaborative innovative activity, are reported in the remaining columns. Column (3) reports the ordinary standard errors. Column (4) displays the boostrapped standard errors (1000 iterations). Results are generally robust to the implementation of the boostrapping procedure and both GOVFUNDS and UNIVERSITY are weakly or not significant, thus indicating that they were good instruments in the first stage equation. The coefficient of $\hat{\lambda}_j$ is negative and very significant suggesting that not correcting for sample selection would have produced biased estimations and that the decision to co-operate and the choice of a governance mode are not disjointed. More specifically, our findings indicate the significant role played by organizational, individual, and project level characteristics for the choice of a governance mode.

Concerning the impact of organizational characteristics, the negative and significant coefficient of FIRM suggests firms are more likely to choose less hierarchical governance modes than the reference category (i.e. public and private research organizations). Concerning the influence of individual characteristics of the inventor, we find a negative and significant coefficient of AGE and a positive and significant coefficient for PHD, suggesting that young and better educated inventors are more likely to choose hierarchical modes of governance. The coefficient of CITY is positive and significant albeit weakly. This result suggest that location of inventors in big towns is associated to the choice of more hierarchical modes of governance as a consequence of raising monitoring problems due to potential higher geographical dispersion. The coefficient for MOBILITY is not significant thus indicating that high mobile inventors, which in theory should increase monitoring problems, do not seem to lead to the choice of more hierarchical modes of governance. This result is surprising although it is probably related to the presence cross-country differences in labor market legislation which are captured by the dummy variables at the country level.

More interesting are the findings for the variables related to project level characteristics. The positive and significant coefficient of COMPLEXITY indicates that higher levels of project complexity, as measured by the man months required for the research, are associated to more hierarchical modes of governance. High uncertainty complicates property rights definition and leads organizations involved in the collaboration to further protect their interests by combining patenting with tighter forms of governance. BREADTH enters positively and significantly suggesting that patents spanning across several technological classes are associated to more hierarchical modes of governance. This result can be due both to property right definition and to the presence of monitoring issues. On the one hand, increasing the technology scope of a research project complicates the definition of the property rights. On the other hand, monitoring problems increases with the number of technologies involved in a project. In both cases, the stipulation of tighter modes of governance is required. COMPENSATION enters negatively and significantly suggesting that the presence of a personal monetary compensation for the production for the patent is associated to the choice of less hierarchical modes of governance. Finally the coefficient of LICENSED is negative and significant, indicating that patents that have been licensed are associated to relatively less tight modes of governance. Our explanation for these results is the following. Offering a monetary compensation is a way of rewarding the inventor above and beyond sharing the rights linked to the patent’s ownership. The presence of such a reward fulfills inventor’s reward expectations while preserving the rights of the organization that owns the patent. The presence of voluntary licensing instead is in itself an indication of the absence of problems in property right specification, monitoring and/or enforcement of within the context defined by the patent, either because of characteristics of the technology or because of the presence of mutual trust between the partners. Within this context less tight modes of governance are preferred to more hierarchical ones.

Altogether, our findings are as expected. First, availability of Government funds, presence of incoming spillovers (both public and private), and firm size increases the probability to engage in R&D cooperation. In the case of firm size, the relationship is not linear. Second, the choice of a specific mode of governance is mainly driven by project characteristics. In particular, project complexity and technology scope increase the probability of choosing more hierarchical modes of governance. The presence of licensing and compensation scheme is instead associated to less strict governance modes. Third, younger and better educated inventors have higher probability to choose tighter modes of governance. Finally, organizational characteristics such as the type of organization involved in the cooperation also matters, though to a lesser extent.

4.2. Robustness Check

To check the robustness of the results we carry out an additional estimation analysis by looking at the probabilities of choosing a specific mode of governance. To account for possible correlation between the alternatives, we run a Multivariate Probit estimation with and without country fixed effect with sample selection.

The estimation of the maximum likelihood function has been carried out using the recursive conditioning simulator implemented for STATA by Cappellari and Jenkins (2003). The number of recursive draws was equal to 50. This type of analysis allows us to gain further insights on the determinants of the choice of a specific governance mode as well as to account for the presence of interdependences (i.e. complementarity or substitutability) among the modes of governance.

[Table 4 approximately here]

The introduction of country fixed effect does not substantially change the results so we comment on the second estimation (columns (9) to (12)).

Our findings indicate that the predictive power of our model differs across modes of governance. Concerning the impact of organizational characteristics, we find that inventors located in universities and firms are engaged in co-assignment less than those working in Research Organizations (both public and private). Being funded by government decreases the probability of doing informal agreements and co-invention. Looking at the individual characteristics of the inventor, we find some evidence supporting the negative and significant effect of age on co-assignment. Results for education are interesting. Better educated inventors have a higher probability to co-invent, probably the consequence of the presence of an extensive network of trusted colleagues, but a lower probability to set up an agreement both formal and informal. Consistently with the previous results, we find that increasing project complexity and technology scope of the patent are associated to a lower probability of engaging in formal agreements. However, these project characteristics do not have statistically significant impact on more hierarchical modes of governance such as co-invention and co-assignment. Finally, licensing is more likely to be associated to the presence of a formal agreement and less likely to co-invention.

All in all these findings seem to suggest that different types of characteristics seem relevant for some governance modes but not for others. They are also informative on the relationship between the different modes of governance. Table 5 reports the estimates of the disturbance covariance matrix from the estimation with country fixed effect.

[Table 5 approximately here]

Coefficients are generally negative and some of them are highly significant thus suggesting that the modes of governance identified are substitute for each other rather than complement.[2] Substitutability is particularly high between co-invention and co-assignment and between co-invention and formal agreement. Indeed, while organizational characteristics matters for co-assignment, individual characteristics are significant determinants of co-invention and co-assignment to a certain extent, and project level characteristics for formal agreements an co-invention.

5. Conclusion

This paper has provided a preliminary analysis of the determinants of governance in successful collaborative inventive activities. First, we looked at the determinants of probability to engage in innovative collaborative projects. We found that firm size and incoming spillovers have a positive impact on the probability to co-operate. Second, we focused on four possible modes of governance: co-assignment, co-invention, formal agreement, and informal agreement. We found that higher project complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes.

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[2] Interdependence may also be the consequence of omitted firm specific factors affecting the modes of governance.

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Table 1
Number of collaborations and mode of governance

	No of cases	Percent
Co-Assignment		
Single applicant	8460	93.80
Co-Assigned Non Collaborative (i.e. co-assignee same company)	230	2.60
Co-Assigned Collaborative (i.e. co-assignee different company)	323	3.60
Co-Invention		
Single inventor	3261	37.40
Co-Invented	4159	47.60
Co-Invented Collaborative	1309	15.00
Collaboration		
Collaborative Agreements	1745	20.50
Only Formal (i.e. no co-inventor or co-assignee)	102	
Only Informal (i.e. no co-inventor or co-assignee)	246	
Non Collaborative	6756	79.50

Table 2
Descriptive statistics

	Mean	S.D.	Min	Max
Coll.	0.27	0.444	0	1
Mode	1.929	0.736	0	3
Inf. Agrm.	0.011	0.106	0	1
Form. Agrm.	0.027	0.163	0	1
Co-Invention	0.124	0.33	0	1
Co-Assign.	0.036	0.186	0	1
Firm Size (Log)	4.985	1.39	0	5.521
Public Spillovers (Incoming)	0.315	0.24	0	1
Priv Spillovers (Incoming)	0.469	0.257	0	1
Age (Log)	3.814	0.215	2.639	4.454
Mobility	0.354	0.478	0	1
PhD	0.26	0.439	0	1
Firm	0.931	0.253	0	1
University	0.032	0.177	0	1
GovFunds	0.087	0.281	0	1
City	0.493	0.5	0	1
Complexity	1.976	1.063	0.693	4.277
Breadth (Log)	0.857	0.245	0.693	2.197
Compensation	0.416	0.4930	0	1
Licensing	0.114	0.318	0	1

Table 3

Determinants of Governance mode choice. Ordered Probit model. Estimates with sample selection.

Dependent variables: Mode

	Selection Equation (Probit)	Marginal Effects	Regression Equation (Ordered Probit)	
	(1)	(2)§	(3)	(4)‡
Firm Size (Log)	0.144	0.033		
	[0.070]**	[0.016]**		
(Firm Size)^2 (Log)	-0.043	-0.009		
	[0.012]***	[0.003]***		
Public Spillovers (Incoming)	0.765	0.175		
	[0.079]***	[0.027]***		
Priv Spillovers (Incoming)	0.134	0.031		
	[0.072]*	[0.017]*		
GovFunds	0.427	0.120	0.192	0.192
	[0.060]***	[0.021]***	[0.111]*	[0.115]*
University	0.364	0.099	-0.219	-0.219
	[0.124]***	[0.039]**	[0.166]	[0.163]
Firm			-0.380	-0.380
			[0.142]***	[0.142]***
Age (Log)			-0.526	-0.526
			[0.153]***	[0.151]***
Mobility			-0.072	-0.072
			[0.070]	[0.074]
PhD			0.206	0.206
			[0.070]***	[0.069]***
City			0.115	0.115
			[0.067]*	[0.065]*
Complexity			0.052	0.052
			[0.032]*	[0.031]*
Breadth (Log)			0.233	0.233
			[0.133]*	[0.130]**
Compensation			-0.003	-0.003
			[0.001]***	[0.001]***
Licensed			-0.149	-0.149
			[0.089]*	[0.089]*
$\hat{\lambda}$			0.572	0.572
			[0.174]***	[0.178]***
Sectoral Dummy	Yes		Yes	Yes
Country Dummy	Yes		Yes	Yes
Constant	-0.838			
	[0.145]***			
Observations	6963		1258	1258
Log Pseudo LL	-3750.27		-1249.87	-1249.87
Wald Chisq	597.93***		64.04***	74.26***
Pseudo Rsq	0.074		0.024	0.024

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.

Robust standard errors.

§ Marginal effects calculated at the median. For dummy variables the effect is for a discrete change of variable from o to 1

‡ Bootstrapped standard errors in brackets (1000 iterations)

Table 4

Determinants of Governance mode choice. Multivariate Probit model. Estimates with sample selection.

	Inf. Agrm. (5)	Form. Agrm. (6)	Co-Invention (7)	Co-Assign. (8)	Inf. Agrm. (9)	Form. Agrm. (10)	Co-Invention (11)	Co-Assign. (12)
GovFunds	-0.737	-0.092	-0.012	0.019	-0.793	0.014	-0.185	0.009
	[0.252]***	[0.135]	[0.101]	[0.128]	[0.260]***	[0.143]	[0.108]*	[0.130]
University	0.023	-0.161	0.129	-0.366	0.031	-0.126	-0.021	-0.374
	[0.307]	[0.227]	[0.171]	[0.211]*	[0.326]	[0.229]	[0.176]	[0.216]*
Firm	-0.071	0.232	-0.315	-0.450	-0.090	0.041	-0.040	-0.381
	[0.227]	[0.179]	[0.143]**	[0.162]***	[0.269]	[0.199]	[0.156]	[0.178]**
Age (Log)	-0.266	0.031	-0.043	-0.372	-0.073	0.078	-0.003	-0.321
	[0.120]**	[0.081]	[0.063]	[0.076]***	[0.147]	[0.110]	[0.083]	[0.099]***
Mobility	0.172	-0.041	-0.027	0.007	0.173	-0.114	0.019	0.049
	[0.109]	[0.088]	[0.065]	[0.083]	[0.110]	[0.091]	[0.067]	[0.081]
PhD	-0.449	-0.319	0.301	-0.057	-0.347	-0.235	0.166	-0.003
	[0.150]***	[0.095]***	[0.070]***	[0.089]	[0.158]**	[0.099]**	[0.074]**	[0.094]
City	-0.194	-0.034	0.007	0.070	-0.168	-0.034	-0.018	0.053
	[0.118]*	[0.085]	[0.064]	[0.083]	[0.118]	[0.084]	[0.064]	[0.080]
Complexity (Log)	-0.030	-0.131	-0.037	-0.018	-0.052	-0.159	-0.011	-0.018
	[0.054]	[0.041]***	[0.029]	[0.038]	[0.056]	[0.042]***	[0.030]	[0.036]
Breadth (Log)	-0.259	-0.346	-0.164	0.222	-0.204	-0.339	-0.124	0.148
	[0.236]	[0.166]**	[0.120]	[0.149]	[0.236]	[0.167]**	[0.120]	[0.144]
Compensation	0.003	0.005	-0.001	-0.001	-0.000	0.003	-0.002	0.002
	[0.002]	[0.017]***	[0.001]	[0.001]	[0.002]	[0.002]	[0.001]	[0.001]
Licensed	0.187	0.199	-0.110	-0.120	0.212	0.205	-0.160	-0.088
	[0.142]	[0.107]*	[0.087]	[0.114]	[0.145]	[0.110]*	[0.063]*	[0.105]
$\hat{\lambda}$	-0.188	-0.780	0.437	0.451	-0.202	-0.340	-0.255	0.283
	[0.22]	[0.213]***	[0.162]**	[0.198]**	[0.332]	[0.277]	[0.199]	[0.255]
Count. Dum.	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1711				1711			
L Pseudo LL	-2346.45				-2301.58			
Wald Chisq	4512.22***				4441.32***			

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.

Robust standard errors.

Table 5
Estimates of the disturbance covariance matrix (1711 observations)

	Informal Agreement	Formal Agreement	Co-Invention
Informal Agreement	1		
Formal Agreement	0.096 [0.045]**	1	
Co-Invention	-0.426 [0.055]***	-0.526 [0.038]***	1
Co-Assigment	-0.018 [0.065]	-0.125 [0.039]***	-0.824 [0.046]***

Firm Acquisitions and Technology Strategy: Corporate versus Private Equity Investors

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Abstract

Over the last years, private equity sponsored firm acquisitions have increased significantly. Although there is an ongoing public debate in Europe about this phenomenon, the antecedents and outcomes of private equity acquisitions have received little attention in research. In this paper we analyze different acquisition motives for corporate and private equity investors. How do their acquisition targets differ? How important are technologies, a major motive behind corporate acquisitions, for private equity investors? Our empirical results for European fir acquisitions in the period from 1997 to 2003 confirm that there is a significant premium that private equity investors pay relative to corporate investors. Furthermore, corporate investors pay a higher price for patented technologies, especially if those patents have the potential to block technology competitors. In contrast, the blocking potential of patents does not matter for private equity investors.

Keywords: M&A, technology, patents, corporate and private equity investors

Acknowledgements:

We thank Rene Belderbos, Bruno Cassiman, Dirk Czarnitzki, Bronwyn Hall and Christian Rammer for invaluable comments and discussions. Moreover, we thank Dietmar Harhoff for making the EPO citation data available to us. Katrin Hussinger gratefully acknowledges financial support under the grant KUL – OT/04/07A.

1 Introduction

Over the last years, worldwide merger and acquisition (M&A) activity has increased sharply. By the end of 2006, the volume of M&A transactions had increased from 10,700 transactions in 2000 to more than 37,600 while the total deal value had leaped a new record high at 2.85 trillion Euro in 2006 compared with 2.71 trillion Euro in 2000.[1] This development, however, was not only due to a growing number of corporate acquisitions but also to increased investments by financial investors. In fact, the share of worldwide private equity sponsored acquisitions in terms of total deal value has increased from 21.6 percent in 2000 to 33 percent by the end of 2006. The increasing activity of private equity investors has, particularly in Europe, been subject to a public debate on the motivation and objectives of such investors as well as on the effects of their engagement on firm performance, long-term innovativeness and growth. However, research on private equity acquisitions and how they might differ from corporate acquisitions is scarce. This paper is intended to contribute to our understanding of the motivation and objectives of both types of investors. We pay particular attention to the importance of technologies in firm acquisitions as these play a key role for innovativeness and value creation.

In fact, gaining access to technological knowledge has, for a number of years, been one of the major motives for corporate M&A (Graebner, 2004). In acquiring technology from external sources, firms aim at the development of innovative products or services that lead to improved firm value (Griliches, 1981; Pakes, 1985). Under the accelerating pressure of timing in innovation, M&A transactions give access to technology as a firm-specific resource enabling firms to pursue a resource-based strategy (Barney, 1991; Conner, 1991; Peteraf, 1993; Wernerfelt, 1984). This strategy aims at accumulating valuable technological assets combined with an ambitious intellectual property policy. A firm's patent portfolio can be assumed to have a direct influence on innovative capacities (Mansfield, 1986), especially in case of technological complementarities between the target and acquiring firm (Cassiman *et al.*, 2005; Hussinger, 2005).

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[1] Source: ZEPHYR database, Bureau van Dijk Electronic Publishing.

These resource-based motivations for acquisitions have gained a lot of attention in the literature (see Veugelers, 2006, for a survey), but it might be questionable if and to what extent they also apply to private equity investors. Obviously, private equity investors do not intend complementing their own patent portfolio. They rather strive at financing the target firm's activities for a limited period while siphoning off the profits (Thomsen & Pedersen, 2000). Nevertheless, technology should be important as private equity investors frequently benefit from disentangling valuable resources and stripping the technological assets. To a large extent, a firm's endowment with technological assets will hence determine the price that is paid by corporate or private equity investors at the market for corporate control. It has remained unexplored so far, however, what particular value both types of investors attach to a target's technological assets, given their different motivational structure.

Financial market efficiency suggests that the market value of a firm reflects the available information that relates to its current and future profitability (Fama, 1970). Jensen and Ruback (1983) have argued that acquisitions typically involve a significant positive control premium over the market value of the target firm. Moreover, Gompers and Lerner (2000) have shown that substantial capital inflows into private equity funds increase the valuation of these funds' investments. We hypothesize that the type of acquirer affects the price and hence also the premium paid for a target's technological assets. On the one hand, we argue that this is due to information asymmetries between the two types of acquirers (Heeley *et al.*, 2007). While corporate investors possess an in-depth knowledge on relevant technologies in an industry, which they might have accumulated through own research and development (R&D) activities, private equity investors should typically lack this knowledge. On the other hand, there are also synergy considerations as the discussion of technological complementarities indicates (Cassiman *et al.*, 2005). Corporate investors should presumably be willing to pay more for a related technology while this should not make any difference for private equity investors that do not have to take existing technologies into account.

Based on a sample of 1,441 European firms that were subject to acquisitions in the period from 1997 to 2003 our results suggest that private equity investors systematically overvalue their targets relative to corporate investors. With respect to the innovative assets we find that corporate investors are more interested in technologies – represented by the patent stock of the target – than private equity investors. Accounting for patent quality – in terms of citations received by other patents – our findings show that private equity and corporate investors pay the same for valuable patents. Digging deeper into the strategic dimension of technology acquisitions, however, our results indicate that corporate investors have a significant interest in patents with a potential to block competitors' innovation activities, whereas such patents do not matter for private equity investors. We contribute to the literature on patent indicators (Trajtenberg *et al.*, 1997; Trajtenberg *et al.*, 2000) by proposing a new measure to assess the blocking potential of patents, which is based on forward patent citations using detailed information on the patent application process at the European Patent Office (EPO). Our results have implications for policy makers and managers in that M&A transactions may considerably decrease competition in technology markets which needs to be reflected in a firm's M&A strategy.

The remainder of the paper is organized as follows. The next section outlines our theoretical considerations and establishes a set of hypotheses. Section 3 introduces the data set we use and shows descriptive statistics. The empirical test of our hypotheses is provided subsequently. Section 5 discusses our results and provides implications for management. The last section concludes with a critical evaluation of the study and points out potentials for further research.

2 Theory and hypothesis development

2.1 A closer look at corporate and private equity investors

Drawing a broad distinction between corporate and private equity investors seeking acquisition targets at the market for corporate control is somewhat coarse as it does not reflect the variety of possible types of investors, including wealthy individuals, the own management of a firm or bidding consortia that could be composed of a corporate investor and one or more private equity investors. Nevertheless, these categories provide a useful reference to study differences in the valuation and financing of targets.

Corporate investors, on the one hand, typically represent horizontal acquirers active in the same industry as the target company. They engage in technology acquisitions to realize *economies of scale* in R&D (Cassiman *et al.*, 2005). In response to a technology acquisition R&D fixed costs can be spread over the larger post-acquisition R&D output of the merged entities and costs can be further decreased as duplicated inputs for the same output are eliminated. A second important factor in technology acquisitions are *economies of scope* in R&D (Cassiman *et al.*, 2005). Post-acquisition R&D investments can be jointly optimized using the fact that costs can be spread over different R&D projects. Cost reductions can be realized because personnel, laboratories and technical instruments can – at least partly – be used in different projects. A further important motivation for M&A transactions that has received a lot of attention in the past (see Veugelers, 2006, for a survey) are expected *synergy effects* from the combination of two technology portfolios. The target's technology portfolio often complements the technology stock of the acquiring firm (Ahuja & Katila, 2001) and enhances the technological core competencies of the merged entity (Cassiman *et al.*, 2005; Hussinger, 2005). Through a close collaboration after the acquisition the *level of spillover effects* from R&D investments can increase (Arrow, 1962; D'Aspremont & Jacquemin, 1988). Further, *intellectual property rights* often play an important role for corporate M&A transactions because corporate investors can necessitate the ownership of intellectual property held by the target firm in order to continue or expand ongoing research (O'Donoghue *et al.*, 1998; Lerner *et al.*, 2003). Besides the acquisition of technology, corporate investors aim at gaining market share, getting access to certain markets and products, increasing efficiency as well as eliminating competition (Chakrabarti *et al.*, 1994; Mukherjee *et al.*, 2004).

Private equity investors, on the other hand, are mainly motivated by financial success to be obtained in a relatively short time frame (Thomsen & Pedersen, 2000). They supply private equity to the target firm in order to initiate often broad and widespread reorganization processes as well as to impose tight financial and operational controls with the objective to increase the target's competitiveness and value. Depending on the maturity of the target, private equity can take on the form of venture capital which is typically less risk averse (Gompers & Lerner, 2001; Wright & Robbie, 1998). Venture capital as a subtype of private equity is mainly concentrated on bringing a new and prospective technology to the market. It has been shown to considerably spur innovation (Fenn & Liang, 1998; Kortum & Lerner, 2000). Later stage private equity includes buyouts of undervalued or distressed companies to reap the profits from disentangling resources and stripping the assets (Kucher & Meitner, 2004). Moreover, private equity can implicate significant benefits for the target, e.g. by mobilizing research and commercial partners (Folta & Janney, 2004) or by providing management advice (Kaplan & Strömberg, 2003). In any case, the acquirer's engagement at the target is limited in time and geared towards a successful exit, e.g. in the form of an initial public offering (IPO) at the stock market, a trade sale to a corporate investor or a secondary purchase of another private equity firm (Brav & Gompers, 1997).

According to the European Private Equity and Venture Capital Association (EVCA, 2006), private equity transactions in Europe, including its subtype venture capital, leaped to a record level of 71.8 billion Euro in 2005, more than two and a half times the amount of 27,5 billion Euro raised the year before. Among the institutions investing into private equity funds, pension funds were the largest contributor, followed by banks. Particularly pension funds increased their investment allocation to private equity funds in the belief that the returns are largely uncorrelated with public markets (Gompers & Lerner, 2001). The assumption here is that firms receiving private equity remain privately held for a number of years. However, there appears to be a clear linkage between the public and private equity market that becomes apparent when the investor prepares its exit, e.g. through an initial public offering (Brav & Gompers, 1997).

Regarding the structure of private equity investments, buyouts represented 68.2 percent of the total amount but only 22 percent of the total number of investments. Seed investments accounted for only 0.2 percent by amount and 4 percent by number while start-up investments represented 5 percent by amount and 29 percent by number. A share of 42 percent by number and 21.8 percent by amount is due to expansion investments. The remainder refers to replacement capital (EVCA, 2006). The majority of private equity deals hence refers to venture capital investments (seed, start-up and expansion) which, however, only correspond to 27 percent of the total amount invested. In the following, we will focus on private equity buyouts and exclude venture capital from our discussion. First, venture capital can be regarded as a very special form of private equity that is brought in when technologies have not been commercialized yet and the firm might not have even be founded (Wright & Robbie, 1998). In contrast to this, private equity buyouts address rather mature firms with an established technology commercialization process which makes them comparable to corporate acquisitions. Second, venture capital engagements would in most cases not qualify as an M&A transaction which is why they would not show up in M&A databases either.

2.2 Target valuation and deal financing

When it comes to the valuation of a potential target firm by the investor there are a number of aspects related to the financing of the transaction that distinguish corporate from private equity investors. As the literature on company ownership suggests, the type of acquirer might have a considerable impact on objectives, corporate strategy and performance (Thomsen & Pedersen, 2000). This is assumed to be reflected in profit goals, dividends, capital structure and growth rates (Short, 1994). Private equity buyouts are typically structured as leveraged buyouts with a high share of debt. The private equity firm collects funds to set up a new firm as an acquisition vehicle that is equipped with the desired amount of debt and equity. This firm is subsequently used to acquire the selected target and finally merged with it to create a new company with a capital structure different from the initial structure of the target. A major advantage of debt financing is that it can be raised at significantly lower costs than equity, especially when interest rates are low as they have been worldwide for a couple of years now. By employing a share of 70 to 80 percent of debt to finance an acquisition private equity investors thus have the chance to considerably leverage their internal rate of return (Arundale, 2002). To apply such a financing structure to a potential target firm, however, requires the capital structure of the target to be suitable for this. This means that the debt to equity ratio must not exceed a certain threshold where additional debt would overburden the firm after the acquisition. In this case the firm would not be able to afford the interest and repay the debt in the long run.

In contrast to that, corporate investors tend to finance their transactions with a larger share of equity, for example by an exchange of stock. The higher costs of equity have in turn an impact on the evaluation of potential acquisition targets. Hence, the higher the expectations of the shareholders for the profitability of their equity the lower the price will be that the corporate investor can afford to pay for the target. Private equity investors will therefore presumably be able to afford a higher control premium than corporate investors until the net gain from the acquisition turns less favorable.

Moreover, as the EVCA figures indicated, there has been an abundance of funds over the last years that private equity investors almost desperately need to invest into prospective target companies. The abundance of funds might even crowd out corporate investors. For the venture capital market Gompers and Lerner (2000) have argued that increasing capital inflows lead to higher security prices, or colloquially, "too much money chasing too few deals". Their results show a strong positive correlation between the valuation of such investments and capital inflows. In this relationship, a doubling in public market values is associated with a 15-35 percent increase in valuation while a doubling of capital inflows leads to an increase between 7 and 21 percent. As they find inflows into leveraged buyout funds to be a reliable instrumental variable for inflows to venture capital funds we can assume that the abundance of funds available to private equity investors positively affects the acquisition price of private equity deals. Taking the arguments on deal financing and capital inflows together leads to our first hypothesis:

Hypothesis 1: Private equity investors systematically pay a higher price for acquisition targets than corporate investors.

2.3 Information asymmetries and the pricing of technological assets in M&A transactions

2.3.1 Technological content and the value of technology

We have argued that technological assets in acquisitions serve different objectives for the two types of investors. Corporate investors presumably screen technology markets carefully as they are interested in acquisition targets that complement their technology portfolio most effectively (Frey & Hussinger, 2006). Corporate investors are hence interested in technologies and intellectual property with a particular *technological content*. In contrast, private equity investors are typically not interested in specific technologies as long as the technologies employed in a potential target company serve as a basis for revenue generation. Consequently, corporate investors will also be in a better position to judge the potential of externally available technologies.

A firm's capability to achieve this has been summarized in the literature as absorptive capacity (Cohen & Levinthal, 1989, 1990). Absorptive capacity is generally developed as a by-product of own R&D activities. It is made up of three major components: The identification of valuable technological knowledge in the environment, its assimilation with existing knowledge stocks and the final exploitation for successful innovation. Absorptive capacities hence increase the awareness for market and technology trends, which can be translated into pre-emptive actions (Bowman & Hurry, 1993). As a result, they enable firms to predict future developments more accurately (Cohen & Levinthal, 1994).

Private equity investors, in turn, will presumably possess a rather low ability to identify valuable technological knowledge if at all. They would have to avail themselves to technology experts or cultivate their own specific knowledge, e.g. by hiring staff with special industry knowledge. Moreover, private equity investors will probably choose to diversify the risk of their portfolio by avoiding a concentration on only one industry. This makes it even more difficult to build-up expert knowledge regarding specific technologies. Hence, when it comes to the evaluation of the technological assets of a potential target at the market for corporate control there will be *information asymmetries* between corporate and private equity investors. These are particularly severe because of the uncertainty related to R&D activities in innovative firms. Knowledge about the innovation quality, however, yields important information on the pricing of the technological assets in an acquisition (Heeley *et al.*, 2007).

Determining the innovation quality of a potential target ideally requires detailed information on every single innovation project. Each innovation project has its own specific attributes which are generally kept secret by a firm to ensure the appropriability of the returns from innovation activities. As the corporate and the private equity investor are equally affected by the level of confidentiality, they will presumably use information sources like patent data to assess the quality of a firm's innovation activities (Heeley *et al.*, 2007). In order for a patent to be granted and offered protection, the technological content of the patent needs to be disclosed by the applicant to the patent office. The information disclosed in the patent, however, provides only little, if any, clue on the ability of the patent holder to extract value from commercialization activities. As it is highly technical information providing only those "skilled in the art" with relevant knowledge about the true content there is a substantial information asymmetry between informed and uninformed investors. This difference is even higher when technological complexity increases as it is typically the case in high-technology industries. To sum up, the content of a patent usually does not provide any usable information for most potential investors who are not skilled in the art.

Hence, for private equity investors patents and the innovation history of the acquisition target in general are supposed to rather serve as *signals* in the first place (Ndofor & Levitas, 2004; Levitas & McFadyen, 2006; Heeley *et al.*, 2007). A patent acts as a positive signal as it shows that the firm in question has already proven its technological expertise and capabilities and that it has a well-functioning laboratory and inventor team. Moreover, patents can be sold individually after the acquisition. The expected resale value of patents in the technology market might be of particular interest for private equity investors in an asset stripping. As for both types of investors patents have a signaling and a potential resale value but, on top of that, for corporate investors also a value from a combination with existing knowledge stocks we hypothesize that private equity investors will pay a relatively lower price for patents than corporate investors.

Hypothesis 2a: The price paid for an acquisition target with a patent is ceteris paribus higher than for a target without a patent.

Hypothesis 2b: Corporate investors pay, on average, more for a target‘s patent stock than private equity investors.

Recalling the argument that corporate investors have developed absorptive capacities to identify and assess external technological assets, these investors will presumably be much better able to recognize the value of a potential target’s technology. Private equity investors, in contrast, will presumably have to employ external industry or technology experts to judge the value of technology. Nevertheless, their ability to assess the value of the technology will be lower as the total R&D capacity of a corporate investor can assumed to provide a much better basis for this purpose. Corporate investors can hence be regarded as technological insiders who successfully reduce information asymmetries about the value of a target’s innovation activities (Aboody & Lev, 2000; Heeley *et al.*, 2007).

Hypothesis 3a: The price paid for an acquisition target with more valuable patents is ceteris paribus higher than for a target with less valuable patents.

Hypothesis 3b: Corporate investors pay, on average, more for valuable patents than private equity investors.

Finally, there are also information asymmetries between both types of investors and the vendor of a potential target. Assuming a generally lower level of relevant technological knowledge of the private equity investor the target's vendors might succeed in obtaining a higher price for the firm from private equity investors compared to a sale to a corporate investor who should be able to reduce information asymmetries considerably. This argument provides additional support for our first hypothesis that private equity investors systematically pay a higher price for a target than corporate investors.

2.3.2 Competitor blocking as strategic value of patents

Besides the acquisition of valuable technological assets that might complement the existing technology portfolio or that serve as a basis for revenue creation, another objective for M&A transactions has been identified as to enhance the position of the merged entity in technology competition (Cassiman *et al.*, 2005; Williamson, 1975). Through the pooling of technological assets the merged entity is in a position to create significant barriers to entry into particular technology lines. In other words, patents can be used to block competitors from developing a competing technology alternative (Heeley *et al.*, 2007). This section therefore shifts emphasis on a third function of patents. Besides the knowledge protection character of patents and their signaling effect for potential investors, patents can block successive patent applications by threatening their novelty requirements (Scotchmer, 1991; Shapiro, 2001; Jaffe & Lerner, 2004).[2] In fact, survey evidence for the US and Europe has shown that the protection of intellectual property, i.e. what patents are originally made for in order to stimulate incentives to innovate by granting the inventor a temporary monopoly on her invention, is not what makes them attractive in the first place (Arundel *et al.*, 1995; Cohen *et al.*, 2000). The value of patents is often rather determined by their importance in licensing and M&A negotiations and by their capability to block the inventions of competitors. A recent survey for Germany shows that more than 40 percent of patenting firms apply for patents in order to block competitors (Blind *et al.*, 2007). Especially, Blind et al. (2007) find striking evidence for "defensive blocking"

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[2] There is a huge body of theoretical literature on the optimal "patent breadth", i.e. the degree of the patent protection, from a welfare perspective. The more "narrow" a patent is the easier it is to "invent around" the patent. Surveys on this particular literature are provided by Denicoló (1996) and Takalo (2001).

through patenting what they define as a forward-looking protection strategy directed at protecting the firm's position in technology markets.

Again, the identification of patents that can actually be used to block competitors in technology markets (blocking patents) should strongly depend on the ability of an investor to recognize those patents. Private equity investors, however, presumably lack the necessary in-depth knowledge on technology markets and their future development in order to predict which patents might reduce future technology competition. This requires detailed information on the technology development process which usually only firms doing research in a particular field possess as they get immediately confronted with existing patent fences. Nevertheless, blocking patents will generally be valuable for both types of investors as such patents should possess a higher potential resale value. As before, however, corporate investors will be much better able to identify and value the blocking patents.

Hypothesis 4a: The price paid for an acquisition target with blocking patents is ceteris paribus higher than for a target without these patents.

Hypothesis 4b: Corporate investors pay, on average, more for blocking patents than private equity investors.

In conclusion, we argue that technological assets of a potential target firm are a major driver for the price paid at the market for corporate control. However, the two basic types of investors – corporate and private equity investors – are supposed to attach systematically varying values to the target's assets. The valuation stems from different levels of knowledge about the technologies employed by the target which are a result of different absorptive capacities of the acquirer.

3 Methods

3.1 Empirical Model

In our empirical model we explain the deal value of the acquisition, i.e. the price paid by the acquirer, by the target firm's assets and characteristics in order to derive insights on the importance of technologies for different types of acquirers. We define the acquired company in a hedonic way as a bundle of its characteristics and assets X (Gompers & Lerner, 2000). The deal value of the target V is a function of those characteristics X. In the presence of efficient markets and full information $V(X)$ equals the price at which the target firm's assets are traded. Our empirical model shows how the deal value is decomposed with respect to the target firms characteristics and assets. As outlined above, our main focus is on the contribution of different variables capturing the target's innovative assets. We use a flexible specification that allows deals with private equity investor involvement (*PEI*) to differ from corporate investor acquisitions in their intercept as well as in their slope coefficients:

$$V(X) = c + (1 - PEI) * f(X) + PEI * f(c_{PEI}, X) + u\,.$$

u is the error term of the empirical model which can be estimated using ordinary least squares (OLS). c refers to the intercept of the model and c_{PEI} depicts the expected premium paid by private equity investors. The target's bundle of characteristics is defined as its total assets, return on assets, total liabilities and firm age. To test our hypotheses on the value of technologies for different acquirers we introduce different measures for the target's technological assets: the patent stock, the forward citations that its patents received in a five-year window and a measure for the capability of patents to block other patents into the empirical model. Their definition will be detailed in the following section. Further, industry and year dummies are included to control for the different economic conditions and stock market levels during the period from 1997 to 2003. All continuous variables reflect the target's assets and characteristics in the pre-completion year of the acquisition; they are all measured in logarithms to take account of the skewness of their distributions.

3.2 Data sources and variable definitions

Our main source of data is the merger and acquisition database ZEPHYR of Bureau van Dijk Electronic Publishing. We identified firms located in Europe that were subject to an acquisition by a corporate or private equity investor in the period from 1997 to 2003. To distinguish between corporate and private equity investors we relied on the acquirer industry classification provided in the ZEPHYR database. Moreover, only targets from the manufacturing sector were included as patents are of minor importance for services. Our sample consists of 1,441 target firms with known deal values. Financial information on the firms is taken from the Amadeus database of Bureau van Dijk Electronic Publishing. As our main focus is on innovative assets, we linked the acquisition targets to their patent history as patent applicants at the

European Patent Office (EPO).[3] Based on a computer supported text based search algorithm, target firms and patent applications were linked to each other using firm names and addresses in both databases. Each potential match proposed by the search engine was checked manually.

Focusing on the target's technological assets we use three variables to capture different aspects of the innovative activities of the target companies. In line with many recent papers all measures are based on the EPO patent data. First, we use the patent stock (*PS*) to proxy the number of technologies the firm owns, which is calculated as follows:

$$PS_t = PS_{t-1}(1-\delta) + patent\_applications_t$$

where δ represents the constant knowledge depreciation rate, which is set to 15 percent as is standard in the literature (e.g. Hall, 1990). This variable is used to test the importance of the quantity of patents held by the target company for the acquirer (Hypotheses 2a, 2b). The second variable describes the average patent value which is proxied by the sum of citations the patents received in a five-year window after the patent priority date (Hypotheses 3a, 3b). Patent citations have frequently been shown to be a reliable measure of patent quality and hence value (Harhoff *et al.*, 2003; Harhoff *et al.*, 2005). Patents receive citations when subsequent patents make reference to relevant prior art during the patent application process. The more frequent a patent is cited by other patents the higher its importance in a particular technology field can assumed to be. The citations are hence called "forward citations". As the citations a firm receives are highly correlated with the patent stock of a firm we divide them by the number of patents for our empirical specification. The estimated coefficient can be interpreted as the premium an acquiring firms pays for the value of the target's patents on top of the price he pays for the patented technologies themselves.

The third technology measure we use is a proxy for the potential of patents to block other patents (Hypothesis 4a, 4b). The measure we propose is also based on forward citations, making particular use of the citation system at the EPO. For each EPO

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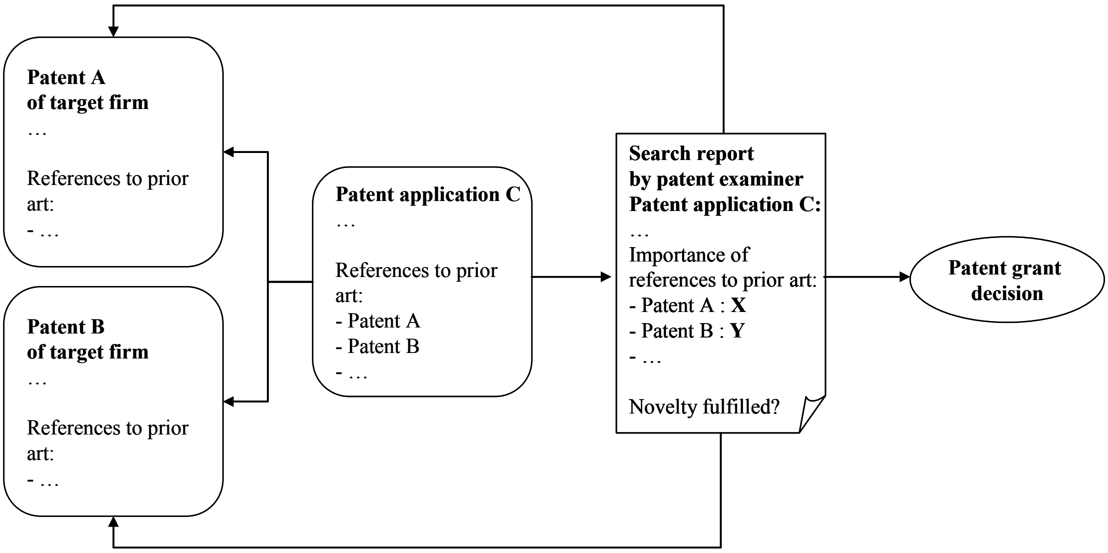
[3] Dating patents according to their application date as opposed to the granting date conforms with common practice (e.g. Griliches, 1981). The application date has the advantage to be closer to the actual completion of the invention.

patent the patent examiner prepares a search report that lists all important documents, which are considered as prior art. Based on the search report it is decided whether a patent application is novel enough to be granted. An interesting feature of the EPO search reports as opposed to search reports at the United States Patent and Trademark Office (USPTO) is that references to prior art are classified according to their importance for the patent filing. Prior art which threatens the novelty requirement of the patent application is made visible in that way. In the search report those references are marked with an "X" if the invention cannot be considered to be novel or cannot be considered to involve an inventive step when the referenced document is taken into consideration alone. References are marked with a "Y" if the invention cannot be considered to involve an inventive step when the referenced document is combined with one or more other documents of the same category, such a combination being obvious to a person skilled in the art (Harhoff *et al.*, 2005). Figure 1 gives an overview of the patent application procedure at the EPO.

Figure 1: Patent application procedure at the EPO



We assume that patent A and patent B are held by a potential target firm. Both patents are cited by an incoming patent application C as prior art. In the search report, the patent examiner evaluates the importance of the references made by assigning a code letter "X" and "Y", respectively (for a full description of all EPO code letters see Harhoff *et al.*, 2005). We use the sum of X and Y citations that patent A and patent B receive in a five-year window to proxy their value as a blocking patent. To account for the high correlation between citations received and the subset of X or Y citations received we normalize this measure by the total number of forward citations. Hence we use the percentage of X and Y citations in order to depict the threatening power of the patents. Again, the estimated coefficient depicts the premium that acquiring firms pay for the blocking potential of the target company's patents on top of what they pay for the patented technologies and their value as measured by citations.

Finally, to control for technological proximity of the patent portfolios of acquiring and target firm we use the proximity measure introduced by Jaffe (1986). As the technological content of the assets to be acquired is assumingly only important for corporate investors the proximity measure is only calculated for these investors. After all, it would be impossible to calculate the measure for private equity investors as these do not possess a patent portfolio.[4] In order to calculate this measure we determined for each firm patent stocks for each 2-digit technology class according to the International Patent Classification (IPC). This yields a technology vector F for each target i and acquirer j, which can be interpreted as their technology portfolio. Using these vectors (as a percentage of the total patent stock) technological proximity T is now calculated as:

$$T_{ij} = \frac{F_i F_j}{\sqrt{(F_i' F_i)(F_j' F_j)}}; \qquad 0 \le T_{ij} \le 1.$$

Prior literature suggests an inverted U-shaped relationship between the relatedness of the acquirer's and target's technology portfolio and innovation performance (Ahuja & Katila, 2001). On the one hand, new acquired knowledge may provide additional stimuli and information to the acquirer's knowledge base. On the other hand, acquired knowledge that is too closely related to the existing knowledge presumably limits the benefits. This pattern should be reflected in the price that acquiring firm's pay for their purchase as the deal price is supposed to capture the expected value of the assets for the acquiring firm.

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[4] An exception might be private equity investors that follow a buy-and-build strategy. In that case the patent portfolios of the firms in the private equity portfolio would have to be taken into account. However, information on the complete portfolios of these firms is not available to us.

4 Results

4.1 Descriptive statistics

Table 1 presents the descriptive statistics for the sample of target firms. All continuous variables except for the deal value refer to the pre-completion year of the acquisition. First of all, the descriptive statistics show that corporate investors pay, on average, a much higher price for their targets than private equity investors. This is related to the average size of the targets as targets of private equity investors are significantly smaller than firms being subject to corporate acquisitions in terms of pre-acquisition total assets. Furthermore, targets of private equity investors are, on average, less profitable as indicated by the returns on assets, defined as the sum of profits earned by the firm and the capital gains of assets over the market value of assets in the year prior to the acquisition. For both types of acquisition targets the average return on assets is negative. Regarding the liabilities of the targets over total assets, i.e. the leverage of the firms, acquisition targets involved in a deal with a corporate investor exceed on average those with a private equity investor which indicates a higher risk associated with such targets. Table 1 further indicates that private equity investors prefer younger firms by showing that targets of private equity investors are on average 10 years younger than those bought by corporate acquirers. The descriptive statistics thus already hint at a considerably different firm profile in which corporate and private equity investors are interested. The findings suggest that private equity investors – in comparison to corporate investors – tend to prefer rather distressed firms or younger firms with potentially unstable revenue and earning flows.

Regarding the technological assets of the target, Table 1 shows that acquisition targets of private equity investors are on average five times as innovative as the targets of corporate investors in terms of their patent stock over total assets. The difference, however, diminishes when the average patent value is considered as proxied by the sum of citations the patents received. However, 79 percent of the patents owned by the targets of corporate and private equity investors receive no citations at all, which indicates a highly skewed distribution of patent value (Harhoff *et al.*, 2003; Harhoff *et al.*, 2005). Interestingly, the descriptive statistics show that the patents of targets involved in deals with a private equity investor have, on average, more blocking citations (i.e., X and Y citations) than the patents acquired from targets of corporate investors.

Table 1: Descriptive statistics

	Private equity targets # 784 Mean (st.dev.)	**Corporate targets** # 657 Mean (st.dev.)	Mean difference (std.err.)
deal value (mio EUR)	39.196	103.073	63.876***
	(153.098)	(317.770)	(12.824)
total assets (mio EUR)	67.963	96.000	28.037**
	(170.643)	(258.808)	(11.391)
return on assets (%)	-11.844	-0.291	11.55***
	(25.007)	(18.268)	(1.173)
leverage	0.573	0.587	0.015
	(0.329)	(0.258)	(0.016)
age (years)	10	21	10.453***
	(20)	(24)	(1.14)
patent stock/assets	0.0005	0.0001	-0.0003***
	(0.0020)	(0.0011)	(0.0001)
technological proximity		0.006	
		(0.041)	
citations/patents	0.410	0.481	0.071
	(0.931)	(1.370)	(0.061)
blocking citations/citations	14.95	6.45	-0.075***
	(27.85)	(17.12)	(0.012)
Patenting firms only:	# 198	# 104	
patent stock/assets	0.0019	0.0001	-0.0011***
	(0.0036)	(0.0027)	(0.0004)
technological proximity		0.007	
		(0.040)	
citations/patents	0.786	0.956	0.170
	(0.989)	(0.796)	(0.1122)
blocking citations/citations	0.365	0.262	-0.103***
	(0.024)	(0.026)	(0.038)

***, **, * indicate statistical significance at the 1%, 5%, 10% level.

To further explore the relationships between the variables, Table 4 in the appendix reports the bivariate correlations. The coefficients above the diagonal refer to the corporate investors while the coefficients below the diagonal depict the private equity investors. It turns out that for both corporate and private equity investors total assets are positively correlated with the deal value. Regarding the return on assets, however, there is a positive relationship with the deal value only for the private equity investors. This suggests that private equity investors are much more interested in the financial profitability of the target than corporate investors who might have different priorities. In fact, corporate investors seem to put a much higher emphasis on the technological assets of the target. The patent stock, the patent value and the blocking potential of the patents are positively correlated with the deal value, whereas only the patent value seems to be of importance for private equity investors. Their interest in blocking patents turns out to be much weaker. Finally, the age of the target firm is positively correlated with the deal value for both types of investors. However, this relationship proves to be stronger for private equity investors.

4.2 Empirical analysis

Table 2 shows the results from the OLS estimation in three different model specifications. Results of F-tests for equality of the coefficients between the two groups are provided in Table 3. Regarding the intercept for private equity firms, the results indicate that private equity investors pay, on average, significantly more than corporate investors confirming our first hypothesis. Given that the deal value consists of the market value of the respective target plus a merger premium, this shows that private equity investors systematically overvalue their targets relative to corporate investors.

Focusing on the value of technologies the first specification, which controls for the volume of technological assets only, suggests that patents are valuable for both types of investors (Hypothesis 2a) and that corporate investors valuate patents much higher than private equity investors (Hypothesis 2b). Part of this can be attributed to the different meaning patents have in acquisitions. On the one hand, patents have a technological value that can be exploited in the merged company or through selling the patents after the acquisition. On the other hand, patents work as a signal for the technological fitness of a potential target company. The signaling function and the technological value of patents is supposed to be the more important feature of patents for private equity acquirers as their acquisitions are supposed to be less content driven in technological acquisitions. Hence, private equity firms cannot realize an additional value trough the combination of the acquired patents and own existing knowledge stocks. When citations as a measure for the value of the technological assets are taken into account (specification 2) it turns out that a significant part of the attractiveness of patents is explained by their value rather than by the patent stocks (Hypothesis 3a). Further, Table 3 shows that there is no significant difference between the coefficients for corporate and private equity investors. Hypothesis 3b is hence rejected. Accounting for the value of blocking patents, specification 3 shows that corporate investors are highly interested in securing or enhancing their position in technology markets through firm acquisitions, whereas there is no such evidence for private equity investors. Therefore, hypothesis 4a is rejected while hypothesis 4b receives support. This most complete specification shows that a significant part of the difference between private equity and corporate investors in technologies relates to their different valuation of blocking patents. Including this measure into the regression does not alter the coefficients discussed above. In fact, results turn out to be robust across the three specifications. To sum up, the most notable difference in the investors' attitude towards patents lies in their ability to secure a firm's future position in technology markets through the blocking potential of its patents.

Apart from the variables used to test the hypotheses the results show that the relatedness of the target firm's technology portfolio is of high importance for the corporate investors. As expected, the coefficients hint at an inverted U-shaped relationship between the relatedness of the technology portfolios and the deal value. Corporate investors are hence willing to pay for technological assets that provide opportunities for cross-fertilization. However, the deal value is negatively affected when the technology portfolios are too closely related. Similar results for the relationship between technology relatedness and innovation performance (Ahuja & Katila, 2001) can therefore be extended to the market for corporate control. In fact, the price paid for a target should reflect the future innovation potential of the merged entity.

Furthermore, Table 2 and Table 3 show some interesting results regarding the remaining variables that refer to the target's characteristics and assets. Focusing on total assets the coefficients for both types of investors are positive and significant. The magnitude moreover indicates that corporate investors attach a higher importance to the target's assets. Referring to the return on assets there tends to be a rather small positive effect for both types of investors on the deal value. As Table 3 shows, differences between the coefficients for both types of acquirers are significant. The leverage of the target firm turns out to be not important for the deal value. Moreover, we cannot observe a significantly different effect of the target's age on deal value for both corporate and private equity investors. Finally, industry and year dummies were tested for joint significance which can be confirmed.

Table 2: Ordinary least squares regression for the deal value

	Model 1		**Model 2**		**Model 3**	
	Coefficient (st. err. ^{A})		Coefficient (st. err. ^{A})		Coefficient (st. err. ^{A})	
Private equity investors						
intercept	2.424	***	2.391	***	2.324	***
	(0.497)		(0.495)		(0.495)	
patent stock/assets	0.065	**	0.060	**	0.055	*
	(0.031)		(0.030)		(0.031)	
citations/patents			0.162	**	0.137	*
			(0.073)		(0.079)	
blocking citations/citations					0.182	
					(0.166)	
log(total assets)	0.223	***	0.216	***	0.214	***
	(0.024)		(0.024)		(0.024)	
return on assets	0.004	**	0.004	**	0.004	**
	(0.002)		(0.002)		(0.002)	
leverage	0.173		0.179		0.184	
	(0.144)		(0.142)		(0.142)	
log(age)	0.135	**	0.125	**	0.126	**
	(0.055)		(0.056)		(0.056)	
Corporate investors						
patent stock/assets	0.212	***	0.204	***	0.176	***
	(0.068)		(0.066)		(0.066)	
tech. proximity	7.907	***	7.086	**	6.138	**
	(3.065)		(3.075)		(3.025)	
tech. proximity-squared	-15.472	***	-14.672	**	-12.657	**
	(6.306)		(6.257)		(6.180)	
citations/patents			0.125	***	0.099	**
			(0.045)		(0.041)	
blocking citations/citations					0.964	***
					(0.388)	
log(total assets)	0.503	***	0.495	***	0.480	***
	(0.037)		(0.038)		(0.038)	
return on assets	0.010	***	0.010	***	0.011	***
	(0.003)		(0.003)		(0.003)	
leverage	-0.118		-0.116		-0.068	
	(0.209)		(0.208)		(0.208)	
log(age)	0.171	***	0.160	***	0.160	***
	(0.058)		(0.057)		(0.057)	
constant	4.268	***	4.275	***	4.391	***
	(0.469)		(0.470)		(0.470)	
8 industry dummies	LR-Chi^2 = 16.23**		LR-Chi^2 = 16.12**		LR-Chi^2 = 14.48**	
6 year dummies	LR-Chi^2 = 32.79***		LR-Chi^2 = 29.86***		LR-Chi^2 = 31.05***	
Number of observations			1,441			
F-statistic	18.53***		17.84***		17.31***	
R-squared	0.27		0.28		0.29	

***, **, * indicate statistical significance at the 1%, 5%, 10% level.

^{A} Standard errors are based on the Huber/White estimator to account for heteroscedasticity.

Table 3: F-Tests for equality of coefficients for private equity and corporate investors

	Model 1 F-statistic	**Model 2** F-statistic	**Model 3** F-statistic
log(total assets)	50.03***	49.65***	44.48***
return on assets	2.74*	2.61*	3.12*
leverage	1.19	1.24	0.89
log(age)	0.26	0.25	0.23
patent stock/assets	6.74***	6.51**	4.34**
citations/patents		0.25	0.23
blocking citations/citations			3.83**

***, **, * indicate statistical significance at the 1%, 5%, 10% level.

5 Discussion and conclusions

Our results have shown that technology considerably matters in firm acquisitions – but to a varying extent and depending on the acquirer's identity. First of all, private equity acquirers systematically pay more for a target while controlling for the target's assets and characteristics. This result can be attributed to a number of reasons: First of all, private equity investors are able to pay a higher price than horizontal acquirers as these transactions are typically structured as leveraged buyouts with a high share of debt while horizontal transactions tend to be financed with equity (Arundale, 2002). Debt can be raised at significantly lower costs than equity which is why private equity investors can afford a higher merger premium. Moreover, private equity investors tend to expect higher returns from their investment in a shorter time. To achieve this objective, private equity investors can usually take more rigorous steps in the reorganization of the target than a corporate acquirer as the target is still a legally independent firm and – besides a buy-and-build strategy – there are no plans for integration into the parent. In contrast to that, corporate acquirers have to cope with significant integration efforts when they try to integrate the target's technology portfolio into their own portfolio. This post-merger integration considerably affects the innovation processes of a firm and hence requires a well-planned integration approach (Grimpe, 2007). Apart from the high failure rate of such transactions (Miles & Snow, 1984), it is not clear at the time of the acquisition whether the integration of technology portfolios proves to be beneficial for innovative capacities. Corporate acquirers presumably take this risk into account when they decide on the acquisition price. Together with the higher cost of equity this could lead to a higher merger premium of private equity acquisitions relative to corporate acquisitions. Our results also support the findings of Gompers and Lerner (2000) for leveraged buyout funds regarding the positive impact of capital inflows on target firm valuation.

Moreover, our results indicate that patents have a high importance in M&A transactions. Patents indeed serve as a signal to exhibit technological capabilities which reduces uncertainties associated with the firm acquisition for the investors (Ndofor & Levitas, 2004; Levitas & McFadyen, 2006). Results of prior work on the importance of patents as signals in initial public offerings (IPO) can hence be transferred to the market for corporate control (Heeley *et al.*, 2007). This seems to be particularly true for private equity investors as they should typically lack the technological expertise to evaluate a potential target's patent portfolio. Although patents disclose technological information that can be taken as an indicator for future innovation performance, this technical information is hardly interpretable for investors not skilled in the art. In this context, corporate investors benefit from having built up absorptive capacities through own R&D activities that enable them to identify and evaluate relevant technological assets in the external environment. What is more, private equity investors should not normally have certain considerations how the acquired technology fits into an existing technology portfolio. Rather, they are supposed to be interested in patents because they provide an indication of potential revenue flows and because of their expected value if sold after the acquisition. The technological content and the possibility to exploit protected knowledge in combination with own knowledge stocks is, however, of great importance for corporate investors as they deliberately strive to complement their own technology portfolio in order to increase own innovative capabilities (Cassiman *et al.*, 2005; Hussinger, 2005). Corporate investors, hence, attach a higher value to patents than private equity investors.

Both types of acquirers are found to pay higher prices for targets with valuable technological assets. Obviously, there seems to be no significant knowledge gap of private equity investors compared to corporate investors. In other words, both types of investors seem to have developed the necessary knowledge for identifying valuable technologies. However, when the blocking potential of acquired patents is taken into consideration there is a clear difference in the valuation between corporate and private equity investors. Corporate investors deliberately identify targets with such patents that could, on the one hand, be used to extend present R&D activities into areas that were previously blocked by competitors. On the other hand, these patents provide a basis to protect and secure own technology domains. Patents in corporate acquisitions therefore always serve a technological but also a strategic objective in technology markets (Blind *et al.*, 2007). Surprisingly, private equity investors do not show an interest in patents with a blocking potential although these patents should serve as a basis for sustainable rent appropriation from innovation activities. This result may be attributed to a lack of specific knowledge that might be necessary to identify particularly relevant patents for future innovation trajectories. Such knowledge could hence be at the core of the corporate investors' absorptive capacities.

In this respect, our results extend existing knowledge on the motivation for firm acquisitions. For the first time, the two key functions of patents – as monopoly rent devices and as blocking instruments – are shown to be reflected in the market for corporate control. Their importance, however, differs according to the type of acquirer. Especially the deliberate acquisition of patents with a blocking potential by corporate investors has a significant impact on the allocation of technological assets in the market as it hints at a concentration of key technologies in technological markets through acquisitions. This links our results with an important implication for competition policy in that M&A transactions, to a large extent, are meant to create barriers to entry in specific technology markets and, hence, decrease competition. This tendency needs to be reflected in a firm's M&A strategy. Firms need to have a particular eye on the key technologies in their industry and identify the underlying intellectual property. They need to understand that reorganization in the industry through M&A transactions could be directed at a concentration of key technologies and that these might, in a new combination with other technological assets, serve as a basis to threaten the novelty requirements of future patent applications.

This result is also of high relevance for private equity investors who apparently do not attach particular importance to patents with a blocking potential. The value of the acquired firm's technological assets may, however, depreciate substantially if the firm is blocked in its subsequent R&D activities by other firms' patents. Given the rather short investment horizon of private equity investors there is a clear need to make sure that the technological assets are not threatened by other patents. As this would sharply decrease the price that a private equity investor can obtain upon its exit, it should be a key interest to secure those targets with the necessary patent endowment.

6 Limitations and future research

This paper has shown for a sample of European firm acquisitions with the involvement of corporate and private equity investors that technology matters in firm acquisitions but to a varying extent and in different ways when the acquirer's identity is taken into account. Our results, however, provide no indication whether there is an effect of acquirer identity on innovation performance following the deal. Thomsen and Pedersen (2000) provided evidence that private equity investor ownership leads to higher shareholder value. It is questionable though whether such an effect also holds in the context of technology. Previous studies have indicated that the interpretation of the post-merger developments in R&D is not that straightforward. A decrease in technological engagement after an acquisition might correspond to post-merger integration difficulties (as the integration of two firms' R&D departments) that hinder the exploitation of the joint capacities (Ahuja & Katila, 2001; Grimpe, 2007). However, a post-merger decrease in technology outcome can also be the response to a dominant position of the merged entity in technology markets (market power effect), which reduces the incentives to innovate. In such cases that infer a decrease in technology activities, an independent advancement of the technology portfolio in a firm owned by a private equity investor might lead to a superior technological outcome. This perspective opens the door for future research that should try to generate empirical evidence on the longitudinal performance of firm acquisitions with respect to different acquirer identities.

Moreover, it would be desirable to identify buy-and-build strategies that private equity investors execute to create a new and integrated company. In that case, motivations regarding the acquired technologies should also differ as the acquired firms are expected to fit together technologically. More valuable patents and those with a blocking character should hence also receive more importance for private equity investors.

7 Appendix

Table 4: Bivariate correlations

Corporate investors **Private equity investors**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**
1. Log(deal value)		0.47 ***	0.05	-0.05	0.09 **	0.11 ***	0.16 ***	0.22 ***
2. Log(total assets)	0.35 ***		-0.14 ***	0.03	-0.03	-0.09 **	0.09 **	0.18 ***
3. Return on assets	0.17 ***	0.22 ***		-0.12 ***	0.12 ***	0.09 **	0.00	-0.08 **
4. Leverage	0.02	-0.07 **	0.08 **		-0.04	-0.04	-0.02	-0.09 **
5. Log(age)	0.16 ***	0.21 ***	0.30 ***	0.05		0.04	0.05	0.03
6. Patent stock/total assets	-0.01	-0.26 ***	-0.02	0.02	-0.02		0.04	0.20 ***
7. Citations/patents	0.16 ***	0.13 ***	0.03	-0.02	0.09 **	0.05		0.24 ***
8. Blocking citations/citations	0.07 **	0.02	-0.11 ***	-0.09 ***	-0.05	0.24 ***	0.39 ***	

***, **, * indicate statistical significance at the 1%, 5%, 10% level; n = 1,441

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Mathematical Modelling of Innovation Dynamics: An Empirical Analysis of the Photovoltaic Market in Germany[1],[2]

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Abstract

The objective of this paper is the analysis of dynamics of innovation processes in science-driven markets. In order to gain deeper insight in the science-based market formation different empirical studies are taken. The empirical investigations are summarised in a stylized model which provides the basis for the econometric analysis. This paper is focused on the interaction of particular variables in the model and its reaction to exogenous parameters. The photovoltaic market (PV market) in Germany is chosen as an example for econometric modelling. Using an error-correction model (ECM) short and long term effects in interaction between patent applications and scientific publications are analysed. The results verify empirical evidence of long-run equilibrium between publications and patents and confirm the basic hypothesis that two quite different development phases due to basically different sets of determinants can be observed in the development of science-based markets. In the first period from 1973 to 1990, the oil price development influences the interdependency between science and technology. In the second period from 1991 to 2001 the Renewable Energy Sources Act and the Electricity Feed Act have significant effect on the development of science and technology.

Key words: science-based technologies, time-series analysis, non-stationarity, cointegration, error correction models.

JEL classification: C51, C32, O34, Q2

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[1] Acknowledgement: This work was financed by the Volkswagen-Stiftung. The author is thankful to Prof. Hariolf Grupp, Dr. Dirk Fornahl and Dr. Ulrich Schmoch for their helpful suggestions.

1. Introduction

Technical progress and its dynamics are in the core of growth and employment problems of modern industrialised societies. Economic competition, high income, and prosperity are usually attributed to technical progress. Under the assumption that technological development shows an increasing trend towards the science base within a national innovation system, and if it is true that there is pressure from the international innovation competition of enterprises to get access to the science base of several nations, then the analysis of innovation processes in science-driven markets turns out to be of great importance for the common economic development and the competitiveness of industrialised nations. The importance of stimulation of the emerging new knowledge has been also recognized by the European Union (EU). The ambitious goals of Lisbon and Barcelona and the creation of the European Research Area (ERA) can be taken as a sure indication of this acceptance (see Commission's 2006 report; European Commission (2007)).

Certain institutional arrangements are required for creation and development of science-based technologies. However the nature of scientific knowledge has frequently a spontaneous order, i.e. it is the result of the activities from many individuals and groups, which neither individually nor collectively intend to bring about that particular state of the body of knowledge (e.g. Radnitzky (1989)). Therefore it appears to be difficult to precisely forecast the future trend of technological change. Nevertheless, it is helpful to enter into the black box of "science-based" models and try to understand the dynamics of innovation processes in science-driven markets. This paper aims to analyse the interaction of different factors like science and technological activities, state funding, legislation and the impact of external effects, such as oil price on the basis of econometrical analysis.

This paper is structured as follows: after introduction section 2 reviews some empirical investigations, which deal with the question of science-based market formation. A theoretical description of science-driven market is given. The stylized model offers descriptive summary of these empirical investigations. Section 3 considers particularly the Photovoltaic market and describes the model variables, which are selected to analyze the market development. Section 4 presents an econometric model for formation of the Photovoltaic markets. Section 5 concludes the paper by summarising the results.

2. Empirical Evidence and Stylized Model

The subject of this paper is the innovation process in case of science-based technologies. Unfortunately, there is not any clear, generally accepted categorisation of a specific technology as science-based. A pioneering typology for sectoral patterns of technical change was suggested by Pavitt (1984). In this empirical work Pavitt distinguishes between supplier-dominated sectors, scale-intensive sectors, special suppliers, and science-based ones. Based on an analysis of approximately 2000 innovations in British industry within the period of 1945-1979, Pavitt found typical innovation patterns in these broader sectors of industry. Innovations in science-based sectors display a close relationship to basic research and scientific progress. The innovations in these sectors require high investment in research (not only in product development), but offer properties of key technology with a strong diffusion potential in other industrial sectors (see also Martin, 1992). Marsilli (2001) suggests further splitting the science-based sectors into two main categories: the “life science-based” (drugs and bioengineering) and the “physical science-based” (computers, electrical telecommunications instruments). However, these studies offer sectoral classification. Segmentation according to technology fields was not intended.

Another quantitative possibility to identify scienced-based technologies was suggested by Narin and Noma (1985) and widely used for analytical proposes by Grupp and Schmoch (1992a); Schmoch (1993); Meyer-Krahmer and Schmoch (1998). This approach is based on the citations of scientific papers in official reports of patents. In checking the novelty of a patent application the inventors and the patent office examiners prepare a list of citations of published prior art documents. This list can include other patents or scientific publications. The patents are more preferable, because they describe technical features more clear then scientific articles. But occasionally relevant patents are not possible to find. In this case scientific papers are cited. According to this, science-based technologies are defined as fields with frequent references to scientific publications. A list of 28 technology fields, measured by the relative science reference, is documented in the work of Grupp et al. (1996). According to this study genetic engineering, pharmaceuticals and laser technology have the highest science linkage followed by telecommunications, information storage, data processing, image transmission as well as sensor technology.

The dynamics on the time scale of innovation processes in science-based markets has not been explored to a great extent. There are some empirical investigations which deal with the question of market formation in science-based sectors (Schmoch, 2007). The empirical exploration to study these special markets often uses one or several of the following indicators:

- Measurement of scientific activities based on bibliometric indicators (scientific publications) (van Raan, 1997),

- Measurement of technological development by patent applications or patent grants, respectively, and

- Measurement of installed or sold (shipped, respectively) products to grasp diffusion.

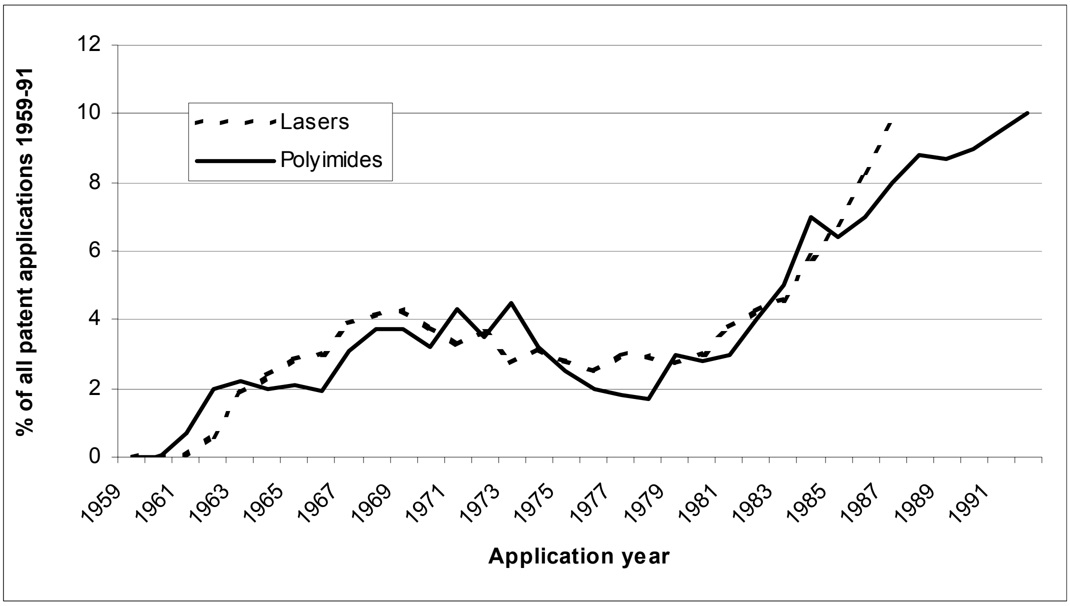


Figure 2-1: Long-term development of patent applications for lasers and polyimides from1959 to 1991.

Source: Grupp, Schmoch (1992b), p. 278.

Already at the beginning of the 1990s, patent applications for polyimides and lasers were studied and showed a characteristic non-linear pattern with two maxima (Grupp, Schmoch, 1992b). First, the number of patent applications increased continuously until a first maximum was reached. Later, the number decreased and a phase of stagnation started because the first inventions were considered not very tuned to user preferences and too much dependent on "laboratory thinking". Many years after these first activities in science and technology a second dynamic wave may start allowing patent applications to increase again and surpass the level of the first maximum (Figure 2-1).

In case of laser and polyimide basic scientific theories, the first wave of activities and the final market-driven growth lasted for a period of fifty years or more (Grupp, Schmoch, 1992b). In case of the laser market the number of scientific publications was very low during the first years of activity. Yet with an increasing number of patents also the number of scientific publications grew. From this observation it is concluded that scientific activities not always precede technological development but, due to intensive interaction in the scientific community, science and technology are intertwined.

Parallel to the observations by Grupp and Schmoch (1992b), Rickerby and Matthews (1991) described what they called the "technological commercial exploitation curve" for surface engineering (Figure 2-2). Their description is not supported by quantitative data, but is based on qualitative experience of engineers. Striking is the similarity of this qualitative experience with the indicator-based patent curves for lasers and polyimides.

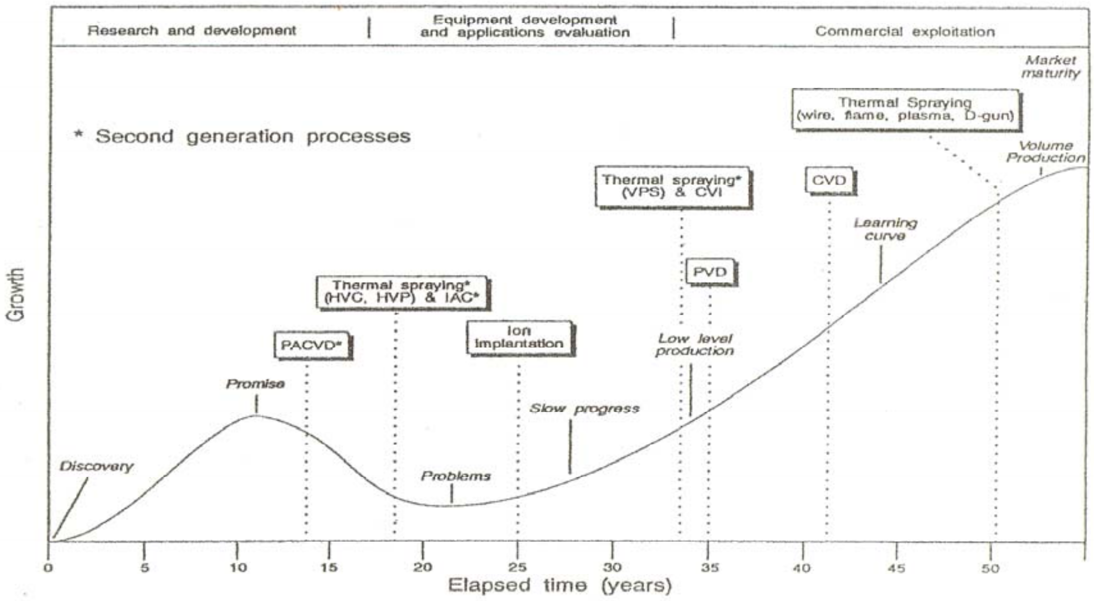


Figure 2-2: Technological commercial exploitation for surface technologies.

Source: Rickerby, Matthews (1991), p. 347.

Development of some emerging technologies are also illustrated by Gartner consultancy (www.garthnergroup.com), giving a graphical modelling of the maturity, adoption and business application of specific technologies. This hype cycle approach highlights the progression of an emerging technology from market over enthusiasm through a period of disillusionment to an eventual understanding of the technology's relevance and role in a market or domain. Technologies are described in term of visibility and maturity. The dimension of visibility does not offer any clear differentiation between technology and market development but concludes both kinds of activities (Figure 2-3).

According to Gartner's Hype Cycle graph, handwriting recognition, software as service and location-aware applications have reached the bottom of the trough and are starting to climb into the "slope of enlightenment". In this phase, the majority of consumers, not just the early adopters and technology enthusiasts, start to see the benefits of the technology and become more educated.

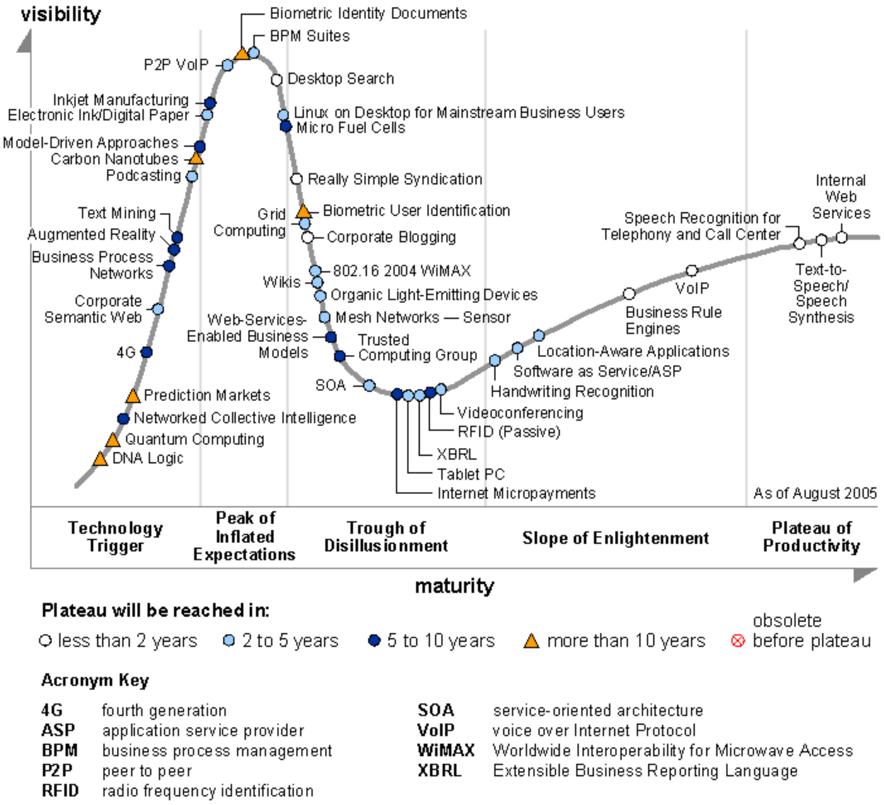


Figure 2-3: Hype Cycle for Emerging Technologies, 2005

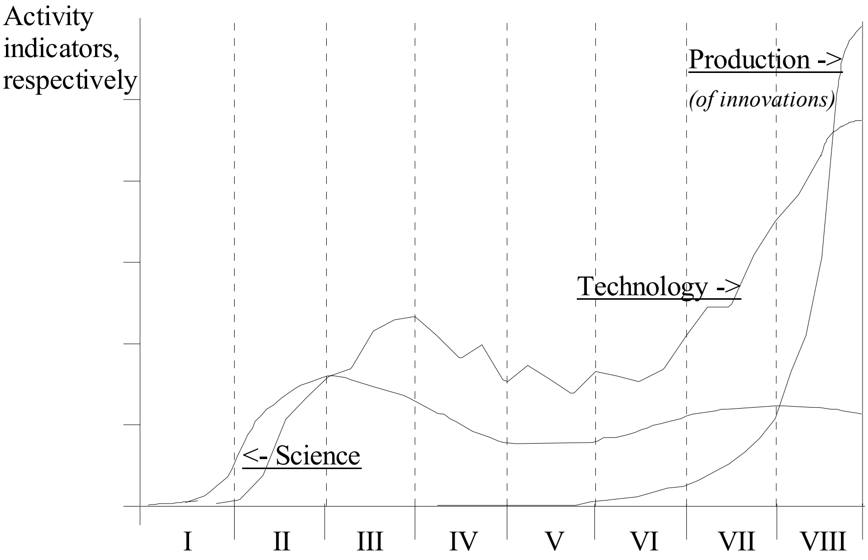
Source: Gartner(2005).

Laser, polyimides, technologies for surface engineering, genetic engineering, pharmaceuticals, emerging technologies of hype cycle represent quite different technologies in relation to scientific background, market size, industrial application, etc. The striking similarity in the development of these technologies seems to be unexpected. The reason for the "striking correspondence" is science-intensive nature of both technologies on the one hand and potential of numerous practical applications on the other hand (see also Grupp and Schmoch , 1992b, p. 282). Stokes (1997) pools such technologies together as "Pasteur's quadrant". Although research in this quadrant has potential real-world utility, its investigators never lose sight of the desire to advance scientific understanding.

Two main stages of market formation of "Pasteur's" technologies can be distinguished. In the first phase "voice of the market" is largely absent and the development goals are oriented towards internal success in the scientific communities. (Hekkert et al. 2007). The misunderstanding or, better yet, non-interaction between the side of science and the demand side is largely due to intellectual, but also normative differences; questions of safety, standardisation, and compatibility are more often than not overlooked (Blind, 2004). Although some of these differences may be larger in perception and rhetoric than in reality, they tend to lead to stagnation and thus cause the end of the first maximum of activities as observed in the empirical studies. Consequently, the emergence of innovations is seen as "driven by individual genius" or as stochastic events (which are known as serendipity effects in basic research). If radical innovations had immediately a better price-performance ratio, then substitution on consumer markets would be a simple matter (Geels, 2006). But radical innovations are usually born as "hopeful monstrosities" (Mokyr, 1990), i. e. as interesting and promising ideas with crude performance. Much work is needed to make radical innovations technically and economically viable. Small market niches as "incubation rooms" are also essential to protect their early development. (Geels, 2005). Technical feasibility is not the same as product development and introduction to the market. Here, socio-technical alignment is required, where economics, politics, consumer circles, and aspects of quality of life play a role. But the topic of user preferences is underdeveloped in economics; what happens on the demand side remains largely a black box.

Obviously, some scientific discoveries can not break the deadlock after a first maximum of activities (Scherer, 1986). But it may also happen that further improvements and investigations open a bridge towards demand and consumer preferences after a while. The second stage of market formation begins. This regime shift may give rise to a wave of activities and, indeed, in the case studies mentioned above, this was always observed. Among the many factors that work against the introduction and diffusion of technologies, Kemp et al. (1998) mentions technological factors, government policy and regulatory frameworks, cultural and psychological factors, demand and production factors, infrastructure and maintenance, as well as undesirable social and environmental effects of new technologies. Other barriers include high investment costs, “split incentives”, lack of awareness of potential by customers as well as by policy makers and so on (Philibert, 2006). If the scientific and technological potentials of new technology fit with the demand side, market introduction and diffusion may take place.

Before turning to econometric modelling, a standardised reference scheme of the formation of science-based markets summarises empirical findings and provides basis for the further analysis (Figure 2-4). This model is to be found in Grupp (1998). Eight phases of market formation are comprised here. In the first two stages, principles and phenomena are clarified scientifically or theoretically, models are devised and the basic effects discovered. Academics, in this case extra-industrial research, are responsible for the lion’s share. In case of dominant designs (phase III and IV), industrial actors become involved in R&D, but extra-industrial research mostly with a fundamental bias, continues to be important. Even at launch of innovations (V and VI) extra-mural R&D activities of enterprises play an important part. Ultimately, it comes down to widespread utilisation and general application of new products and processes (VII and VIII), which according to imitation and diffusion arguments, likewise do not need to proceed without the extra-industrial research system (Grupp, 1998, pp. 34).



I: First explorations in the scientific domain.
II: Properly developed science; first technical achievements.
III: Science fully developed; technology still capable of extensions; prottypes.
IV: Difficulties discernible in economic transposition.
V: Temporary stagnation in science and technology; reorientations.
VI: Industrial R&D envisages new possibilities; but still capable of expansion.
VII: First commercial applications; industrial R&D fully developed.
VIII: Penetration of all markets; importance of R&D waning relative to turnover.

Figure 2-4: Standardised reference scheme of the formation of science-based markets measured by different types of indicators: publications (for science), patent applications (for technology) and installed or sold (shipped, respectively) products (for production).

Source: Grupp (1998), p. 34.

The present state in this research area provides us with a lot of studies on either the science push or the demand pull side. Most of these papers are of qualitative nature. It is the challenge of this study to reconcile both views into a formal mathematical model. The basic hypothesis is that in the development of science-based markets two quite different development phases due to basically different sets of determinants can be observed. The main aim is to transfer the stylized model (Figure 2-4) into a formal mathematical one. The interaction of particular variables in the model and reaction of models to exogenous parameter is the centre of attention.

3. Photovoltaic Market and Model Variables

Presently, it is still an open question whether this qualitative stylised model given in Section 2 can be transformed into a formal econometric model and verified for empirical case studies. The Photovoltaic market (PV market) in Germany is chosen as an example for econometric modelling. This decision is guided by the following factors:

(1) Strong dependency of the PV market on new scientific inventions and discoveries can be observed during common history of photovoltaic technology. Photovoltaic is the direct conversion of sunlight into electrical energy using a semiconducting material. The PV effect was discovered in 1839 by Edmond Becquerel. For a long time it was a scientific phenomenon with few device applications. The problem of the first practical solar cells was their lower degree of efficiency. After the introduction of silicon as the prime semiconductor material in the 1950s, silicon PV diodes became available (see Shah et al. 1999). The new way to make silicon solar cells helped reach an efficiency of nearly 6 percent. In the 1954 a solar-powered radio transmitter was presented at a meeting of the National Academy of Science. Technological improvement continued and solar cells with higher efficiency were developed. But commercial success evaded solar cells because of their prohibitive cost in the research and manufacturing processes. The industrial development in the 20th century and the use of fossil fuels slowed down research in the area of photovoltaic energy. Until 1960 this type of technology was used in situations where electrical power from the grid was unavailable, such as in space industry for satellites. Due to enormous oil and gas prices in the late 1970s and early 1980s many governments were forced to consider alternative technologies. This resulted in rapid development of photovoltaic programmes. The public expenditures were allocated to different components of the R&D chain: basic research, applied research, experimental (technology) development, and demonstration. Today we can encounter photovoltaic in a wide variety of applications for commercial, industrial and scientific purposes.

(2) Despite of the scientific character of the PV-technology solar cells have existed on the market for the last 40 years. However, it was not until the late 1980s before PV penetrated the market. From that time on, laboratory and commercial PV technology development has shown steady progress. There is a variety of PV technologies. Most of them try to achieve low cost or high efficiency, or a combination of the two. New technologies are at various stages of development. However, commercial PV modules have existed on the market for a long time and this allows the construction of econometric model which analysis the development pattern of this science-driven technology.

(3) Environmental and economic aspects of PV market: From an environmental point of view, the use of solar energy as a replacement for fossil fuel generated

electricity has a number of environmental benefits. Solar energy is clean, silent, and freely available. Although the Energy Pay Back Time (EPBT)[1] and the CO_2 emissions for present-day systems are still relatively high, the EPBT is lower than their expected lifetime, ranging from 4 to 9 years. It is important, however, that manufacturers claim to be able to optimise PV module energy requirements, making possible a future decrease in the EPBT for grid-connected PV systems to around 2 years. However, photovoltaic is now a proven technology which is inherently safe as opposed to some dangerous electricity generating technologies.

Photovoltaic industry has experienced a strong growth over the last 20 years. According the Photovoltaic Energy Barometer 2006[2] of the European Photovoltaic Industry Association (EPIA), this growth could be even greater under advantageous conditions. Demand for photovoltaic products is growing, but the temporary lack of silicon prevents the sector from growing as quickly as in the previous years. The German PV market dominates the European market now. The Photon International magazine announced 687 MWp[3] installed in 2004. PV systems with nearly 950 MWp were installed in 2005. Germany's overwhelming success has inspired other countries to set up conditions to develop their own solar sectors. Spain installed 20.2 MWp last year, followed by 6.4 MWp in France, 5 MWp in Italy, 2.5 MWp in the UK and 2.3 MWp in Austria (see Photovoltaic Energy Barometer 2006)

To analyze the market development of solar cells the following variables were selected: patents (notation: patents), scientific publications (notation: publ), public subsidies (notation: subs), compensation according to the Electricity Feed Act (StrEG) and the Renewable Energy Sources Act (EEG) (notation: compens), the price development of crude oil (variable: fueloil), and installed peak solar power capacity (MWp) (variable: sunenergy). It is only a very restrictive selection of indicators which reflect the development of the market and measure important exogenous factors. Therefore, the length of the time series poses several problems. It can also be expected that the future PV market development will be faced with another problems. For example the shortage of silicon that is used in semiconductors and photovoltaic cells offers a problem for the booming PV industry. But it is also possible to test the impact of other factors.

A short description of the model variables[4] is given below.

The number of scientific publications is commonly used as an indicator to quantify the relevant scientific activities. In order to collect data for the publication statistics for the PV market the online version of the Science Citation Index (SCI, host STN) was chosen. Thereby, the following keyword search strategy: (solar cell or solar cells or photovoltaic#) was used. Before 1991 searching for keywords was only possible for titles, after 1991 the search was extended to the Basic Index. From 1974 to 2004 23.390 scientific articles in the technology field 'solar cells' were identified. The curve of these scientific activities has a double peak structure. The first peak was year 1984; after year 1992 the number of scientific articles increased rapidly. The second extremum occured in 2004. Nonetheless, scientific activities in the PV field continued to rise.

Patents are frequently used as innovation indicators as patent records are publicly available and easily accessible. Moreover, patent data are classified by technical fields, and patent time series allow for the convenient study of historical trends. There are a lot of free and commercially available patent databases which are potentially helpful for the research. The decision to work with the World Patent Index (WPI) was guided by two factors:

- WPI provides the bibliographic details for patent records from 42 patent-issuing authorities including the applications from European Patent Office (EPO) and the Patent Cooperation Treaty (PCT) applications.
- Secondly, WPI allows search of the relevant patent records by using key-words.

Due to foundation of the EPO in the year 1978 there are two ways in which an applicant can file patent applications in Europe. The one possibility is to register an invention directly at the national office, such as the DPMA. As an alternative, the applicant may file an international application at the EPO in which he can designate different european countries in which patent protection is desired. Each option has its advantages. The best solution depend on invention and market where company operates in.

In order to create long time series for patent activities in photovoltaic patent applications at the DPMA and the EPO have to be considered. The patent sample includes documents which were researched with the following retrieval strategy:

1. Patent records with the IPC = H01L 031/04 or IPC= H01L 31/06 in the main group or subclasses.
2. Patent records with the IPC = H01L 31 and the keyword solar+[5] in the title.
3. Union of the sets 1, 2.

4. From 1970 to 1990 the patent applications at the DPMA and from 1990 to 2001 the patent applications at the EPO were considered. The absolute levels from both time intervals were matched in 1990.

There are 2.874 retrieved documents from 1970 to 2001. The graph of patent activities referring to the technology field 'solar cells' clearly qualifies as a 'double-boom' cycle. The first maximum (95 documents) was reached in 1982, then a decrease of patent activities is apparent. The second peak (271 documents) occurred 17 years later, in 1999.

In general, there is an equilibrium between scientific and patent activities. It is interesting to see, that scientific activities have a lag in development in comparison withtechnological activities. In this particular case the PV Market is similar to empirical investigations for laser market. Further analysis of interaction between scientific community and industrial R&D is worthwhile.

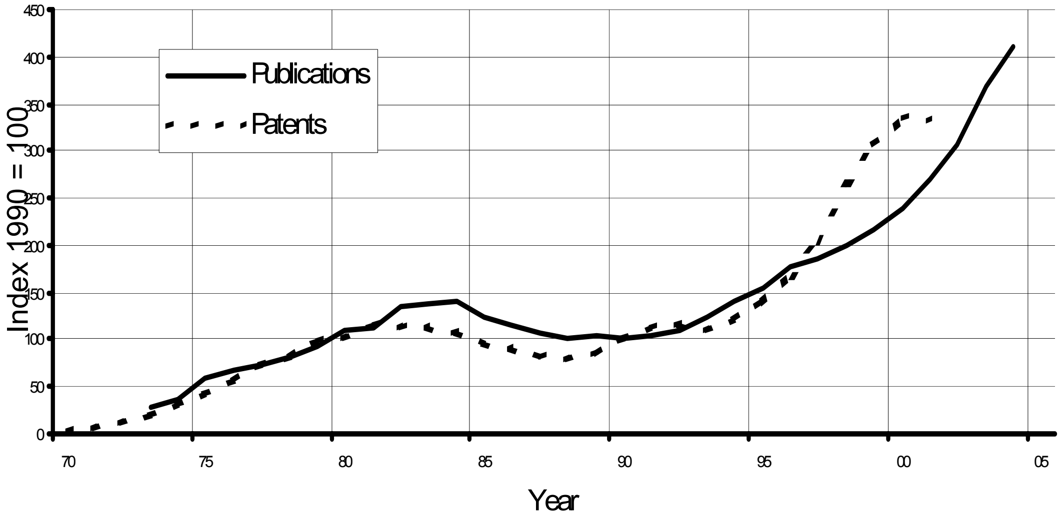


Figure 3-1: Long-term development of patent applications and scientific articles for solar cells since 1970.

Source: WPI and SCI.

Subsidies given by the government are very important for the PV market. A time series of public subsidies is the third relevant variable in the econometric model. According to the Public Promotion Catalogue[6] of the Federal Ministry of Education and Research nearly 850 million EUR were spent by the government from 1975 to 2006 for photovoltaic promotion. About 60% of all public expenditure for photovoltaic energy was spent in the years between the 1987 and 1997. Since year 1993 subsidies are stagnant at the constant value (Figure 3-2).

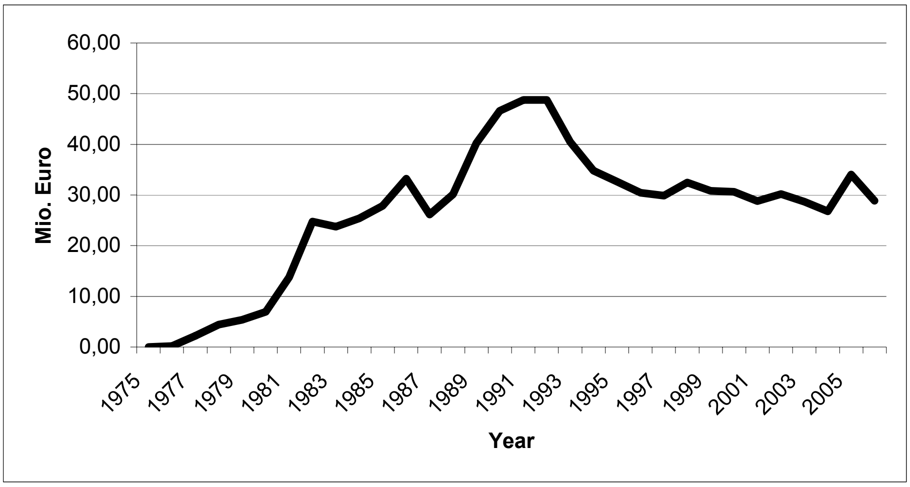


Figure 3-2: Photovoltaic subsidies given by the German government from 1975 to 2006.

Source: FöKat

There are different programmes that support the PV industry in Germany. For example there was the 100.000 Roofs Programme, which aimed to install 300 MW of solar cells by the end of 2003. A total of 350 MWp PV capacities were installed on more than 60,000 roofs under the programme. The empirical data of this programme is going to be included in the model as dummy variable.

Replacing the Electricity Feed Act, the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz; EEG) regulates the prioritisation of grid-supplied electricity from renewable sources. These two of Germany's principal renewable energy support instruments are also going to be treated in the model. (Figure 3-3).

The price of crude oil has a wide influence on the development of the PV market. Especially the first oil crisis in 1973 and the second oil crisis in 1979 revealed the fragility of energy supply systems of industrialized countries. (Figure 3-4).

Installed capacities of photovoltaic system are the last indicator in the model. Unfortunately, there are a lot of contradictory statements in empirical data for this indicator. According to AGEE-Stat[7] (statistics organisation of the Ministry of the Environment) the German Photovoltaic Market reached 600 MWp installed solar power in 2005, bringing the cumulated total of installed German capacity to 1 508 MWp. Germany now represents 85.8% of the total capacity installed in the European Union. (EurObserv'ER 2006, p.13). Based on data collection of Photon[8] (the Solar Electricity Magazine), in 2005 there was 857,78 MWp of new solar capacity installed which corresponds with total cumulated solar power of 1694,22 MWp. Photon's statistics are grounded on information from grid operators and energy supply companies which are committed to purchase the electricity generated from renewable energies. The problem is that this data are collected only for the short period from 2000 to 2005. For this reason statistics from AGEE-Stat are used.

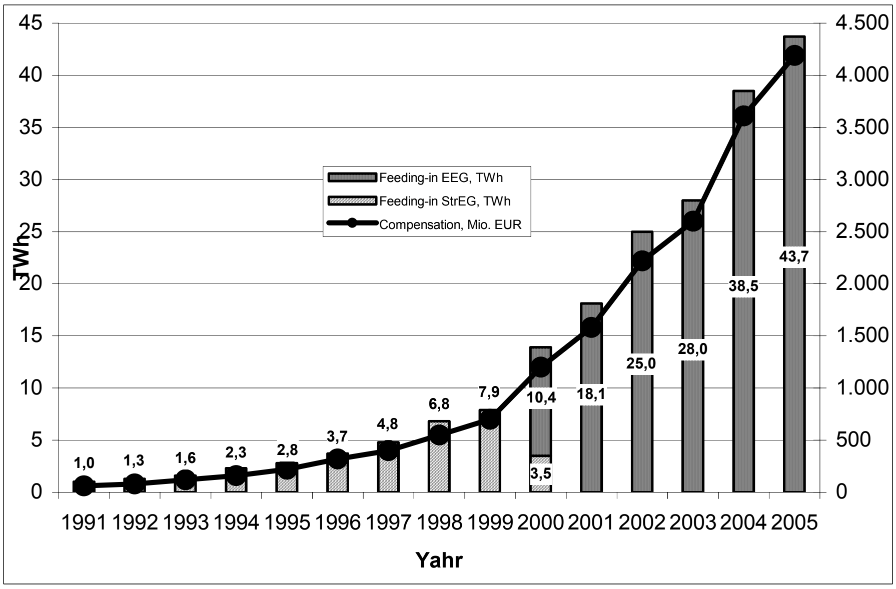


Figure 3-3: Feeding-in and Compensation according to the Renewable Energy Sources Act (StrEG) and the Electricity Feed Act (EEG)

Source: BMU (2006), p. 23.

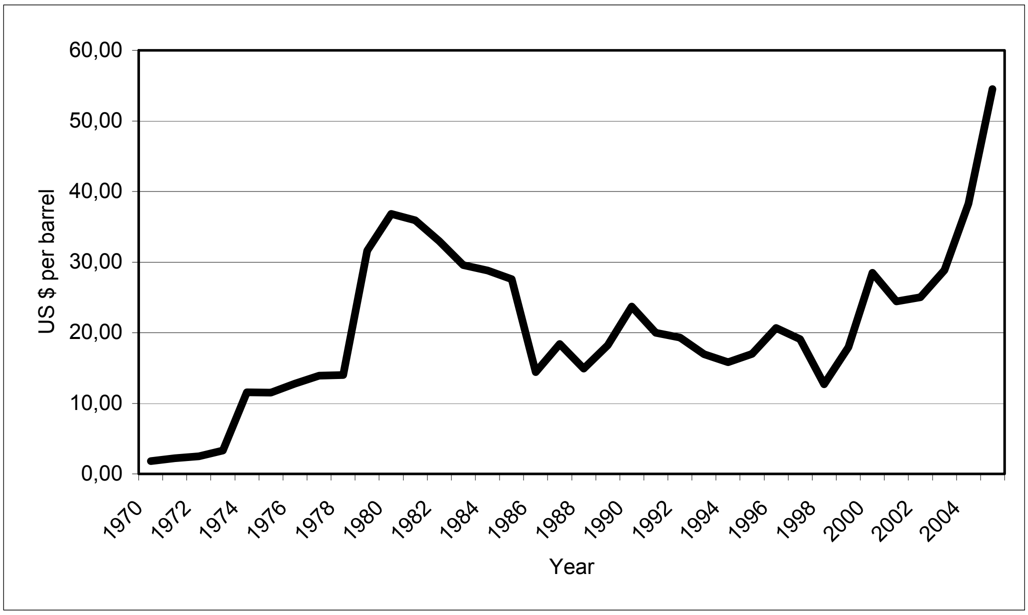


Figure 3-4: Crude Oil Prices 1970 – 2005.

Source: BP Statistical Review of World Energy.

4. The Model

Every analysis of an economical system is based on some underlying logical structure (known as model) that describes the behaviour of agents in the system and is the basic framework of analysis. This model is set up in the form of equations, which describe the behaviour of economic and related variables[9]. The economic agents try to reach their aims with given factor endowment. The required decisions are based on individual or collective need and run through complex evolutionary selection mechanism, which is not observable in total. The representation of the PV market processes in this study is given by selected variables which will be compiled as time series in equal intervals and in a common measurement system of market formation. Yet time series data only give us a very crude numerical picture of the complex econometric decision making on various levels. In addition there may be data problems from measurement and compilation errors.

A short description of main steps in modelling is given here: The construction of the model starts with an univariate data analysis. Here the properties of single variables, like trend and order of integration are checked. All time series seem to be non-stationary[10] and follow non-linear trend. A common assumption in many time series techniques is that the data are stationary. Standard techniques are often invalid where data are non-stationary. The knowledge about non-stationarity of the time series helps to identify some features of the underlying data-generating process. In the next step the causal relationships between variables are tested by Granger Causality Test. The results of Granger Causality Test help to identify bidirectional causal relationships between the variables. Estimates of cointegrating relations are obtained using Johansen's multivariate procedure. Statisticaly significant cointegration vectors will be included in the estimation of the error correction model (ECM). ECM’s are widely used in econometrics studies due the following advantages: Firstly, the ECM allows to analyse both short term and long run effects of explanatory time series variables. Second, the estimated equation includes only stationary variables: cointegrating relationship between the level variables (long run) and the short run relationship between the first differences of the variables. Hence there is no problem with spurious correlation. The ECM is the final result of this empirical study. An interpretation of achieved empirical results concludes the model construction.

4.1 Unit Root Tests

There are different ways of testing the stationarity of time series. The most popular test in literature is the augmented Dickey-Fuller (ADF) test. The ADF-Test is also used in this approach. The starting point of the ADF-test is the ordinary least squares (OLS) estimation of regression model:

$$(1)\,\Delta y_t = (u-1)y_{t-1} + \sum_{j=1}^{p} \alpha_j \Delta y_{t-j} + \varepsilon_t \ ,$$

where Δ is the first difference operator, ε_t~i.i.d.(0, σ^2) are the error terms, p is the autoregressive lag length large enough to eliminate possible serial correlation in ε_t, and u is the coefficient of interest. If u=1, then the data series contain a unit root implying non-stationarity, whereas if u<0, there is no unit root implying stationarity. In the ADF-Test, the null hypothesis of unit root, i.e. H_0: u=1 is tested against the alternative hypothesis of no unit root, i.e. H_1: u<0 using a t test[11]. Two major issues in performing ADF tests are the inclusion (or non-inclusion) of an intercept term, a trend term, or both, and a selection of a truncation lag. ADF test results are very responsive to the presence of intercept and trend terms, and to the number of lags which are included. In general, including too many deterministic regressors results in lost power, whereas not including enough of them increases the probability of not rejecting the unit-root null[12].

Table 1 presents the ADF-test results for the levels and first differences of the variables. The results of the ADF test show that time series are not stationary in levels. After observing the first difference of the variables the null hypothesis can be rejected with a significance level of 5%. This means that all variables are integrated of order one, I(1), in level forms. Since the variables are considered to be I(1), cointegration analysis, using an error correction model (ECM), is appropriate to equilibrium model.

Variable	Level	First difference
log_patents	-3.296699	-3.253264*
log_publ	-3.201560	-3.96844*
log_compens	-2.592318	-4.642917*
log_subs	-2.670163	-6.767453*
log_sunenergy	-2.973974	-6.632623*
log_fueloil	-3.286873	-5.110945*

Notes: Significance level of 5% level is indicated with *. A time trend was not included in the first differences of the variables.

Table 4-1: ADF Tests for unit roots: levels and first differences of variables.

4.2 The Granger Test for Causality

The next step in model construction is the identification of bidirectional causality relationships between the variables using the Granger Test for Causality. The idea of this test is quite straightforward. The test states that x_t is Granger causal for y_t if the past values of x_t help predict future values of y_t. It should be noted that Granger causality is not causality in the more common sense of the term. It is often in the economy that the variables of the models react to some unmodeled factor (for example the oil crisis) and if the response of x_t and y_t is staggered in time Granger causality can be observed though the real causality is different. Regrettably, it is not possible to solve this problem. Granger causality measures whether one thing happens before another thing does and helps predict it - and nothing else. But it can be accepted that it partly catches some real causality in the process (see Sørensen (2005)).

Granger causality can be described by the following model:

$$y_t = \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{j=1}^{q} \beta_j x_{t-j} + u_t$$

where u_t is white noise, p is the order of the lag for y, and q is the order of the lag for x. The null hypothesis that x_t does not Granger-cause y_t is that $\beta_j = 0$ for $j=1,2,...,q$. The test statistic is the standard Wald F statistic. If the F statistic is significant (p-value < 0.05) then the null hypothesis is rejected and the alternative hypothesis is accepted. The Granger causality test is carried out for all possible pairs of the time series. In order to test whether the linkage between the variables is stable or not, different lag length was selected. As a result of the Granger Causality Test the following hypotheses were tested:

Hypothesis 1: The scientific publication Granger-causes the patent applications and visa versa.

Only a few decades ago it was a fact that patents were a matter of industrial firms and private inventors. However, academic researchers preferred to publish their achievements in scientific papers. Today, there is not any traditional boundary between the industrial and academic research. On the one hand it becomes apparent that there is a clear trend toward commercialisation of academic science, on the other hand the industrial research is increasingly dependent on new acquisitions of the science[13]. In either case these considerations hold for the science-driven markets in general, and also for the PV market. Therefore it can be accepted that there is a strong causal relationship between the patent applications and scientific publications.

Hypothesis 2: Compensation from the Electricity Feed Act and the Renewable Energy Sources Act is Granger-causes the installed solar power.

Replacing the Electricity Feed Act (Stromeinspeisungsgesetz; StrEG), and the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz; EEG) regulates the prioritisation of grid-supplied electricity from renewable source[14]. Compensation according to the StrEG, and later the EEG, has to be paid for electricity generated from different kind of renewable energy and not only from solar radiation energy. But according to the EEG the amounts for solar generated electricity are the highest in comparison to other renewable energy sources. Because of this, the EEG has a crucial role in the development of the PV market in Germany.

Hypothesis 3: The subsidies of the government are Granger-cause the patent applications.

R&D expenditures for PV may be used as a yardstick for a willingness to establish a market for PV. Under the terms of the priority that Germany gives to R&D related to PV it has in third position after the USA and Japan. Funding of R&D projects by the German government supports improvements of PV technologies. These improvements can be measured by the number of patent applications.

Hypothesis 4: There is a link between installed solar power and patent applications / scientific publications.

Sold and installed solar plants connote the refinancing of the investment costs for PV industry and progress of PV technologies. This development is reflected in increase of patents and publications.

Table 4-2 reports the Granger causality test results. All hypothesis could be confirmed at a significance level of $p<0.05$. Results show a strong evidence for bidirectional causality between the patent applications and the science publications, and installed solar power and compensation from the StrEG and the EEG. For first pair of variables the existence of a long run-equilibrium relationship was investigated using Johansen cointegration methodology. Since the variables have similar development, two kinds of cointegration relationships were tested including trend (linear and nonlinear). The last pair of causality seems to be obviously because the EEG provides compensation for solar power fed into the grid and in Europe photovoltaic is primerly used with grid-connected systems. For this reason this relationship is not considered in this study.

Pairs of time series	Lag's number				
	2	3	4	5	6
fueloil compens	←	-	-		
patents compens	→	-			

publ compens	←	-	←		
sunenergy compens	←→	←→	-		
subsid fueloil	→	→	→	-	-
publ patents	←	←→	←	←→	←→
subsid patents	-	→	→	→	→
sunenergy patents	→	→	→	-	←→
subsid publ	-	←	←	←	-
sunenergy publ	→	←→	-	-	→
sunenergy subsid	-	-	-	-	←

Table 4-2: Results of Granger-Causality Tests.

4.2 Cointegration Analysis

The Johansen approach (Johansen (1995)) for testing the existence of cointegrating relationships has become standard in the econometric literature because its advantages. An important aspect of the Johansen approach is that it allows us to test for various restrictions on the cointegrating vectors. We can also test the impact of exogenous shocks. The Johansen approach can be applied to the models with several endogenous variables. The appropriate estimation procedure contains three steps:

1. Determining the number of cointegrating vectors (cointegration rank).

   Two tests are used to determine the number of cointegrating vectors: the trace test[15] and the maximum eigenvalue test[16]. Both tests are carried out sequentially. The trace test has a null hypothesis of r cointegrating vectors against the alternative that the cointegration rank is equal to r+1. According to the trace test, the null hypothesis of no cointegrating vectors is rejected (p=0.0124) and the null hypothesis that there is no less than 1 cointegrating vector is accepted (p=0.3172). The maximum eigenvalue test provides an alternative check for the number of cointegrated variables and achieves the same result. The null hypothesis of 0 cointegrating vectors is rejected (p=0.01106) and the null hypothesis that there is at the most one cointegrating vectors is accepted (p=0.3172) (see Table 4-3). Therefore, there is a long term equilibrium relationship between patents and publications.

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None*	0.493404	19.36152	15.49471	0.0124
At most 1	0.036373	1.000383	3.851466	0.3172

Table 4-3: Johansen's Cointegration Test Results: unrestricted cointegration rank test (Trace)

2. The estimation of cointegrating vectors.

Since the variables have similar developing, two kinds of cointegration relationships including trend linear and nonlinear are tested. As a result of the causality test some different factors can be identified which have an influence on the relationship between publications and patents. These factors are included in the model as exogenous variables. The purchase of following exogenous variables is evaluated: log_compens, log_subsid, and log_sun_energy. Dummy variable 100000_roof was also included to represent the implementation of the 100.000 roof program. Because the time series have a short length, all exogenous variables were not included at once, i.e. the impact of every factor is tested one by one. The best results is achieved with compensation from the StrEG and the EEG as exogenous variable and with non linear trend. The analysis provides a significant adjustment coefficient of 0.522 (s.e. 0.07621), indicating that 52 per cent of disequilibrium in publications is eliminated every year and the disequilibrium is corrected quite fast. (Table 4-4).

1 Cointegration Equation:		Log likelihood 36.42467
Normalized cointegration coefficients (standard error in parentheses)		
log_patents	log_pub	
1.000000	3.353231 (0.43059)	
Adjustment coefficient (standard error in parentheses)		
d(log_patents)	-0.029768 (0.14172)	
d(log_publ)	-0.522288 (0.07621)	

Table 4-4: Cointegration Equation

3. In the next stage of the model building an error correction model (ECM) is estimated.

According to the Granger representation theorem, two or more integrated time series that are cointegrated have an error correction representation. If there is an error correction representation for two or more time series, then these variables are cointegrated. This means that for any set of I(1) variables error correction and cointegration are two equivalent concepts. The idea of ECM is based on the behavioural assumption that there is one equilibrium relationship between two or more time series which causes both short- and long-run dynamics. In this study there is a bivariate ECM:

$$(2)\ \Delta y_t = \alpha_0 + \alpha_1 (y_{t-1} - \beta_1 x_{t-1}) + \alpha_3 \Delta x_t + \alpha_4 z_t + \varepsilon_t$$

The current changes in *y* are the function of current changes in *x* and the gap of two time series from their equilibrium in the previous time period. Specifically, α_3 captures any immediate effect that *x* has on *y*. Therefore, this term of the equation describes the short dynamics of the relationship between *x* and *y*. The coefficient, β_1, reflects the equilibrium effect of *x* on *y* and is estimated in the cointegration vector. The absolute value of the coefficient α_1 can be interpreted as the speed of adjustment parameter. The coefficient α_4 displays the impact of exogenous variables.

The interpretation of the coefficients will be demonstrated with a simple example. Let's assume we regress the first difference of publication numbers on one lag of publication numbers, one lag of patent applications, one lag of the first difference of patent applications and the impact of exogenous factor for example effect of the EEG. The estimated coefficients are $\alpha_1 = -0.52$, $\beta_1 = 3.35$, $\alpha_3 = 0.64$.

If the number of patent applications increases by 3%, the number of scientific publications will increase by 1.92% immediately (3*0.64, the coefficient α_3). The ECM reveals an equilibrium relationship between patent applications and publications, i.e. the changes in patents applications disturb the equilibrium, causing the number of scientific papers to be too low. Consequently, the number of publications will increase by roughly 10% (3*3.35, the coefficient β_1), but this will not happen at once. This return back to the equilibrium extends over several years. The speed of adjustment is determinated by the coefficient α_1, i.e. 52% of the derivation from equilibrium is eliminated during the next time period. It means that the number of scientific papers rises 5.2% one year later, 2.7% two years later and 1.4% three years later and so on, until the number of scientific publications has increased 10% in total. And this will happen in about four years. In this way patent activity has two effects on scientific activities: one that occurs immediately, and another that is dispersed across future time periods.

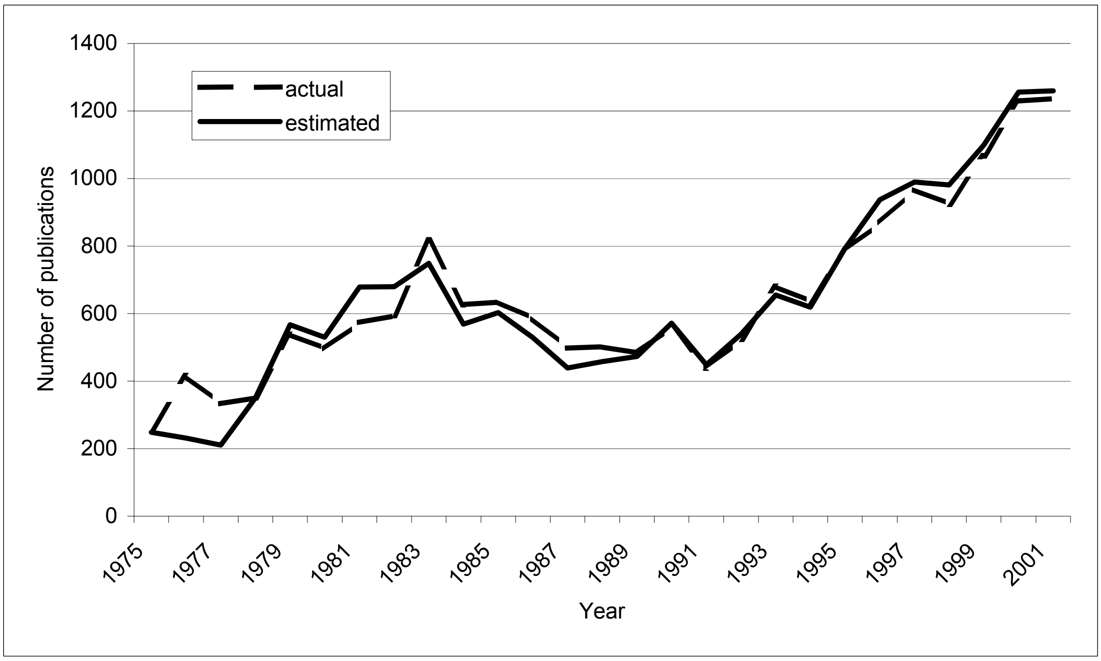


Figure 4-1: Publications statistics for the PV market 1975 until 2001. Real data (SCI) and model results.

According to the basic hypothesis that there are two different phases in development of science-driven market with different sets of determinants. The ANOVA F-statistic (21.4666) suggests significant difference (p-value < 1%) in means for two time periods: from 1973 to 1990 and from 1991 to 2001. Correspondingly, the time between 1973 until 2001 is splitted up in two time periods: 1973 until 1990 and 1991 until 2001. (Figure 4-1)

The estimated results for publication statistics are illustrated in. Table 4-5 and Table 4-6 show the results of Error Correction estimates for the time period between 1973-1990, and 1991-2001 respectively. The fit of the model was improved in due consideration to exogenous variables. Different exogenous variables were included in the account. The best results were achieved including the impact of the fuel oil prices for the first time period and including the impact of the StrEG and the EEG for the second time period. The models were compared using adjusted R^2 and "information criteria" such as the Akaike Information Criterion (AIC) and Schwartz Criterion. If scientific publications are taken as dependant variables then the fit of the model improves. Basically, all coefficients are significant. The comparison of the ECM's for two time periods follows below.

Cointegration Equation:	CointEq 1	
log_patents (1)	1.000000	
log_publ(-1)	10.06718 (1.05040) [9.58411]	
C	-66.26657	
Error Correction :	d(log_patents)	d(log_publ)
CointEq1	-0.041104 (0.01291) [-3.18309]	-0.124823 (0.01784) [-6.99729]
d(log_patents(-1))	-0.174286 (0.27419) [-0.63564]	-1.264204 (0.37877) [-3.33763]
d(log_publ(-1))	0.195682 (0.10016) [1.95368]	0.129222 (0.13836) [0.93393]
C	-0.331441 (0.25380) [-1.30593]	-1.840807 (0.35060) [-5.25043]
log_fuelog_oil	0.241306 (0.15616) [1.54525]	1.205227 (0.21572) [5.58694]
R-squared	0.818192	0.858479
Adj. R-squared	0.752079	0.807016
F-statistic	12.37581	16.68170
Log likelihood	22.77421	17.60440

Table 4-5: Vector Error Correction Estimates for the period 1973-1990. (Standard errors in () & t-statistics in [ ])

Cointegration Equation:	CointEq 1	
log_patents (1)	1.000000	
log_publ(-1)	3.353231	
	(0.43059)	
	[7.78744]	
C	-27.31604	
Error Correction :	d(log_patents)	d(log_publ)
CointEq1	-0.029768	-0.522288
	(0.14172)	(0.07621)
	[-0.21005]	[-6.85293]
d(log_patents(-1))	0.821573	6.642510
	(0.52916)	(0.28458)
	[1.55260]	[2.257775]
d(log_publ(-1))	0.272983	0.253222
	(0.33226)	(0.17869)
	[0.82161]	[1.41713]
C	0.015894	0.817880
	(0.17275)	(0.09290)
	[0.09201]	[8.80370]
log_compens	0.028834	0.708735
	(0.18139)	(0.09755)
	[0.15897]	[7.26542]
R-squared	0.395023	0.926195
Adj. R-squared	-0.0088295	0.876992
F-statistic	0.979433	18.82386
Log likelihood	13.48513	20.308816

Table 4-6: Vector Error Correction Estimates. (Standard errors in () & t-statistics in [ ])

The estimated coefficients are α_3 = -1.26 and 0.64, β_1 = 10.067 and 3.35 and α_1 = -0.12 and - 0.52, respectively. It is remarkable that the sign of coefficient α_3 is not the same for both time periods. It can be interpreted as follow: although the coefficient β_1 shows the statistical significance of the equilibrium effect between patents and publications during both intervals, the short-term fluctuations of patents and publications can have different trends in the first and in the second interval.

For example the decrease of the number of patents can be used as evidence for rising technical problems in the first phase and it can be taken as a challenge for science. Consequently, the number of publications increases. But in the second phase the main problems seem to be solved, and a decrease of the number of patents can be taken as a temporary lack of interest implicating a decrease in publication statistics.

The speed of adjustment is the time it takes to reach a new equilibrium after an initial shock is determined by the coefficient α_1. The data indicate magnitudes varies across years, from very low speed of adjustment in 1973-1990 (-0.12), or 12% of the derivation from equilibrium is eliminated in the next time period to relatively fast adjustment in 1991-2001 (–0.52) or 52%. Adjustment to equilibrium takes only about four year.

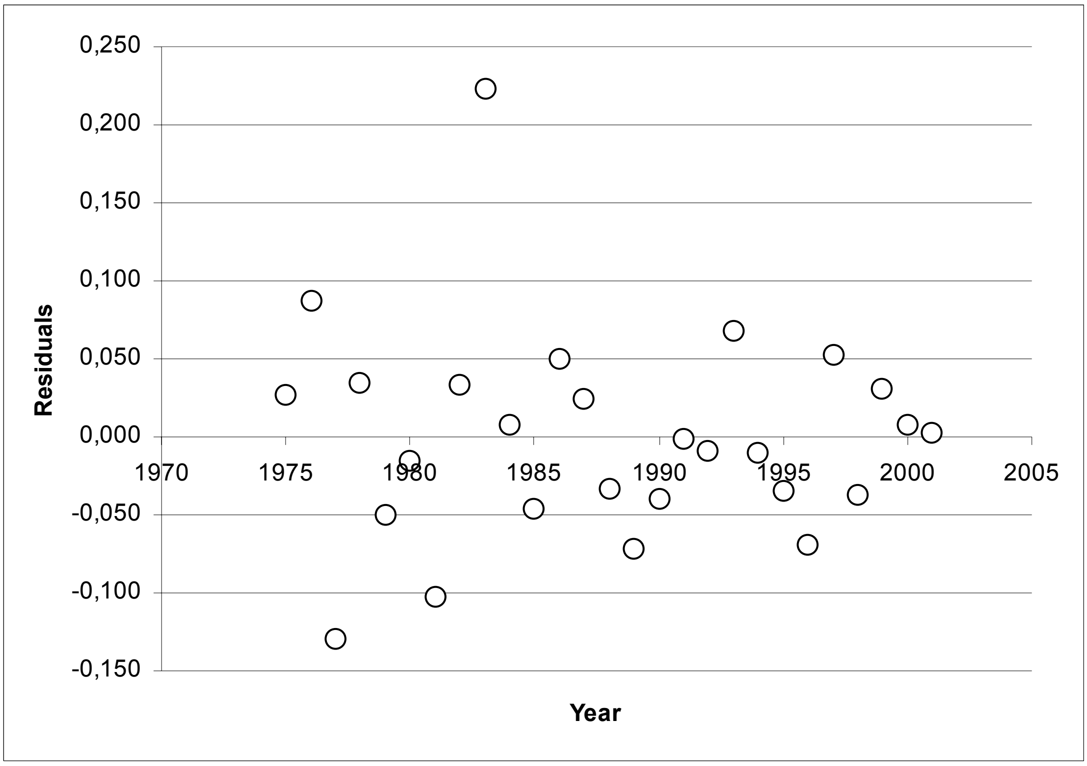
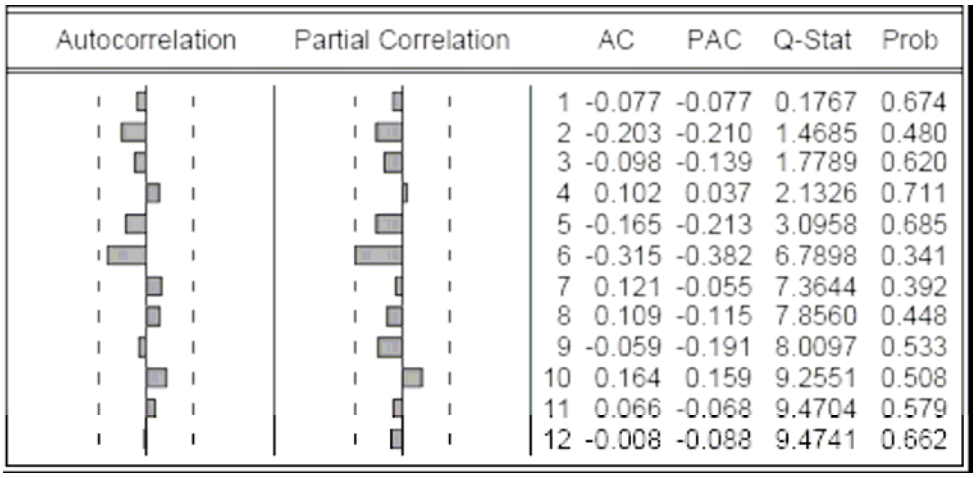


Figure 4-2: Residual plot for EC model.

Using different goodness of fit tests the validity of the model was checked. The adjusted R-squared statistic is 0.807 and 0.877 respectively, which is relatively good explanatory power. The F-test for the significance of the goodness of fit is 16.68 and 18.82, respectively. The critical values are 5.67 and 15.98 respectively. As F-test statistics are greater, the goodness of fit of regression is significant for both time periods.

In order to have a first impression for identifying the presence of autocorrelation in the residuals the residual plot (Figure 4-2) is considered. Although there are no obvious systematic patterns of any type in this plot, application of formal tests for autocorrelations is necessary. Figure 4-3 displays the autocorrelation and partial autocorrelation functions up to the 12 order of lags. The dotted lines are the approximate two standard error bounds. The autocorrelation and the partial correlation are within these bounds; therefore these statistics are not significantly different from zero at the 5% significance level. The last two columns reported in the correlogram are the Ljung-Box Q-statistics and their p-values. The high p-values indicate also the absence of autocorrelation in the residuals. The same conclusion provides the Durbin Watson (DW) statistic=2.147, well above the upper bound for this test when k=4 and n=27. The null hypothesis of no autocorrelation cannot be rejected.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.077	-0.077	0.1767	0.674
		2	-0.203	-0.210	1.4685	0.480
		3	-0.098	-0.139	1.7789	0.620
		4	0.102	0.037	2.1326	0.711
		5	-0.165	-0.213	3.0958	0.685
		6	-0.315	-0.382	6.7898	0.341
		7	0.121	-0.055	7.3644	0.392
		8	0.109	-0.115	7.8560	0.448
		9	-0.059	-0.191	8.0097	0.533
		10	0.164	0.159	9.2551	0.508
		11	0.066	-0.068	9.4704	0.579
		12	-0.008	-0.088	9.4741	0.662

Figure 4-3: Correlogram of Residuals for the ECM.

Finally, using White Heteroscedasticity Test the null hypothesis that there is no heteroscedasticity cannot be rejected, since the p-value of the F-statistic is quite high (0.7272 resp. 0.3578). Summarizing, the diagnostic tests support the validity of the estimated model.

5. Conclusions

The subject of this paper is an empirical analysis and dynamic mathematical modelling of innovation processes in science-driven markets. Numerous empirical studies provide evidence that science-driven markets underlie different development patterns then consumer markets, in which the science base of the underlying technological development is rather unimportant. The purpose of this work is the construction of an econometric model which has the power to explain the nonlinear dynamics of science-based innovation processes using a few relevant variables. The model is tested and validated with empirical data in terms of regression and time series analyses.

In the first step and for a better understanding of the relevant influence factors, the evolution of selected technologies is discussed and supported with quantitative data (innovation indicators). The envisioned examples include photovoltaic market. It is a relatively new market with a strong dependence on science and, so far, on an intensive amount of public subsidies for research and development (R&D). Other examples are lasers, polyimides and polyamides, surface technologies, and the like.

In the second step, a stylised model of the formation of science-driven markets is presented. In so doing, the main hypothesis is constructed, namely: in the development of science-based markets two quite different development phases can be observed due to basically different sets of determinants ("double-boom hypothesis"). This corresponds to the mathematical modelling of more than one steady state in the overall development of a new innovative market rather than the usual diffusion modelling ("S-type curves").

The third step consists of model building based on the previously described careful empirical analyses. First, a univariate examination of statistical properties of the selected time series is done. The next step of model construction is the identification of bidirectional causality relationships between the variables using the Granger Test for Causality. Based on these findings, the cointegration vectors are estimated. According to "double-boom hypothesis" the whole data set is splitted into two time periods: from 1973 to 1990 and from 1991 to 2001. For both time intervals the existence of a long-run equilibrium between publications and patents is verified. Although the speed of adjustment to the equilibrium for both time intervals varies strongly, from relatively slow speed of adjustment of -0.12 (≙-12%) in first time period to very fast speed of adjustment of -0.52 (≙-52%) in second time interval. Using an error correction model the impact of different exogenous factor is tested. For the first phase of the PV market development the fuel oil prices play an important part. The influence of the StrEG and the EEG is important in the second phase of market formation.

The current condition in the research of science-driven markets provides a lot of studies on either the science push or the demand pull side. Most of these papers are of qualitative nature. We do not know of major work trying to reconcile both views into a formal mathematical model. This is the challenge of the proposed work: to come up with first solutions to this problem.

6. Notes:

1. The EPBT by EPBT = E_{input}/E_{saved}, where E_{input} is the energy input during the module life cycle (which includes the energy requirement for manufacturing, installation, energy use during operation, and energy needed for decommissioning) and E_{saved} the annual energy savings due to electricity generated by the PV module.

2. http://www.epia.org/03DataFigures/barometer/Barometer_2006_full_version.pdf

3. MWp = Megawatts peak installed (electrical power unit).

4 Before calculation all variables are preliminary log-transformed to achieved a more homogenous variance.

5 + = open truncation

6 FöKat (Funding catalogue of the Federal Ministry for Education and Research): Hhttp://oas2.ip.kp.dlr.de/foekat/foekat/foekatH.

7 AGEE-Stat uses data from the Energy Accounting Association (AGEB); Baden-Württemberg Centre for Solar Energy and Hydrogen Research (ZSW); Federal Statistical Office, Leipzig Institute for Energy Systems and the Environment (IE); Federal Solar Industry Association (BSi); Electricity Industry Association (VdEW); Association of German Network Operators (VdN).

8 www.photon.de/download

9 Ramanathan (2002): p.4.

10 The stationary time series have the property that the mean, variance and autocorrelation structure do not change over time.

11 Note that under the null hypothesis this t statistic is not asymptotically normally distributed, and therefore special critical values are required. Actually, critical values depend on the regression specification and on the sample size. Dickey and Fuller (1979), among others, provide tables with appropriate critical values for some cases.

12 A complete description of unit root tests is beyond the scope of this article. For a more detailed explanation, see Enders (1995), chapter 4.

13 These close relationships between academia and industrial research have many positive aspects, but at the same time there are some doubts about consequences of these changes. The quality of fundamental research can suffer from this trend as research substance might become increasingly applied and field of research without marketing orientation could be disregarded. (see Czarnitzki et al. 2007).

14 http://www.bmu.de/files/pdfs/allgemein/application/pdf/res-act.pdf

15 The name comes from the fact that the test statistic involved is the trace (= the sum of the diago-nal elements) of a diagonal matrix of generalized eigenvalues.

16 The name comes from the fact that the test statistic involved is a maximum generalized eigenvalue.

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The market value of patents and R&D: Evidence from European firms

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31 August 2007

Abstract

This paper provides novel empirical evidence on the private value of patents and R&D in European firms during the period 1991-2004. We explore the relationship between firm's stock market value, patents, and 'quality'-weighted patents issued by the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO). We find that Tobin's q is positively and significantly associated with R&D and patent stocks, but that only those patents taken out in both patent offices or at the USPTO alone seem to be valued. Either forward citations or a composite quality indicator based on forward citations, family size and the number of technical fields covered by the patent are modestly informative for value.

Software patents account for a rising share of total patents in the USPTO and EPO. Moreover, some scholars of innovation and intellectual property rights argue that software and business methods patents on average are of poor quality and that these patents are applied for merely to build portfolios rather than for protection of real inventions. We found that such patents are considerably more valuable than ordinary patents, especially if they are taken out in the U.S. However their quality indicators are no more valuable than those of other patents, suggesting that their primary purpose may be to increase the size of the patent portfolio.

JEL classification: D24, O31, O34, L86

Keywords: market valuation, intangible assets, patents, software

Acknowledgements: We thank Rishab Ghosh and the participants in the EC DG IT study on "The effects of allowing patents claims for computer-implemented inventions" for discussing with us several issues concerning patents and IPR. Moreover, we would like to thank Armando Benincasa from Bureau Van Dijk, Elvio Ciccardini, and Gianluca Tarasconi from CESPRI - Bocconi University for their valuable assistance in data collection and Matteo Magnani from Bologna University for his contribution to matching the names of firms in Amadeus and PATSTAT datasets. Colin Webb has provided us with data on citations to EPO patents. We thank the seminar participants at CESPRI and NBER have also been helpful in producing the current revision.

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The market value of patents and R&D: Evidence from European firms

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June 2007

1. Introduction

Measuring the private returns to investment in innovation or knowledge assets is important both to firms and to economists who wish to assess and compare firm performance in this area. At the aggregate firm level, the primary methods for obtaining quantitative measures of these returns relate profits, revenue, or the market value of the firm to observable measures of innovation investment such as R&D or patents. This paper contributes to this literature by providing novel empirical evidence on the value of a number of different measures based on the patenting activities of European firms, both in Europe and in the United States.

In addition to the goal of measuring innovative assets in European firms, our investigation is motivated by an interest in several issues related directly to the patents themselves. First, we hope to gain a deeper understanding of the 'patent paradox', that is, the fact that the number of patent applications to the USPTO and the EPO continues to grow despite the weakness of patents as an instrument for protecting innovation, documented in various surveys of innovators in a number of different industries and countries (Levin et al 1987; Cohen, Nelson and Walsh, 2000; Arundel 2001, 2003). Previous studies have demonstrated that the distribution of patent technical and economic value is very skewed with only a few patents yielding a significant value to their owners (Harhoff *et al*. 1999). Some argue that the lower barriers to patenting are responsible for an increasing number of low quality patents, that is, patents that have with a low inventive step, overly broad claims, or that should not have been issued under existing legal frameworks. If so, it is desirable to explore whether this is reflected in indicators of individual patent value. In this paper we look at how a firm's stock of patents and different indicators of its 'quality' are priced by the financial markets. We use a number of indicators of technical and economic value: forward citations adjusted for citation truncation, technological scope, measured by the number of technological fields, and family size (the number of different patent systems in which protection for a single invention is sought).

Another motivation of this paper arises from the differences between the US and the European patent systems. Unlike the US system, the European system is very fragmented. Applicants to the EPO systems have to specify the EU countries where the inventions should be protected. If granted, the patent must be defended in national courts because there is at present no European-wide court dealing with patent litigation. The same patented invention then may therefore yield varying private values to its owner depending on the enforcement power offered by the national courts in which the invention is protected. Recently the European Commission (EC) has proposed a new treaty, the European Patent Litigation Agreement (EPLA) that would establish a new European Patent Court. It is unclear whether such a move would represent a significant step towards a "community-wide" patent. However, the proposal testifies to the great concern of the EC about the costs of patenting in Europe and the application of uniform standards in patent examination and enforcement.

In theory the absence of a centralized European patent system, which increases both the application and enforcement costs of EPO patents as compared with US patents, should discourage patent applications to the EPO. However, the EPO examination system appears to be more rigorous than the USPTO (see, for example, Quillen et al. 2002) and this should reduce the expected post-grant litigation costs, especially given the availability of the lower cost opposition system for challenges to newly-issued patents. On the other hand, until the year 2000, patent applications to the USPTO were not published until (and if) they were granted. New applicants then could not know whether their patents were infringing a pending patent. After the year 2000, the US system adopted a variation of the EPO system rule and patent applications are now published after 18 months unless the applicant has sworn not to file in any other jurisdiction. Other differences between the two patent systems pertain to citation of prior art and patentable subject matters. These differences may affect the economic value of patents in the two systems.

This paper looks carefully at the implications of these differences for the economic value of patents by comparing the market value of patents granted by the USPTO and by the EPO. Some European firms protect their inventions in both patent systems and some rely on only one patent system. The choice to protect in one or the other system or in both systems can result from at least two sources: patents on more valuable inventions may be taken out in more jurisdictions (Lanjouw et al. 1998) and firms may differ in their patenting strategies or exposure to international competition. Although we cannot distinguish these two hypotheses precisely in the absence of an appropriate instrument for the choice, we are able to determine whether patents from different jurisdictions yield significantly different consequences for the market value of the firm, or indeed whether measures based on the different patents from the two different systems have different predictive power.

In the last part of the paper, we focus on a specific technological field, software, so that we can distinguish the differences between the two systems from other factors specific to the patent system. Software is of particular interest because it is treated differently in the EPO and the USPTO. A few key decisions taken by the Courts of Appeals for the Federal Circuit (CAFC) in 1994-1995 led the USPTO to release new guidelines for software patentability in 1996 which allowed the patenting of any software embodied in physical media. In 1998 an important decision of the US Federal Circuit removed most of the exceptions to the patentability of software 'as such', i.e., independently of its links with a physical device. Not surprisingly, the number of software patents granted by the USPTO has increased dramatically during the 1990s.

The treatment of software in the EPO is different. According to the European Patent Convention (EPC) (Art 52) computer programs "as such" are excluded from the patentable subject-matter. The EPO recognizes the patentability of computer-implemented inventions (CII), that is "inventions whose implementation involves the use of a computer, computer network or other programmable apparatus, the invention having one or more features which are realized wholly or partly by means of a computer program" (EPO, 2005:3). A further test applied by the EPO relates to the subject matter of any CII, effectively excluding those related to business methods or otherwise "nontechnical" in nature. This distinction has proved difficult to make in practice, but it does lead to rejection of a number of patent applications whose equivalents are granted at the USPTO. The European Commission released a proposed Directive on the Patentability of CIIs in 2002 which effectively codified EPO practice in this area, but the Directive was rejected by the European Parliament in 2005 after considerable amendment of various kinds.

As a preliminary test of the consequences of the different legal treatment of software in the two patent systems we have analyzed EPO patents and found an increasing number of software-related patents during the 1990s.[2] This suggests that, despite the different legal environment, barriers to software patents have fallen somewhat in Europe as well. It is important to note, however, that the majority of software patents in the EPO are probably

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[2] For a detailed analysis of software-related patent applications and the search methodology used to identify this category of patents, see Thoma and Torrisi (2005)

‘software-related’ patents, that is patents granted to computer programs that are implemented in physical devices, rather than “pure” software patents.[3]

Our examination of the market value of patents draws on a body of studies which have addressed the issue of measuring the private returns or value of innovation investments using data on the firm’s valuation in public financial markets. Most of these studies use R&D expenditures and patent counts as measures of technological activity (e.g., Griliches 1981; Hall 1993). More sophisticated indicators of technological assets such as citation-weighted patents have also been experimented with in the literature to account for the great dispersion in the value distribution of patents (Hall, Jaffe, and Trajtenberg 2005). In the absence of more direct measures of the economic value of patents, these studies provide a useful methodological setting to explore the relationship between technological importance and the profitability of patented inventions. These studies have mostly used data for US firms and UK firms.

Research that compared indicators of individual patent value such as citations with survey-based direct measures of profits from the associated invention has found a positive and significant association between them (Harhoff *et al.* 1999). More recently, Gambardella *et al.* (2005) have adopted the same approach as Harhoff *et al.*, but using a new survey of European inventors and found similar results. However, to our knowledge, there are only few studies focusing on European firms which analyze the economic value of R&D or patents using firm market value and most of these are for the UK only: Blundell *et al.* (1995), Toivanen *et al.* (2002), Bloom and Van Reenen (2002), and Greenhalgh and Rogers (2006). The only exception is Hall and Oriani (2006), who look at the market value of R&D (but not of patents) for three continental European countries: France, Germany, and Italy.

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[3] This assertion has been confirmed by Bergstra and Klint (2007), who looked closely at 32 of the patents defined as software using the union of the two methods described later in the paper and concluded that only two were “pure” software.

Several of these market valuation studies rely on measures of R&D expenditure, which is usually considered a measure of innovation input rather than innovation output or 'success' of innovative activities. However, in the case of European firms, data on R&D expenditures are often missing because reporting these expenditures is not required by accounting and fiscal regulations across most European countries. The UK is probably the only European country where an explicit recommendation of accounting practice encourages firms to disclose their R&D expenditures.[4] Nevertheless in this paper we rely on a sample of European firms for which R&D data is available, covering about 70 per cent of European business sector R&D in the year 2000, and then augment this panel with patent data. Patents as a measure of innovation have their own drawbacks but, as Griliches (1990: 1661) has remarked, 'in this desert of data, patent statistics loom up as a mirage of wonderful plenitude and objectivity.'

The paper is organized as follows. The next section describes the method for estimating the private value of R&D and patents using financial data. Section 3 presents the data and describes the main variables while Section 4 reports the main results. Section 5 discusses the results and closes the paper.

2. Estimating the economic value of innovation assets

There are two streams of the literature that attempt to evaluate the economic returns to innovative activities.[5] The first relates innovation as proxied by R&D and patents to total factor productivity or profitability, in most cases capturing a measure of private returns, although in principle the productivity approach can also yield social returns if prices are

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[4] This recommendation dates from 1989 (see Toivanen *et al.*, 2002).

[5] See Hall (2006) for an analytical overview of econometric approaches to measuring the returns to R&D. Mairesse and Sassenou (1991) and Hall (2000) provide surveys of empirical results using the first and second methodologies respectively.

properly accounted for. The second, into which the present paper falls, measures the private returns to innovation using a forward looking measure of firm performance, its valuation in the stock market. Each of the two approaches has both merits and weaknesses.

Total factor productivity (TFP) is simply the ratio of outputs to inputs both expressed in real terms. Assuming only two inputs (capital K and labor L) and taking the natural logs of all variables the TFP of a firm can be expressed as follows:

$$log(TFP) = log(S) - \alpha \cdot log(L) - \beta \cdot log(K) \qquad (1)$$

This is an appropriate measure of productivity under conditions of constant returns to scale and competition in the markets for inputs and outputs.[6] Several studies have showed the importance of technology, measured by R&D expenditures, for the growth of total factor productivity at the firm level (e.g., Mansfield 1968, Gold 1977, and Griliches 1980).

Besides the strong assumptions necessary for TFP estimation, a major problem with this approach is the fact that the lag between R&D and its impact on productivity or profits is usually long and difficult to predict. Since this gives rise to serious measurement problems when the data are not available in long time series and when the process relating input and output is not stationary, much empirical work turns to alternative methods of measurement. In addition, the productivity approach that relies on accounting data often fails to allow for the effects of differences in systematic risk, temporary disequilibrium effects, tax laws and accounting conventions.

Some of these limitations are less important with the market value approach, which combines accounting data with measures of the value of the firm on the financial markets (Lindenberg and Ross, 1981; Montgomery and Wernerfelt, 1988). The market value approach draws on the idea, derived from the hedonic price models, that firms are bundles of assets

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[6] Note that it is possible to relax the assumptions of constant returns and perfect competition in the output market and derive a version of this equation that will still yield a measure of productivity (or profitability) that can be related to innovation inputs.

(and capabilities) that are difficult to disentangle and to price separately on the market. These assets include plants and equipment, inventories, knowledge assets, customer networks, brand names and reputation. The assumption is that financial markets assign a valuation to the bundle of firms' assets that is equal to the present discounted value of their future cash flows. This approach has been used in several studies to calculate the marginal shadow value of knowledge assets across a range of firms (Griliches 1981; Griliches *et al.* 1991; Hall 1993; Hall *et al.* 2005; Hall 2006).

The general functional form of the value function for an intertemporal maximization program with several capital goods is difficult to derive and does not have a closed form in most cases (Wildasin, 1985). In most econometric studies this difficulty has been tackled by assuming that the market value equation takes a linear or log-linear (Cobb-Douglas) form. The typical linear market value model, which we use here, relies on the assumption that a firm's assets enter additively:

$$V_{it}(A_{it}, K_{it})= q_t(A_{it}, + \gamma_t K_{it})^{\sigma_t} \qquad (2)$$

where *A* represents the physical assets and *K* the knowledge assets of firm *i* at time *t*. Under constant returns to scale ($\sigma_t=1$) equation (2) in log form can be written as

$$\log V_{it} = \log q_t + \log A_{it}, + \log(1+\gamma_t K_{it} /A_{it}) \qquad (3)$$

or

$$\log Q_{it} = \log V_{it}/A_{it} = \log q_t + \log(1+\gamma_t K_{it} /A_{it})$$

(4)

The left hand side of equation (4) is the log of Tobin's *q*, defined as the ratio of market value to the replacement cost of the firm, which is typically measured with the replacement value of firm's physical assets. On the right hand side, γ_t is the marginal or shadow value of the ratio of knowledge capital to physical assets at a given point in time. It measures the expectations of the investors over the effect of the knowledge capital relative to physical assets on the discounted future profits of the firm. The intercept ($log\ q_t$) represents the average logarithm of Tobin's q for the sample firms while $q_t\gamma_t$ is the absolute hedonic price of the knowledge capital.

As in Hall *et al.* 2005, equation (4) will be estimated by non-linear least squares. Most earlier research, beginning with Griliches (1981), have approximated the $log(1+\gamma_t K_{it}/A_{it})$ with $\gamma_t K_{it}/A_{it}$ and have estimated the market value equation by ordinary least squares; as the ratio of knowledge assets to ordinary assets has increased over time in many firms, this approximation has become less and less appropriate.[7] To ease interpretation of coefficient estimates for variables measured in widely differing units (dollars, euros, or counts) we computed the elasticity of Tobin's q with respect to each of the main regressors and displayed it in the tables below the coefficients.

$$\frac{\partial \log Q_{it}}{\partial \log X_{it}^{j}} = \frac{\gamma_j X_{it}^{j}}{1+\gamma_1(RD_{it}/A_{it})+\gamma_2(P_{it}/RD_{it})+\gamma_3(CIT_{it}/P_{it})} \qquad (5)$$

where X^j_{it} is the regressor of interest - R&D stock/physical assets, patent stock/R&D stock (total or software patents) and citation stock/patent stock. We computed these elasticities and their standard errors using the "delta" method for each observation in the dataset and then averaged them. The tables show the average elasticity and its average standard error.

Note that in general, shadow prices are equilibrium prices resulting from the interaction between the firm's demand and the market supply of capital for a specific asset at a given point in time. This implies that no structural interpretation should be attached to estimates of the market value equation. However, the values obtained by estimation of the market value equation are still informative, in the sense that they do measure the average

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[7] We have also used OLS for comparison but the results are not reported here due to lack of space.

marginal shadow values of an additional euro spent in R&D or an additional patent filed at a particular point in time.[8]

The market value approach rests on the restrictive hypothesis of capital market efficiency and therefore it can be used only for firms quoted in well-functioning and thickly traded stock markets. In fact, financial markets are not always perfect and there are persistent institutional differences across countries which may result in different evaluations of intangible assets.[9] To have an idea of the differences in the level of development of the stock market across countries, we looked at a somewhat imperfect measure, the ratio of stock market capitalization (aggregate market value of equity) to GDP (IMF 2006) in the right hand column of Table 2.

This ratio ranges from about 1.37 in the UK (very close to 1.36 of the US) through 0.73 of France, 0.43 in Germany, 0.45 in Italy to 0.11 in emerging Eastern European countries like Poland, Hungary and Ukraine.[10] The differences in financial development across European countries persist over time despite the rapid overall growth of the European financial markets during the 1980s and the 1990s (Rajan and Zingales, 2003) and tthese differences in financial market development could have a confounding effect on our estimates of the market value of intangible assets. For example, Hall and Oriani (2006) found that financial markets in France and Italy placed little value on the R&D performed in firms where the largest shareholder owned more than 30 per cent of the firm. However, over time the globalization of financial institutions (e.g., IMF, 2007) probably reduces the differences

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[8] For a more detailed discussion of various problems concerning the estimation and interpretation of the market value equation, see Hall (2000, 2006).

[9] We should note that other indicators of patent value have their own drawbacks. For example, survey data obtained by interviewing inventors may suffer from retrospective response bias. Data on patent renewal as an indicator of patent value do not provide information on the upper tail of the value distribution, where the most valuable patents are located.

[10] The large numbers for Switzerland and Spain presumably reflect the global nature of the financial sector in those countries, relative to the size of these country's economies.

in asset valuation across countries with different financial development. In the regressions that follow, we control for country-specific differences in valuation (which are significant), but it would be desirable to probe this question more deeply in future work.

Not surprisingly, most empirical studies that follow the market value approach rely on data from the US and the UK, where the stock markets are larger and more thickly traded than in other countries. For related reasons, studies based on data from these countries also benefit from the availability of large sets of firm-level panel data. These studies find that R&D stocks are significantly valued by financial markets in addition to physical assets. The empirical evidence for the US also shows that patent counts have an additional, albeit weaker, impact on market value after controlling for R&D. Finally, Hall *et al.* 2005 find that citation-weighted patents are more informative than mere patent counts about the market value of innovation.

A series of studies based on European datasets have used the varying indicators of innovation (R&D, patents and patent citations) to confirm that, by and large, innovative assets impact significantly upon the firm market value (see Table 1 for a list of these studies).

[Table 1 about here]

3. Data

3.1. Sample

To construct our sample we started with 10,218 publicly-traded firms headquartered in 33 European countries over the period 1980-2005. Our sample includes a large variety of countries with different levels of financial development and accounting regulations, ranging from the UK, a common-law country with an active equity market, to emerging Eastern European countries with a very small market capitalisation-to-GDP ratio. Only 2,197 firms reported data on R&D expenditures for one or more of the sample years. For these firms we collected data on patents and found that 575 were granted at least one patent and 165 at least one software patent by the EPO during the period 1985-2005.

Data on corporate structure (date of incorporation, ownership structure, ultimate parent company, subsidiaries) and balance sheet were obtained from the Bureau van Dijk's Amadeus database. Changes in corporate structure were checked for the years 1998 to 2006 by drawing on different issues of Amadeus. Data on market capitalization at the end of each year were obtained from Thomson Financial's Datastream. R&D data were obtained from Amadeus, Thomson Financials' Global Vantage and the UK Department of Industry's R&D Scoreboard. More precisely, we extracted from Amadeus all quoted companies reporting positive R&D expenditures for at least one year between 1980 and 2005 and filled in any missing R&D numbers for these firms using data from the other sources.

Firms' patent counts in all technological classes were obtained by matching the name of the assignee from the PATSTAT patent database with the company name in Amadeus. Patent citations and the number of IPC classes were also extracted from the PATSTAT database, available under license from the EPO-OECD Taskforce on Patent Statistics (PATSTAT 2006). For companies with subsidiaries, the patents of the ultimate parent company have been consolidated on the basis of the 1998-2006 ownership structure reported in Amadeus. Further information on corporate structure was collected from Hoovers, Who Owns Whom, and company websites for the period before 1998. Holding companies have been reclassified manually according to the main line of business or their most important subsidiaries using additional information from Amadeus, Hoovers, and company websites.

After dropping a few observations with extreme outliers in the patent data, very small firms and those with unconsolidated data, our final sample consisted of 1,060 firms for the period 1991 through 2002. The choice of time period was dictated by the fact that the patent quality measures are based on forward citations, and we required at least three years in which to observe them following the patent application (that is, 2003-2005). We consolidated some of the countries with small numbers of firms into larger groupings in order to reduce the number of dummies needed (e.g., all Eastern European countries form one group, and Spain and Greece another).

As Table 2 shows, over 90 per cent of the sample of firms for which both R&D and market capitalization are available generally consists of medium to large firms (over 5 million sales and 100 employees according to the Eurostat definition). About two-thirds of the sample is composed of firms with over 100 million sales (the Eurostat definition of a large firm is one with more than 20 million sales).

[Table 2 about here]

Tables A.1 and A.2 in Appendix A report the distribution of the firms in the sample by market capitalization and the main stock markets involved. About half the firms in this sample have a market capitalization less than 100 million euros and only about 10 per cent of firms have a capitalization above 5 billion euros, with over half of these very large firms having been established before 1970. On the other end of the distribution, about one third of firms with a capitalization less than 1 billion euros were incorporated since 1990; 20 per cent of those with capitalization between 1 and 5 billion euros are also new firms. This latter fact is in part the result of restructuring, liberalization and privatization of formerly state-owned corporations in many European continental countries during the 1990s. Another reason is the entry of software and “internet economy” companies such SAP, Business Objects, Infineon Technologies and O2.

The R&D-reporting firms in our sample are in a large number of sectors (see Table A.3 in the Appendix) and about half of these firms hold EPO or US patents. However, although about 20 per cent have US software patents, only 30 firms have EPO patents that we identify as “pure” software, reflecting the fact that such patents are not usually granted at the

EPO.[11] Of these 30 firms, two-thirds are in computing hardware and software, telecommunications, electronics, and electrical machinery.

The distribution of patents and R&D expenditures across industries is reported in Table A.4. The most important sectors in terms of R&D expenditures are pharmaceuticals and chemical products, motor vehicles, electronic instruments & communications equipment, and electrical machinery. These are also the most important sectors in terms of total US and EP patents. As expected software patents are more concentrated in few industries, with electrical machinery alone accounting for half of EP software patents and 32 per cent of US software patents. Electrical machinery, electronics and communication equipment, and telecommunications services together account for over 85 per cent of EP software patents and 65 per cent of US software patents.

We should note that the high concentration of software patents in few sectors is due in part to the exclusion of non-European firms from the sample. For example, IBM accounts for about 10 per cent of total EPO software patents granted to business enterprises, followed by Siemens and Canon (about 4 per cent each). Other large electronics firms are also relatively large software owners – e.g., Philips (3.4 per cent) and Sony (2.5 per cent). The largest software firm among the top owners of EPO software patents is Microsoft with a one per cent share.

3.2. Variables

Our dependent variable is Tobin's *q* for the firm, that is, the ratio of the firm's market value to tangible assets. Firm's market value is defined as the sum of market capitalization (price multiplied by the number of outstanding shares at the end of the year) and non current

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[11] The exact definition of a software patent used here is given in section 3.5 of the paper.

liabilities less a correction for net current liabilities plus inventories.[12] Tangible assets are the net costs of tangible fixed property and inventories used in the production of revenue, and are obtained as the sum of gross fixed assets plus inventory stocks less depreciation, depletion, and amortization (accumulated), investment grants and other deductions.[13]

Corporate finance scholars have developed alternative, more complex estimations of the Tobin's q which rely on estimated market value of the firm compared with that used in this paper (e.g., Perfect and Wiles, 1994). These alternative approaches to Tobin's q measurement produce more precise estimations but are computationally costly. Moreover, their greater precision is traded off by a larger selection bias. DaDalt et al. (2003) have used the Compustat dataset and found that using the Perfect and Wiles' approach produces a 20 per cent loss in sample size. It is important to note that DaDalt et al (2003) have estimated that simple methods, like that used here, and complex ones, like that of Perfect and Wiles, agree in approximately 90% of cases for values of q below 0.8 and above 1.2. As Table 3 clearly shows, for most firms in our sample the Tobin's q value falls in this range.

The R&D expenditure history of each firm was used to compute R&D stock. R&D spending includes amortization of software costs, company-sponsored research and development, and software expenses. As mentioned earlier, European firms are not required or recommended to disclose information on their R&D expenditures, implying that the availability of data on R&D expenditures is potential source of sample selection bias. Reporting R&D is then an endogenous variable since the decision whether or not to disclose this information rests upon the discretion of the firm. Hall and Oriani (2006) found that

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[12] Outstanding shares include both common shares and preferred shares.

[13] All values expressed in domestic currencies have been converted into euros by using annual average exchange rates reported by EUROSTAT.

selection was not a factor for most of the countries they considered. We treat this issue in Section 4 of the paper.

Since the stock of our key regressors cannot be measured directly from the firm books we rely on proxies obtained from current and past flows of R&D and patent-related variables. R&D stocks (*KRD*) were obtained using a declining balance formula and the past history of R&D spending:

$$KRD_t = R\&D_t + (1-\delta)KRD_{t-1}$$

where δ is the depreciation rate. We chose the usual 15 per cent depreciation rate for easy comparison to earlier work. Our starting R&D stock was calculated for each firm at the first available R&D observation year as $KRD_o = RD_o/(\delta+g)$. This assumes that real R&D has been growing at a constant annual growth prior to the sample; we used a growth rate g of 8 per cent. Patent stocks were obtained using the same methods, except that the initial available patent counts were not discounted to obtain an initial capital stock because we have a longer pre-sample history of patenting (back to 1978) than for R&D, so the impact of the initial stock is minimal.[14,15]

Our controls include firms' annual sales, which account for scale effects in the market value equation, industry dummies, country dummies and year dummies.[16] Firms' R&D and sales have been depreciated by the annual GDP deflator extracted from the AMECO-EUROSTAT web directory. In future work, we will control for differences in ownership structure (see also Hall and Oriani, 2006).

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[14] Because our patent data begin in 1978 and the first year we use in the regressions is 1991, the effects of omitted initial conditions will be small ($0.85^{14} = 0.10$).

[15] Our approach to the construction of patent stocks follows the methodology in Hall, Jaffe, and Trajtenberg (2005), in order to facilitate comparison with that paper's results.

[16] We use sales rather than assets to reduce measurement error bias arising from the fact that assets also appear on the left hand side of the equation.

3.3. Patent variables

For each of our firms, we have data on their EPO patents (and European national patents) as well as data on their USPTO patents. We have also constructed the ‘family’ of each patent as described in the next section. We then identified the categories of patents shown in the table following:

(i) EP	All EPO patents (labelled European in the tables)
(ii) EP only	EPO patents only (i.e., EPO patents without US equivalents, although they may have equivalents elsewhere in the world or in the European national offices)
(iii) EPUS	EPO patents with at least one US equivalent (i.e., patents whose family includes at least one US patent)
(iv) US	All USPTO patents (labelled US in the tables)
(v) US only	USPTO patents only (i.e., USPTO patents with no EPO or European national office equivalents, although they may have equivalents elsewhere in the world)
(vi) USEP	US patents with at least one EPO or European national office equivalent

Note that (i) is the disjoint sum of (ii) and (iii) and (iv) is the disjoint sum of (v) and (vi), but that (i) and (iv) may contain many of the same inventions. Note also that in principle (ii)+(v)+(iii) should be approximately equal to (ii)+(v)+(vi) and that either should cover all inventions that are patented in the US and/or the EPO.[17] In the regressions presented in section 4 we have explored the significance of these different measures by including (i) and (iv) separately and then breaking these into their constituents.

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[17] The counts are not identical between whether one starts with EP or US patents, for two reasons: 1) the equivalence correspondence may be one-to-many in either direction; and 2) our name-matching of patents to firms may not have picked up all the US subsidiaries of the European firms. However, the two stocks are correlated 0.96 so that the error from (2) is fairly small,.

3.4. Patent quality measures

Research on the economic importance of individual patented inventions have demonstrated that the distribution of patent value is very skewed (e.g., Harhoff *et al.* 1999). The large majority of patents have an extremely limited commercial value and only few represent an important source of revenues to the assignee. It is therefore desirable to make use of patent stock measures that are adjusted for the quality of the patents they contain. We make use of two such quality weights, both of which have been used in prior empirical investigations: forward citations (as in Hall, Jaffe, and Trajtenberg 2005) and an index derived from a factor model based on three indicators, as suggested by Lanjouw and Schankerman 2004. The indicators we use are forward citations, number of IPC classes, and family size). We describe each of these two quality measures in more detail below.

Forward citations received by a patent indicate that the information in an invention has served as a basis for a future invention. Citations, i.e., citations of 'prior art' that is relevant to a patent, serve an important legal function, since they delimit the scope of the property rights awarded to the patent. Thus, if patent B cites patent A, it implies that patent A represents a piece of previously existing knowledge upon which patent B builds, and over which B cannot have a claim. Citations to other patents then can be considered as evidence of spillovers or knowledge flows between patented inventions.

However, the usefulness of citations as a proxy for knowledge spillovers is limited by the fact that citations are not always added by the inventor (Jaffe *et al.* 2000). In the US, the applicant is required to disclose her knowledge of the prior art, although in fact, references to prior art are often found by the inventor's patent attorneys, rather than the inventor, and the decisions regarding which patents to cite ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence to be able to find prior art that the applicant misses or conceals.

In the case of EPO patents, inventors are not required to cite prior art and therefore references to earlier patents are usually added by patent examiners. This suggests that patent citations to EPO patents may be even less useful as a measure of spillovers. However, compared to the USPTO, citations contained in EPO patents tend to be more consistent and objective because they are assigned by a single team of patent examiners. Unlike that at the USPTO, EPO citation practice also tends to minimize the number of citations per patent. For more information on the meaning of European patent citations, see Harhoff, Hoisl, and Webb (2006).

In order to make citations to EPO and USPTO patents as comparable as possible given these differences, we have to take into account another important difference between the two patent systems. Unlike US patents, a large share of EPO patents are cited indirectly through their non-EPO equivalents, i.e., different ‘incarnations’ of the same inventions in other patent systems such as the European national patent offices and the USPTO. For this reason Harhoff et al. (2006) suggest that citation links to EPO patents should include also citations received by their equivalents. To account for this difference in citation patterns we counted direct and indirect citations to both EPO and USPTO patents.

We used PATSTAT (release of September 2006) to retrieve data on citations counts, which reports around 63 million citing correspondences up to December 2005. US patents received directly about 42.6 million or 68 per cent of all world citations contained in the PATSTAT dataset (for comparison, US patent applications were about one quarter of worldwide applications during the 2001-2004 period, according to the WIPO statistical database). 5.5 million US patents have received at least one cite.

After excluding patent applications that were not yet granted, we retrieved information on the publication dates of the citing patents. When the publication date of the citing patent was missing or it was antecedent to the date of the cited patent (approximately

2.7 million citations, about 7 per cent of the total number), the citation was not included in the analysis. Our final sample consisted of approximately 4.7 million U.S. patents having at least one citation prior to December 2005, 3.1 million patents having at least one citation within 5 years from the publication date, and 2.45 million having at least one citation within 3 years from the publication date.

EPO patents, which are about 8 per cent of worldwide applications during the same period, receive far fewer citations directly. EPO patents and their non-EPO equivalents overall receive about 1.8 million citations (2.8 per cent of the total) and 529,161 EPO granted patents have at least one cite. Restricting the citation lag to three years gives 460,142 citation links, of which about half are accounted for by citations to non-EPO equivalents of EPO patents.

For comparability we used the same search strategy for both EPO and USPTO patents, including citations to their equivalents. In particular, for EPO patents we considered as a citation link to an EPO patent the direct citation to a direct equivalent of that EPO patent. For example if the EPO patent X had two direct equivalents Y and Z respectively in two other patent offices, the citation count of X included not only the direct cites to X but also the direct cites to Y and Z (with duplicate cites removed). The same search strategy was followed for USPTO patents. For more details on this methodology see Harhoff *et al.* (2006).

Previous studies have also used backward citations as a measure of the quality of the citing patent. Some scholars have suggested that large numbers of citations to others reveal that a particular invention is likely to be more derivative in nature and, therefore, of limited importance (Lanjouw and Schankerman 2004). However, a large number of backward citations may also indicate a novel combination of existing ideas. This is probably the reason why Harhoff *et al.* (1999) have found that backward citations are positively correlated with patent value. Because of this ambiguity we do not use this variable in our analysis.[18]

Our second measure of patent quality was based on three indicators of patent value rather than one; in addition to forward citations, we used family size (the number of jurisdictions or countries the patent has been applied for) and the number of different technological classes assigned by patent examiners to a given patent.[19]

Our measure of family size was obtained as follows. We identified all priorities for the EPO patents in our sample firms (recall that there is a many-to-many correspondence between patents and priorities). Using this information, we found the non-EPO patents that reported the same priority. This first step gives a lower bound on the family size. The second step was to find all applications (EPO and non-EPO) that report an EPO application from one of our firms as a priority.[20] After removing any double counting, the number of patent applications thus identified plus those from the first step constitute the size of the patent family. The same procedure was followed to obtain the family size of US patents. Note that our definition is the same as the middle of the three definitions (equivalent, family, and extended family) suggested by Harhoff *et al.* (2006).

The number of technological classes have been shown to be an indicator of technological "quality" similar to the number of citations by Lerner (1994). To guarantee a reasonable level of precision, we use the number of eight-digit IPC classification codes reported in the patent document. The number of IPC classes can be viewed as a measure of

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[18] Our results do not change substantially when backward citations are used along with other indicators of patent quality.

[19] Other studies have also used the number of claims which delimit the scope of the invention as a measure of patent quality; this variable was not available to us in PATSTAT.

[20] EPO patents which refer to earlier EPO patents as their priority are classified as divisional patents by the EPO and correspond to continuations in the USPTO system.

technological scope or generality of the patent even though, as noted by Guellec and Pottelsberghe de la Potterie (2000), it may be also a measure of ambiguity reflecting the difficulty of the examiner in locating the invention in the technological space.

These three indicators were combined into a composite index of patent ‘quality’ derived from a common factor model in an approach developed by Lanjouw and Schankerman (2004). The common factor explains as much as possible the total variance of each indicator while minimizing its idiosyncratic component. The methodology is briefly described in Appendix B. The three component indicators are all strongly correlated with each other at the 1% level of significance.

3.5. Correcting for citation truncation

Patent citations suffer from several potential sources of biases, the most obvious of which is truncation. The number of citations to any patent is truncated in time because only citations received until the end of the dataset are observed. The observed number of citations to any given patent may also be affected by differences across patent cohorts, technological fields and patent offices. The observed citations then have to be adjusted or normalized for this multiplicity of effects. For this purpose we have adopted the approach developed by Caballero and Jaffe (1993) and Hall *et al.* (2005) – hereafter referred to as the HJT method- which is based on the estimation of a semi-structural model where the citation frequency is explained by cited patent-year effects, citing patent-year effects, technological field effects and citation lag effects. The estimated parameters of this model can be used to correct observed citation rates. Appendix B reports a brief description of the HJT method and the distribution of the weights used by technology field. The inverse of the numbers in Tables B.1 and B.2 gives the proportion of the lifetime citations that are predicted to occur in the time window observed. Actual citations are multiplied by the numbers given to correct for truncation.

3.6. Software patents

One of the goals of the research reported here was to get a picture of the use and valuation of software patents in European firms. More precisely, comparing the existence of and valuation of software patents in the US and the EP patent systems may shed light on some differences between these two patent systems. Software represents an interesting technology for our purposes because of the growing attention to software patents amongst business practitioners, scholars and policy-makers. Critics claim that software patents have an average poor quality and are applied for mainly for ‘strategic’ reasons rather than for protecting real inventions, whereas advocates maintain that software inventions are technological inventions like any other and should be entitled to patentability. Scholars looking at software-related patents have found evidence consistent with the hypothesis that strategic patent portfolio building in the ICT sector lies behind the increase in software patents. Studies using different definitions of software patents all find that the number of USPTO software patents is large and growing and that the holders of these patents are large hardware rather than software firms (Bessen and Hunt 2004; Graham and Mowery 2003; Hall and MacGarvie 2006). Bessen and Hunt (2004) have pointed out that IBM alone accounts for over 20% of software patents held by US firms. Hall and MacGarvie (2006) find that the widespread introduction of software patenting in the U.S. via court decisions was initially negative for software firms, but that these patents have become more privately valuable than other patents in the recent past. At the same time, their “quality” as measured by citations does not matter for hardware firm value, which suggests that adding an additional patent to the portfolio is more important than the patent *per se*.

Even in the U.S., it is difficult to find a simple definition of a software-related patent that can be used for statistical purposes, that is, does not require the reading of individual patents. In Europe it is even more difficult, because the international patent classification system does not actually recognize their existence. We therefore chose to rely on the methods used in the earlier studies on USPTO data, which are based on keyword searching as well as identifying class/subclass combinations in which pure software firms patent. The three main alternatives are those used by Graham and Mowery (2003), Bessen and Hunt (2004), and Hall and MacGarvie (2006).

Graham and Mowery identify as software patents those that fall in particular International Patent Classification (IPC) class/subclass/groups. Broadly defined, the classes are "Electric Digital Data Processing" (G06F), "Recognition of Data; Presentation of Data; Record Carriers; Handling Record Carriers" (G06K), and "Electric Communication Technique" (H04L).[21] Graham and Mowery selected the subclasses from these classes in which six large U.S. software producers patented between 1984 and 1995. They found that patents in these classes account for 57% of the patents assigned to the hundred largest firms in the software industry.[22]

An alternative definition is that adopted by Bessen and Hunt who define software patents as those that include the words "software" or "computer" & "program" in the patent document description. Patents that meet these criteria and also contain the words "semiconductor", "chip", "circuit", "circuitry" or "bus" in the title are excluded under the assumption that they refer to the device used to execute the computer program rather than the program itself.

Hall and MacGarvie (2004) suggest a third algorithm to define software patents that identifies all the U.S. patent class-subclass combinations in which fifteen "pure" software firms patent, yielding 2,886 unique class-subclass combinations. Patents falling in the classes

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[21] The detailed class/subclass groups included are G06F: 3,5,7,9,11,12,13,15; G06K: 9,15; H04L: 9.

[22] Graham and Mowery (2003), p. 232. The firms are Microsoft, Adobe, Novell, Autodesk, Intuit, and Symantec.

and subclasses combinations obtained from this search method are defined as software patents. The definition preferred by Hall and MacGarvie combines this definition with that of Graham and Mowery and then takes the intersection of the result with the Bessen-Hunt sample. Hall and MacGarvie report that their results for the market value of software patents are not significantly affected by the choice of definition.

We followed a combination of the search methods above to identify software patents at the EPO. First, we searched the title, abstract, claims and description of patents in the EPO dataset by relying on the same keywords used by Bessen and Hunt in their 2002 study of US software patents: ((software) OR (computer AND program)) AND NOT (chip OR semiconductor OR bus OR circuit OR circuitry <in> TI) AND NOT (antigen OR antigenic OR chromatography). To obtain keywords and classification for the patents we relied on the Delphion dataset (www.delphion.com), which gives access to the full-text of the patent document, including the application date, the technological classes and the address of the assignee. This procedure yielded 11,969 patents (in 7,117 different IPC classes-subclasses) (the *keyword method* hereafter).

Second, we analyzed the IPC (International Patent Classification) classes of the patent portfolios of the world's 15 largest specialized software firms (the IPC method hereafter). We expanded the set of firms used in earlier studies to obtain a representative sample of specialized software firms including European companies.[23] The firms we used account for over 30% of the world software market ($227 billion according to European Information Technology Observatory estimates). They have been granted 373 patents in 3,518 different

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[23] The top European software patenters over 1978-2004 are Microsoft, Oracle, Peoplesoft, Veritas, Symantec, Adobe Systems, Novell, Autodesk, Intuit, Siebel Systems, Computare, BMC Software, Computer Associates, Electronic arts (Japan), and SAP (Germany), whereas the top U.S. software patenters during the 1980-2000 period are Microsoft, Oracle, Peoplesoft, Veritas, Symantec, Adobe Systems, Novell, Autodesk, Macromedia, Borland, Wall Data, Phoenix, Informix, Starfish, and RSA Security. Only half the firms are common between the two lists, and only two firms are not U.S.-based.

technological classes-subclasses (117 if one considers only the main IPC codes in each patent).

As in Hall-MacGarvie (2006), we defined a software patent as one that fell in the intersection of the two sets of patents defined by the keyword and IPC methods.[24] As one might expect, this method yielded very different results for patents issued by the two patent systems: in the US, 6.7 per cent of the granted patents applied for during the 1991-2002 period by firms in our sample are software patents by this definition, whereas at the EPO, only 0.4 per cent of issued patents are software patents, a total of 286 patents. Of these, one third of the sample software patents are held by Siemens, and 75 per cent by the top five firms (Siemens, BT, Philips, Oce, and Alcatel). The largest software firm, SAP, holds 5. Two conclusions can be drawn from these facts: first, the EPO has been mostly successful at holding the line against "pure" software patents; and second, to the extent they exist, they are mostly held by hardware rather than software firms, as in the case of USPTO software patents.

3.7. Descriptive statistics

Tables 3a and 3b show some descriptive statistics for the final sample of 1061 firms, an unbalanced panel with 5,312 observations (from 1 to 12 years per firm). Table 3a gives statistics for the continuous variables and Table 3b for the various patent measures. The firms in the sample are large, with median sales of 306 million euros and median employment of

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[24] By relying on the intersection between the two methods we reduce the Type I-error (excluding a patent that we should have included among software patents) and high Type-II error (classify as software patent a patent that is not related to software). Preliminary work by Bergstra and Klint (2007) suggests that there is fair amount of Type-II error in EPO software patents when the union of the keyword and the IPC method is adopted. Using the intersection of the two methods we find few EPO patents that qualify as pure software, which suggests that the EPO is successful in restricting patenting in this area (many pure software patents do not qualify for patentable subject matter because, according to the EPC, they do not produce any technical effect or are not capable of industrial application).

1423. They are fairly R&D intensive, with a median R&D to tangible asset ratio of 0.25, and this is reflected in their median Tobin's q of 1.7, which is well above unity.

Table 3b reports descriptive statistics for granted patents (counted by date of application), the stock of granted patents, the ratio of patent stocks to R&D stocks, and the ratio of citation stocks to patent stocks, for all patents and for software patents separately. In this table the statistics for all of the variables are based on the entire sample, but the number of non-zero observations is reported for each variable. For the patent flows, we report statistics on the six types of patents described in the previous section: all EPO patents, all US patents, EPO only, US only, EPO with US equivalents, and US with EPO or European national office equivalents. For the sake of brevity, only the statistics for patent grants include those for EPO only and US only patents, as these can generally be derived for the difference between the total and the equivalents (see the discussion in section 3).

[Table 3 about here]

This table reveals that the firms in our sample take out twice as many USPTO as EPO patents (13 per firm year versus 26 per firm per year) and that this is reflected in a much larger share of inventions for which protection is sought only in the US and not in Europe (about 50 per cent) as compared to the reverse situation (about 25 per cent). The average firm that spends one million euros on R&D obtains 0.3 EPO patents and 0.44 USPTO patents, but of course the distributions are very skew, with medians of 0.08 and 0.15 respectively. USPTO patents receive far more citations (corrected for truncation) than EPO patents (12 versus 3), probably reflecting differences in the two patent systems.[25]

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[25] In principle, the differences in citation behavior should affect the citing, not the cited patent, but to the extent that search is local to a patent office, and also to particular technologies, these differences will also affect the patents being cited.

4. Results

Tables 4 through 7 contain the results of our estimations. The equation estimated is based on equation (4) and is estimated by nonlinear least squares:[26]

$$\log Q_{it} = q_t + \lambda_k + \delta_j + \beta_s \log S_{it} + \log\left[1 + \sum_l \gamma_l X_{it}^l\right] \qquad (1)$$

where *i, t, k, j,* and *l* index firms, years, countries, industries, and variables respectively. *S* is a control for size (the current sales or turnover of the firm); the size coefficient was invariably small and positive, and had little impact on the rest of the equation. The X_{it}^j are the various measures of R&D, patent, and citations stock ratios.

Table 4 contains our basic results using the R&D-assets ratio and various patent stock-R&D stock ratios. Table 5 adds information on software patents, and Table 6 includes information on the two patent value indicators. Table 7 reports results with the value indicators for software patents also included separately. Each table displays coefficient estimates and their robust standard errors in the top panel, and the average elasticities implied by the coefficients in the bottom panel. Below we discuss each of the tables in turn.

4.1. Estimation of the basic model without citations

The results for the basic model that includes R&D stocks, total patent stocks, and software patent stocks are shown in Table 4. For this model only, we also show the coefficients on dummies for zero patent stocks; these were included in all the models to control for possible differences in non-patenting firms or errors in matching, but they are not readily interpretable.

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[26] OLS estimates of the log approximation to equation (4) produced similar results and are therefore not shown. We should also note that approximating the log (1+x) with x reduces substantially the accuracy of estimates. For instance, approximating the log (1+R&D/assests) with R&D/assets=0.2 yields a 10 per cent measurement error (log(1+0.2)=0.18). With a R&D/asset ratio equal to 0.55 the error amounts to about 25 per cent.

The first and by far the most significant and robust result in all the tables is that the ratio between R&D stock and physical assets is positively and significantly related to Tobin's *q* across different specifications of the market value equation. The magnitude of the coefficient (slightly less than unity) is consistent with most of those reported in earlier works on single or multiple countries (e.g., Hall 2000; Blundell *et al.* 2002; Toivanen *et al.* 2002; Hall and Oriani 2005; Greenhalgh and Rogers 2006). The estimated elasticity is even more robust across all the specifications in Tables 4 and 5, taking values within a small interval around 0.20 in almost all cases. The average R&D-assets ratio is 0.51 with a standard deviation of 0.74, so that these estimates imply that firm which is one standard deviation above the mean has a market value that is 30 per cent higher than the average firm.

Second, in all specifications a firm's patent stocks are significantly related to value, above and beyond the R&D stock that generated them, but with some interesting detail, depending on the jurisdictions in which the patent was taken out. As discussed earlier, we have six possible (overlapping) patent measures: (i) EPO, (ii) EPO only, (iii) EPO with US equivalents, (iv) US, (v) US only, and (vi) US with European equivalents. In columns (2) and (3), we compare the use of all EPO and all US patents in the equation and find that both are significantly related to market value, with US patents having a slightly higher coefficient and elasticity (0.05 versus 0.03).

In models (4) and (5) we break up these two measures into patents with equivalents in the other jurisdiction and without. In models (6) and (7) we include the three indicators that should exhaust the information available, first using EP patents with US equivalents and then using US patents with EP equivalents.[27] The message is fairly clear and persists throughout

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[27] It is worth noting that about two-thirds of our firms regularly patent in the USPTO and about one third never patents there. The number of EP patents is smaller than US patents for various reasons. First, the EP system is younger than its US counterpart. Second, the examination-granting lag is larger in the EP. Finally, German firms (and UK as well) tend to apply more to their national patent system and the USPTO than the

these tables with only a few exceptions: Patents taken out at the EPO only are not valued by the financial markets once we control for patents taken out in the US. In addition, patents taken out in both jurisdictions are clearly more valuable than those taken out only in the U.S. An additional US patent with European equivalent per million euros of R&D leads to a 20 per cent increase in market value, whereas an additional EPO patent with a US equivalent leads to a 30 per cent increase in market value. An additional US patent without an equivalent per million euros of R&D leads only to a 12 per cent increase in market value, but an additional patent taken out only in Europe adds an insignificant amount to value. Clearly, there is a substantial premium to geographical scope for EPO patents, even when controlling only for patenting in the US and not for the rest of the world. Financial markets place a positive value on EPO patented inventions owned by European firms only when patent protection is also acquired in the United States.

The average elasticities reported in the bottom panel of Table 4 show that EPO and US patents have a similar impact with an elasticity of 4 and 3 per cent respectively, but with some of the US impact coming from patents taken out only in the US. A one standard deviation increase in the stock of EPO patents with US equivalents relative to R&D is associated with about an 11 per cent increase of market value, and similarly a one standard deviation increase in the stock of US patents with EPO equivalents (relative to R&D stock) yields a 10 per cent increase in market value.

[Table 4 about here]

The coefficients for EPO and US patents in Table 4 are substantially higher than the coefficient obtained by Hall *et al.* 2005 using the same methodology for U.S. firms and U.S. patent data during the 1980s: between 0.16 and 0.18 as compared with 0.03 for the earlier

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EPO. We took account of this fact when defining equivalents to US patents, but data constraints prevent us from including these patents themselves.

period and data. However, they are closer to the estimate obtained by Hall and MacGarvie 2006 for a sample of US information and communication technology (ICT) firms during the late 1990s, which was 0.15. Note that the estimates here are probably the first set of estimates using patents for firms from continental European countries and they seem to suggest that the incremental value of EPO patents above and beyond the R&D that generated them is roughly the same as that of US patents, but only if these patents have equivalents in the US system.

Given the results in Table 4, which shows that patents taken out in only one jurisdiction have little if any association with firm market value, in Table 5, which looks at software patents, we focus on the specifications that break patents up into those that have equivalents in the other jurisdiction and those that do not. This table repeats the regressions of Table 4, adding separate patent stock-R&D stock ratios for software patents. The coefficients of the software patents stock-R&D ratios are to be interpreted as premia or discounts for patents that fall into the software class. However, the elasticities shown are the total elasticities for software patents rather than premia, for ease in interpretation. Because the very small number of EPO only software patents (fewer than 10 per year) and because EPO only patents are generally not value-relevant, we have omitted this variable from the regression in Table 5.

[Table 5 about here]

The results in Table 5 for patents in general are similar to those in Table 4, with the only patents that are informative for market value are those taken out in both jurisdictions and to a lesser extent, those taken out in the US only. US software patents with EP equivalents and EP software patents with US equivalents are both valued at a considerable premium over other patents. Although the coefficients appear very large, it has to be remembered that the variables themselves (software patent-total R&D ratios) are very small so that the elasticities are small. The US software patent-R&D ratio has an elasticity of around one per cent, implying that a doubling of software patent yield per R&D would increase market value by one per cent. Although the coefficient on US software patents is smaller than that on EPO patents the average elasticity of EPO software patents is very close to zero. This is because the higher coefficient for EPO patents is inversely correlated with their smaller numbers. Thus, although each EPO software patent is more valuable than a USPTO patent, the same per cent increase in either stock produces a much smaller impact on market value in the case of EPO patents.

Note also that software patents taken out only in the U.S., which are actually more numerous than those with equivalents in Europe, are no more valuable than other US only patents. These are presumably patents on inventions that are not eligible for patenting at the EPO, and it is interesting that they are not as valuable to European firms as software patents that can be taken out in both jurisdictions.

4.2. Sample selection bias

As mentioned earlier in the paper, the disclosure of R&D expenditures is an endogenous variable and this gives rise to potential sample selection bias. To see whether sample selection biases our results, we first calculated the share of total R&D in the population of manufacturing and utility firms accounted for by our sample. Country-level R&D expenditures were taken from the OECD STAN dataset. As Table A.5 shows, the ratio of total R&D in our sample to the country-level industrial R&D varies across countries. For example, the ratio was 99.5 per cent in France, 98 per cent in Germany and over 100 per cent in the UK and Switzerland.[28] Apparently, the problem of sample selection is potentially relevant for firms from Spain and Italy while it is less important for other firms in our sample.

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[28] The fact that the share is above unity is explained by the R&D activity of their foreign subsidiaries abroad.

Overall, the high coverage of national R&D expenditures demonstrates that in Europe, as in the US, most of the business R&D activity is conducted by large, publicly traded firms. Moreover, our sample accounts for around 15.9% of overall patenting activity and 6.7% of software patenting activity at the EPO. These shares are quite large given that our sample does not include firms from the United States and Japan.

To check for sample selection bias we estimated a sample selection model using the Heckman two step method. For this purpose we collected accounting data for 3,773 publicly-listed firms that report data on R&D and for a matching sample of 3,194 publicly-listed firms from the same countries but which had reported no R&D data over the period 1991-2002.[29] The non-R&D doing firms are smaller, less labour-intensive, have higher leverage, and lower Tobin's *q*.

Our selection equation includes leverage (the ratio of current + non-current debt to tangible fixed assets), capital intensity (the ratio of tangible fixed assets to sales), and labor intensity (the ratio of labor cost to sales), as well as the share of the firm held by the main shareholder to account for observable firm characteristics that can affect its decision whether or not to reveal R&D expenditures. To account for 'environmental' factors we also included industry and year dummies in the equation. The inverse Mills' ratio obtained from the first stage estimation obtained by a probit model was then entered in the market value equation (see Maddala, 1983 and Hall, 1987). Our results show that there is little evidence of sample selection.[30] This result is consistent with that of Hall and Oriani (2006) for firms in France, Germany, and Italy.

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[29] The sample includes all publicly listed firms in the sample countries whose accounting data are available in Amadeus company directory.

[30] The estimated coefficient on the inverse Mills' ratio does not enter significantly in the market value equation at the 10 per cent level . Firms from Austria and Ireland were dropped because of the small number of observations. The results of these estimations are available upon request.

4.3. Accounting for patent quality

Tables 6 and 7 report estimations that include our patent value indicators (forward citations and the composite ‘quality’ index) for total patents and software patents. In these tables we restrict the specifications to two: one that includes EPO only patents, US only patents, and EPO patents with US equivalents, and one that includes EPO only patents, US only patents, and US patents with European equivalents. The first two columns of Table 6 report the results of specification including the average forward citation/patent stock ratios, and the second two columns report those including the average factor index/patent stock ratios. Table 7 reports the same thing including software patents, but only for the second specification (US patents with EPO equivalents) because of the paucity of EPO software patents.

The results in these tables for R&D and patents are similar to those in the previous tables. Citations yield an additional albeit small premium to either the EPO or the US patent counts. It is worth to note that the ‘quality’ of EPO only and US only patents, whether measured by citations or the factor index, does not yield any significant impact on the market value of the firm. Recall that both EPO and US citations include all citations to their equivalents. Probably because EPO citations are more parsimonious in general, the EPO citation-patent stock ratio has a mean and standard deviation of 2.9 and 3.3, much smaller than the US citation-patent stock ratio, with 12.6 and 15.3 respectively. The elasticity of market value with respect to the EPO (with US equivalents) cite per patent ratio is 7.0 per cent, as compared to 2.8 per cent for the US with European equivalents, which suggests that these cites are even more informative about value than would be suggested by the 4 to 1 ratio in which they are received.

[Table 6 about here]

The second pair of columns in Table 6 report similar results using the patent quality index based on 3-year forward citations, family size, and number of IPC classes instead of forward citations alone. The other coefficients in the regression are little affected by the change in quality indicator. However, the elasticity of market value with respect to the index is greater than that with respect to forward citations, suggesting that it is a somewhat better proxy for the average quality of a firm's patented inventions. For EPO patents with US equivalents a one standard deviation increase in average patent quality is associated with an increase in the market value of the firm equal to 5.0 per cent. The same calculations for US patents yields a 7.4 per cent increase. The corresponding numbers for the forward citation measure are 11.1 per cent for average cites to EPO patents with US equivalents and 6.2 per cent for average cites to US patents with EPO equivalents. Thus it appears that citations to EPO patents and their equivalents are a somewhat stronger value indicator than the constructed index, while for US patents both are about the same.

Table 7 reports the results of similar estimations that include software patents. The only significant result for software patents is the positive premium for patents with equivalents, as before. There is no premium for higher "quality" software patents, at least not using our measures of quality; in fact the elasticity of market value with respect to the quality indicators for software patents is almost exactly the same as that for ordinary patents. This result indicates that the financial market does not recognize any additional premium from the "intrinsic" value of software-related inventions.

[Table 7 about here]

Various robustness checks of the above results have been done using regressions that excluded extreme values of R&D stocks, patent stocks, the composite 'quality' index and software citation stocks. The qualitative results are very similar. However, these estimations do not account for bias due to unobserved firm-specific heterogeneity. We defer this to future research using panel data estimation.

5. Discussion and conclusions

This paper reports some new estimates of the economic value of patents in a sample of European firms. The main novelty of the paper consists in the use of both EPO and USPTO patents and quality-adjusted patents in the market value equation. In addition, we explored the question of whether software-related patents in Europe are valued differently from other patents. This exercise was motivated by the growing number of software patents in the EPO, the debate over the patentability of Computer Implemented Inventions and the supposedly poor quality of 'software-related' patents due to their strategic nature.

As far as total patents are concerned, our results demonstrate clearly that the financial markets primarily value those patented inventions for which patents are obtained in both European and US jurisdictions. Although EPO patents held by European firms are valued somewhat more highly than USPTO patents held by the same firms, this result is entirely accounted for by the fact that USPTO patents are slightly more numerous, so that the elasticity of market value with respect to patenting of either type is the same. Compared to USPTO patents held by US firms, patents of either type held by European firms have a slightly greater impact on value than those held by U.S. ICT firms during a similar time period (an elasticity of 0.035 versus about 0.016 reported by Hall and MacGarvie 2006) or those held by all US firms during the 1980s (0.02 reported by Hall, Jaffe, and Trajtenberg 2005).

Although quality adjusting these patents is significant, using either forward citations or an index based on forward citations, family size, and number of IPC classes, it adds only about 0.1 per cent to the explanatory power of the regression. It is also noteworthy that forward citations do almost as well as the 3-component factor index for EPO patents. One reason for this may be that by including patents with equivalents separately in the regression we have already captured much of the information associated with family size. That is, the taking out of a patent at both the EPO and the USPTO is a good enough indicator that it is more valuable than other patents. However, for US patents, the factor index provides more information than citation weights alone.

The insignificant share of software firms in software patenting suggests that most software firms in Europe are not using patents to protect their inventions. It is also true that the very small number of EPO patents we obtain when using a definition designed to capture "pure" software patents suggests that the EPO has been successful in excluding such patenting. Nevertheless, patents identified as software-related in general are more valuable that other patents, whether taken out at the EPO or at the USPTO. More interestingly, the quality-weighted software patents are no more valuable than other patents, suggesting that the value of these patents derives from their numbers rather than the quality of the inventions that they cover.

The present paper is a first investigation of the EPO patent dataset based only on European firms from a limited set of countries. In future research we will try to correct for some limitations of the dataset. First, we want to extend the analysis to other countries and firms, including non-European firms, and accounting for the priority date of the patent (i.e., the date of the first application). Our analysis so far is based on the date of application to the European Patent Office. This leads to some mismeasurement of the timing and to left censoring of the priority date. Second, we aim to examine citation lags by including citations in non-EPO patents. As mentioned before, in the current version of the paper we assumed that the citation lag distribution does not vary between EPO and non-EPO citing patents so that EPO citations can proxy for all citations. Third, we will control for differences between citations to patents held by other firms and self-citations. Although we have included self-citations, we do not expect significant changes in our results from this exploration. Previous work on US data by Hall *et al.* (2005) and Hall and MacGarvie (2006) have found that removing self-citations yields real but limited changes in the impact of citation-adjusted patents on the firm's market value.

Finally, we will control for changes in corporate structure. The results presented in this paper rely on the corporate structure of the firms as of 2005, which was used to match the name of patent assignees in the EPO database with that of companies in Amadeus. Therefore in earlier years our patent variables may include more or fewer patents than are actually owned by the firm, which introduces an unknown source of bias. We recognize that this is a potential source of bias because expectations about future firms' performance (our dependent variable) may be correlated with future acquisitions of patents, implying that the patent variable proxies for growth expectations in some cases.

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Appendix B – Correcting for citation truncation

The HJT method to identify the random process generating citations is based on the estimation of a semi-structural model which is made of two equations. With the first equation the citation frequency is modelled as a multiplicative function of cited-year effects (s), citing-year (t) effects, technology field (k) effects and citation lag effects (Hall *et al.*, 2001). The equation can be written as follows:

$$C_{kst} / P_{ks} = \alpha_0 \alpha_s \alpha_t \alpha_k \exp[f_k(L)]$$

where C_{kst} is the total number of citations received by patents with application date s and in technology k from patents with application date t. P_{ks} is the number of patents in technology k, year s. C_{kst} / P_{ks} is then the average number of citations received by patents k-s by all patents in year t. The parameters α_s, α_t, α_k measure the effect of, respectively, cited-year, citing-year and technology on the probability of citations. The function $f_k(L)$ describes the shape of the citation-lag (L=t-s) distribution, which is allowed to vary across fields. The multiplicative form of the citation frequency relies on the assumption of proportionality, i.e., the shape of the lag distribution is assumed to be independent of the number of citations received.

The α parameters are normalized so that each parameter measures the proportional difference in the citation propensity with respect to the base category. For instance, an estimated coefficient α_k= (k=chemicals field) = 2 implies that the expected citation rate of patents in the chemical field is twice the citation rate of patents in the base field.

The second equation in the model is the following:

$$f_k(L) = \exp(-\beta_{1k} L)(1 - \exp(-\beta_{2k} L)$$

where the parameters β_{1k} and β_{2k} measure the depreciation or obsolescence of the knowledge protected by patents in field k and the diffusion effect, respectively.

Following Hall et al (2001), we estimated this model by non linear least squares. Estimated α parameters can be used to remove cited-patent, citing-patent and technology field effects. Since we are primarily interested in truncation, we used the estimates of β parameters to calculate the expected distribution lags. Table B.1 reports the cumulative citation lag distributions in the seven technological groups defined by Fraunhofer-ISI and the Observatoire des Sciences et des Techniques over the cited period 1978-2004.[31] We used these proportions to correct the observed citation counts. Consider, for example, a chemical patent in year 2002 which has received 5 citations until 2005. Table B.1 shows that the typical chemical patent in year 2002 receives about 48.2% of citations after three years from its application. To correct for truncation we have to 'deflate' the observed citations by 0.48183 obtaining 10.38 citations.

The weights reported in Table B.1 are obtained by using all citations to EPO by year of cited patents, year of citing patents, citation lag and technological field of the cited patent. The source of data is PATSTAT (2006), which reports citations received by EPO patents from the main world patent offices, including the USPTO, the JPTO and the WIPO. Because of the large computation efforts required, we rely on the application year of EPO citing patents only, which account for about one-third of all citations received by EPO patents. Although the weights reported above have been estimated for this subset of citations only, we have used the same weights to correct all citations received by the patents in our sample, assuming that the shape of the simulated cumulative lag distributions does not vary with the citing patent's office. In future research we will collect information on non-EPO citing patents in order to relax this unrealistic assumption.

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[31] http://www.obs-ost.fr

Unfortunately, the EPO system does not require examiners to indicate the ‘main’ technological field. The PATSTAT Data Catalogue_3_22 states that ‘…For other authorities, like the EPO, there is in general no meaning in the position – classes may be quoted in alphabetical order for instance …” p. 50). The problem is serious since many patents are classified in two or more 2-digit IPC fields. In this case, we used the arithmetic mean of the citation lag distribution weighted by the patent’s own IPC distribution (e.g., if it has 3 chemical classes and one drug, we used 3/4 the chemical cite lag and 1/4 the drug cite lag; given the similarity of the lag distributions, this procedure is not likely to introduce much error into the measure.

[Table.B.1 about here]

[Table.B.2 about here]

Appendix C – A Composite Patent Quality Indicator

The construction of the multidimensional measure of patent quality relies on factor analysis. In factor models each series of data (quality indicator in our case) is decomposed into a common component and an idiosyncratic component. The common component is only driven by a few common shocks, denoted by $V < N$, where N is the number of indicators. In a static factor model, the common shocks affect the indicators only contemporaneously. The basic model is given by $X = UB + E = K + E$, where X is the $(T \times N)$ matrix of observations on N series (indicators) of length T. The series are normalized to have mean 0 and variance 1. U is the $(T \times V)$ matrix of V common shocks and B is the $(V \times N)$ matrix of factor loadings, which determines the impact of common shock v on series n. The common shocks and the factor loadings together make up the common component K. After the influence of common shocks has been removed, only the idiosyncratic component (E) remains. To estimate the common component we have to find a linear combination of the indicators in X that explains as much as possible the total variance of each indicator, minimizing the idiosyncratic component (for a technical discussion of factor models see Jolliffe (2002).

The parallel with least squares estimation is clear from this formulation, but the fact that the common shocks are unobserved complicates the problem. The standard way to extract the common component in the static case is to use principal component analysis. In principal component analysis the first V eigenvalues and eigenvectors are calculated from the variance-covariance matrix of the dataset X. The common component is then defined as $K = XVV'$, with $V = [p_1,\ldots,p_V]$ and where p_i is the eigenvector corresponding to the ith largest ($i = 1 \ldots Q$) eigenvalue of the covariance matrix of X. This method does not guarantee a unique solution. A further problem is that *ex ante* it is not known how many common shocks V affect the series in X. Following the approach suggested by Lanjouw and Schankerman (2004), we use a multiple-indicator model with an unobserved common factor:

$y_{k\,i} = \lambda_k v_i + \beta' X + e_{ki}$

where y_{ki} indicates the value of the kth patent indicator for the ith patent; v is the common factor with factor loadings λ_k and normally distributed, while X is a set of controls. The main underlining assumption is that the variability of each patent indicator in the sample may be generated by the variability of a common factor across all the indicators and an idiosyncratic component $e_{k} \sim N(0,\sigma^2_k)$ which is not related to other 'quality' indicators.

In our setting, the common factor is the unobserved characteristic of a patent that influences positively three 'quality' indicators: family size, forward citations, and the number of 8-digit IPC technology fields. The analysis is based on the total number of EPO patents granted between 1978 and 2002 (around 785,740 observations) and of US patents granted between 1978 and 2002 (around 2,756,353 observations).

More precisely, to estimate v we followed a two step estimation procedure. In the first step we regressed the three patent 'quality' indicators against two observable patent characteristics, the year of application and the main technology class of the patent (out of 30 macro-technological classes) using three stage least squares. Estimation of the common quality index v is then based on information extrapolated from the covariance matrix of three observable indicators conditional on year and technology class. In the second step we used maximum likelihood to estimate a factor model using the residuals from the first step under the assumption that $v \sim N(0, \sigma^2)$. We found evidence of the existence of a single common factor which we used as our multidimensional measure of patent 'quality' in the market value estimations. Factor analysis in the second step yields the following factor loadings:

Variable	**EPO patents**	**USPTO patents**
Forward citations	0.289	0.173
Family size	0.301	0.106
Number of IPC classes	0.170	0.334

Table 1
Empirical studies of the market value of innovation using European data

Paper	R&D	Innovation output	Patent citations	Sample size	Geographical coverage	Time period
Blundell *et al.* (1999)	NO	USPTO patents, SPRU innovation counts	NO	340	UK	1972-1982
Bloom and Van Reenen (2002)	NO	USPTO patents	5-year cite stock	404	UK	1968-1996
Toivanen *et al.* (2002)	YES	NO	NO	1519	UK	1988-1995
Greenhalgh and Rogers (2006)	YES	UK and EPO patents	NO	3227	UK	1989-2002
Hall and Oriani (2006)	YES	NO	NO	2156	US, UK, FR, IT, DE	1989-1998
Our study	YES	USPT and EPO patents	Yes	7168	21 European countries	1991-2002

Table 2
Country-size distribution of R&D-reporting firms in our sample

Average sales (euros in 2000)	*< 10M*	*10M-100M*	*100M-1B*	*1B-10B*	*> 10B*	*Total*	*Market cap/GDP**
Austria	1	4	6	3	0	14	0.41
Belgium & Luxembourg	0	9	9	5	1	24	0.77
Switzerland	1	11	39	18	3	72	NA
Germany	8	73	67	35	11	194	0.43
Denmark	2	9	9	4	0	24	0.62
Eastern Europe	0	2	7	1	0	10	0.11
Spain & Greece	0	8	21	3	0	32	0.82
Finland	1	26	21	13	2	63	0.94
France	9	43	44	23	13	132	0.73
UK	51	123	100	55	14	343	1.73
Ireland	2	2	6	2	0	12	0.45
Italy	0	0	1	1	1	3	0.45
Netherlands	2	10	10	9	4	35	0.81
Norway	2	8	8	3	2	23	NA
Sweden	13	28	21	15	3	80	0.97
Totals	92	356	369	190	54	1061	

This variable is the total stock market capitalization for the country over GDP (source: IMF 2006)

Table 3a
Descriptive Statistics

5312 observations, 1061 firms, 15 country/regions, 1991-2002

	Number**	Mean	S.D.	Median	1Q	3Q	Min	Max
Sales*	5312	3749.8	11996.8	306.3	66.9	1950.6	0.0	194,724
Tobin's q	5312	2.99	3.54	1.71	1.14	3.18	0.10	24.85
Employment	4729	16864	47119	1423	298	9600	1	477,100
R&D expenditures*	5312	129.32	485.91	8.11	1.87	36.62	0.000	6,787
R&D stock*	5312	637.45	2396.47	35.16	8.44	183.46	0.01	33,127
R&D stock/assets	5312	0.51	0.74	0.25	0.09	0.59	0.000	4.99

*In millions of current euros

**The number of good observations.

Table 3b
Descriptive statistics for patent variables

5312 observations, 1061 firms, 15 country/regions, 1991-2002

	N nonzero	Mean	S.D.	Median	1Q	3Q
Granted patents by application date						
EPO	3980	13.22	64.04	0	0	4
EPO with US equivalents	3758	9.94	48.40	0	0	3
EPO only	3309	3.28	18.46	0	0	1
USPTO	4253	25.80	134.46	1	0	7
USPTO with European equivalents	4020	12.96	70.41	0	0	3
USPTO only	3383	12.85	81.91	0	0	3
Granted software patents by application date						
EPO	277	0.05	0.58	0	0	0
EPO with US equivalents	205	0.04	0.46	0	0	0
EPO only	150	0.01	0.21	0	0	0
USPTO	2393	1.73	13.35	0	0	0
USPTO with European equivalents	1925	0.68	5.90	0	0	0
USPTO only	1732	1.05	9.30	0	0	0
Stock of granted patents						
EPO	3980	81.67	365.23	3.53	0.00	26.02
EPO with US equivalents	3758	61.75	267.71	2.44	0.00	17.29
USPTO	4253	132.40	607.71	5.89	0.38	39.30
USPTO with European equivalents	4020	74.54	361.60	3.10	0.07	21.21
Stock of granted software patents						
EPO	277	0.25	2.38	0.00	0.00	0.00
EPO with US equivalents	205	0.19	1.72	0.00	0.00	0.00
USPTO	2393	9.56	57.84	0.00	0.00	1.73
USPTO with European equivalents	1925	4.28	30.19	0.00	0.00	0.72
Patent-R&D stock ratios						
EPO	3980	0.30	0.87	0.08	0.00	0.28
EPO with US equivalents	3758	0.21	0.65	0.05	0.00	0.20
USPTO	4253	0.44	1.36	0.15	0.02	0.46
USPTO with European equivalents	4020	0.26	0.75	0.07	0.00	0.25
Patent-R&D stock ratios - software patents						
EPO	277	0.001	0.016	0.000	0.000	0.000
EPO with US equivalents	205	0.000	0.015	0.000	0.000	0.000
USPTO	2393	0.023	0.084	0.000	0.000	0.012
USPTO with European equivalents	1925	0.010	0.047	0.000	0.000	0.003
Citation-patent stock ratios						
EPO	3809	2.92	3.33	2.47	0.00	4.06
EPO with US equivalents	3599	3.10	3.48	2.64	0.00	4.49
USPTO	4141	12.57	15.25	10.00	2.91	16.17
USPTO with European equivalents	3909	14.59	23.94	9.50	0.00	16.69
Citation-patent stock ratios - software patents						
EPO	234	0.21	1.31	0.00	0.00	0.00
EPO with US equivalents	194	0.19	1.30	0.00	0.00	0.00
USPTO	2298	12.80	31.91	0.00	0.00	16.92
USPTO with European equivalents	1861	13.94	49.98	0.00	0.00	12.84

*In millions of current euros

Table 4

Market value regressions with patent stocks

5312 observations for the 1991-2002 period. Dependent variable = log Tobin's Q

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
R&D stock-assets ratio	**0.675 (0.061)**	**0.728 (0.067)**	**0.782 (0.071)**	**0.763 (0.072)**	**0.753 (0.070)**	**0.748 (0.071)**	**0.788 (0.074)**
Patent stock-R&D ratios:							
European		**0.157 (0.034)**					
European only				0.014 (0.030)		0.026 (0.032)	0.007 (0.034)
US			**0.177 (0.031)**				
US only					**0.121 (0.045)**	**0.100 (0.047)**	**0.124 (0.046)**
European with US equivalents				**0.330 (0.066)**		**0.274 (0.065)**	
US with European equivalents					**0.191 (0.042)**		**0.211 (0.049)**
Dummies for zero patent stocks							
European		-0.016 (0.037)					
European only				**0.188 (0.044)**		**0.202 (0.043)**	**0.145 (0.043)**
US			0.062 (0.041)				
US only					**-0.132 (0.034)**	**-0.114 (0.037)**	**-0.161 (0.035)**
European with US equivalents				**-0.101 (0.043)**		-0.047 (0.047)	
US with European equivalents					**0.160 (0.042)**		**0.112 (0.048)**
Log sales (millions of euros)	0.016 (0.005)	0.020 (0.006)	0.024 (0.006)	0.028 (0.006)	0.019 (0.006)	0.022 (0.007)	0.024 (0.007)
R-squared (s.e.)	0.255 (0.729)	0.263 (0.725)	0.266 (0.723)	0.269 (0.722)	0.269 (0.722)	0.271 (0.721)	0.271 (0.721)
Average elasticity (standard deviation)							
R&D stock-assets ratio	**0.194 (0.011)**	**0.201 (0.012)**	**0.205 (0.012)**	**0.199 (0.012)**	**0.203 (0.012)**	**0.198 (0.012)**	**0.205 (0.012)**
Patent stock-R&D ratios:							
European		**0.032 (0.006)**					
European only				0.001 (0.002)		0.002 (0.002)	0.001 (0.002)
US			**0.049 (0.007)**				
US only					**0.014 (0.005)**	**0.011 (0.005)**	**0.013 (0.005)**
European with US equivalents				**0.041 (0.007)**		**0.035 (0.007)**	
US with European equivalents					**0.033 (0.006)**		**0.035 (0.007)**

These regressions include 15 country dummies, 24 industry dummies, and 12 year dummies, as well as dummies for obs with zero patent stocks.

Nonlinear least squares with robust standard errors.

Table 5

Market value regressions with software patent stocks

5312 observations for the 1991-2002 period. Dependent variable = log Tobin's Q

Variable	(8)	(9)	(10)	(11)
R&D stock-assets ratio	**0.722 (0.068)**	**0.790 (0.072)**	**0.710 (0.068)**	**0.746 (0.070)**
Patent stock-R&D ratios:				
US only			**0.100 (0.052)**	**0.125 (0.052)**
European with US equivalents	**0.293 (0.059)**		**0.243 (0.057)**	
US with European equivalents		**0.206 (0.047)**		**0.158 (0.041)**
US only software			-0.003 (0.313)	-0.101 (0.298)
EP software with US equivalents	**2.59 (1.34)**		**2.54 (1.18)**	
US software with European equiv.		**1.57 (0.61)**		**1.50 (0.57)**
Log sales (millions of euros)	**0.020 (0.006)**	**0.028 (0.006)**	**0.015 (0.006)**	**0.018 (0.006)**
R-squared (s.e.)	0.266 (0.723)	0.265 (0.724)	0.268 (0.722)	0.270 (0.722)
Average elasticity (standard deviation)				
K/A	**0.198 (0.012)**	**0.205 (0.012)**	**0.198 (0.012)**	**0.201 (0.012)**
Patent stock-R&D ratios:				
US only			**0.011 (0.006)**	**0.014 (0.005)**
European with US equivalents	**0.038 (0.006)**		**0.032 (0.006)**	
US with European equivalents		**0.034 (.007)**		**0.027 (0.006)**
US only software			0.0009 (0.0025)	0.0002 (0.0023)
EP software with US equivalents	**0.0004 (0.0001)**		**0.0004 (0.0001)**	
US software with European equiv.		**0.0096 (0.0029)**		**0.0092 (0.0028)**

These regressions include 15 country dummies, 24 industry dummies, and 12 year dummies, as well as dummies for obs with zero patent stocks.
Nonlinear least squares with robust standard errors.

Table 6
Market value regressions with patent stocks and patent value indicators
5312 observations for the 1991-2002 period. Dependent variable = log Tobin's Q

Variable	(12)	(13)	(14)	(15)
R&D stock-assets ratio	**0.806 (0.083)**	**0.807 (0.078)**	**0.854 (0.116)**	**0.852 (0.099)**
Patent stock-R&D ratios:				
European only	0.029 (0.037)	-0.002 (0.033)	0.034 (0.037)	0.000 (0.036)
US only	**0.109 (0.053)**	**0.105 (0.047)**	**0.113 (0.056)**	**0.081 (0.046)**
European with US equiv.	**0.300 (0.073)**		**0.308 (0.081)**	
US with European equiv.		**0.237 (0.053)**		**0.258 (0.060)**
Value indicator stock-patent ratios:	*Forward citations*		*Index*	
European only	-0.002 (0.007)	0.001 (0.007)	-0.088 (0.060)	-0.062 (0.056)
US only	0.000 (0.001)	0.000 (0.001)	-0.005 (0.050)	
European with US equiv.	**0.0320 (0.0080)**		**0.200 (0.084)**	
US with European equiv.		**0.0026 (0.0008)**		**0.155 (0.040)**
Log sales (millions of euros)	0.019 (0.007)	0.022 (0.007)	0.022 (0.007)	0.023 (0.007)
R-squared (s.e.)	0.274 (0.719)	0.272 (0.721)	0.272 (0.721)	0.273 (0.720)
Average elasticity (standard deviation)				
R&D stock-assets ratio	**0.191 (0.012)**	**0.202 (0.012)**	**0.197 (0.012)**	**0.203 (0.012)**
Patent stock-R&D ratios:				
European only	0.002 (0.002)	0.000 (0.002)	0.002 (0.002)	0.000 (0.002)
US only	**0.011 (0.005**	**0.011 (0.005)**	**0.011 (0.005)**	**0.008 (0.004)**
European with US equiv.	**0.034 (0.007)**		**0.034 (0.007)**	
US with European equiv.		**0.038 (0.007)**		**0.039 (0.007)**
Value indicator stock-patent ratios:	*Forward citations*		*Index*	
European only	-0.002 (0.009)	0.002 (0.009)	-0.047 (0.034)	-0.035 (0.033)
US only	0.003 (0.005)	-0.004 (0.005)	-0.003 (0.030)	-0.007 (0.031)
European with US equiv.	**0.070 (0.015)**		**0.140 (0.048)**	
US with European equiv.		**0.028 (0.008)**		**0.102 (0.023)**

These regressions include 15 country dummies, 24 industry dummies, and 12 year dummies, as well as dummies for obs with zero patent stocks.

Nonlinear least squares with robust standard errors.

Table 7
Market value regressions
with patent stocks, software patent stocks, and patent value indicators

5312 observations for the 1991-2002 period. Dependent variable = log Tobin's Q

Variable	(17)	(19)
R&D stock-assets ratio	**0.774 (0.074)**	**0.799 (0.093)**
Patent stock-R&D ratios:		
US only	**0.113 (0.053)**	**0.094 (0.052)**
US with European equiv.	**0.185 (0.045)**	**0.196 (0.049)**
SW: US only	-0.149 (0.309)	-0.177 (0.309)
SW: US with European equiv.	**1.47 (0.59)**	**1.55 (0.64)**
Value indicator-patent ratios:	*Forward citations*	*Index*
US with European equiv.	**0.0026 (0.0008)**	**0.157 (0.038)**
SW: US with European equiv.	0.0000 (0.0002)	-0.040 (0.028)
Log sales (millions of euros)	**0.017 (0.006)**	**0.017 (0.007)**
R-squared (s.e.)	0.272 (0.721)	0.272 (0.720)
	Average elasticity (standard deviation)	
R&D stock-assets ratio	**0.199 (0.012)**	**0.199 (0.013)**
Patent stock-R&D ratios:		
US only	**0.012 (0.005)**	**0.010 (0.005)**
US with European equiv.	**0.030 (0.006)**	**0.031 (0.006)**
SW: US only	-0.0003 (0.0027)	-0.0007 (0.0023)
SW: US with European equiv.	**0.0087 (0.0028)**	**0.0090 (0.0029)**
Value indicator-patent ratios:	*Forward citations*	*Index*
US with European equiv.	**0.029 (0.009)**	**0.108 (0.023)**
SW: US with European equiv.	**0.030 (0.008)**	**0.091 (0.031)**

These regressions include 15 country dummies, 24 industry dummies, and 12 year dummies, as well as dummies for obs with zero patent stocks.
Nonlinear least squares with robust standard errors.

Table A.1. Distribution by year of incorporation and market capitalisation

Year of incorporation	Market Capitalisation (million mil EUR - latest year available)									
	<100		100-1000		1000-5000		> 5000		All	
before 1970	142	27.3%	135	42.2%	71	54.6%	49	53.8%	397	37.4%
1971-1980	41	7.9%	27	8.4%	10	7.7%	5	5.5%	83	7.8%
1981-1990	140	26.9%	63	19.7%	25	19.2%	9	9.9%	237	22.3%
1991-2000	183	35.2%	89	27.8%	20	15.4%	25	27.5%	317	29.9%
After 2000	11	2.1%	5	1.6%	1	0.8%	2	2.2%	19	1.8%
N.A.	3	0.6%	1	0.3%	3	2.3%	1	1.1%	8	0.8%
All	**520**	**49.0%**	**320**	**30.2%**	**130**	**12.3%**	**91**	**8.6%**	**1061**	**100.0%**

Table A.2. Distribution by stock market listing

Main exchange	Companies	Share (%)
Athens Stock Exchange	31	2.9%
Australian Stock Exchange	1	0.1%
Budapest Stock Exchange	5	0.5%
Dusseldorf Stock Exchange	1	0.1%
Euronext Amsterdam	24	2.3%
Euronext Brussels	22	2.1%
Euronext Paris	136	12.8%
Frankfurt Stock Exchange	93	8.8%
Hamburg Stock Exchange	1	0.1%
Helsinki Stock Exchange	1	0.1%
Irish Stock Exchange	10	0.9%
Italian Continuous Market	3	0.3%
London Stock Exchange (SEAQ)	154	14.5%
London Stock Exchange (SETS)	182	17.2%
Madrid Stock Exchange	1	0.1%
NASDAQ National Market	3	0.3%
NASDAQ OTC Bulletin Board	1	0.1%
New York Stock Exchange	3	0.3%
Not available	2	0.2%
OFEX	1	0.1%
OMX - Copenhagen Stock Exchange	23	2.2%
OMX - Helsinki Stock Exchange	62	5.8%
OMX - Stockholm Stock Exchange	80	7.5%
OMX - Tallinn Stock Exchange	1	0.1%
Oslo Stock Exchange	24	2.3%
Stuttgart Stock Exchange	3	0.3%
Swiss Electronic Stock Exchange	13	1.2%
Swiss Exchange	57	5.4%
Vienna Stock Exchange	13	1.2%
Warsaw Stock Exchange	2	0.2%
XETRA	106	10.0%
Zagreb Stock Exchange	2	0.2%
Total	1061	100.0%

Table A.3. Distribution of companies by industry – 2.5 digit industry class

	with R&D		with EP pats		with EP software pats		with US pats		with US software pats	
2.5 digit industry class	firms	%	firms	%	firms	%	firms	%	firms	%
01 Food & tobacco	39	3.7	31	4.5	0	0.0	28	3.8	18	4.6
02 Textiles, apparel & footwear	20	1.9	12	1.7	1	2.3	11	1.5	4	1.0
03 Lumber & wood products	7	0.7	3	0.4	0	0.0	4	0.5	2	0.5
04 Furniture	10	0.9	8	1.2	1	2.3	8	1.1	4	1.0
05 Paper & paper products	17	1.6	13	1.9	0	0.0	15	2.0	6	1.5
06 Printing & publishing	14	1.3	6	0.9	1	2.3	7	0.9	3	0.8
07 Chemical products	46	4.3	40	5.8	1	2.3	41	5.5	21	5.4
08 Petroleum refining & prods	20	1.9	16	2.3	0	0.0	17	2.3	12	3.1
09 Plastics & rubber prods	17	1.6	12	1.7	1	2.3	13	1.8	7	1.8
10 Stone, clay & glass	22	2.1	18	2.6	0	0.0	16	2.2	8	2.1
11 Primary metal products	24	2.3	15	2.2	0	0.0	15	2.0	5	1.3
12 Fabricated metal products	28	2.6	21	3.0	1	2.3	22	3.0	10	2.6
13 Machinery & engines	89	8.4	76	10.9	0	0.0	75	10.1	44	11.3
14 Computers & comp, equip,	29	2.7	20	2.9	3	6.8	22	3.0	16	4.1
15 Electrical machinery	39	3.7	30	4.3	3	6.8	32	4.3	17	4.4
16 Electronic inst, & comm, eq,	127	12.0	82	11.8	7	15.9	90	12.1	50	12.8
17 Transportation equipment	10	0.9	9	1.3	1	2.3	9	1.2	8	2.1
18 Motor vehicles	25	2.4	22	3.2	3	6.8	22	3.0	12	3.1
19 Optical & medical instruments	41	3.9	32	4.6	2	4.5	34	4.6	17	4.4
20 Pharmaceuticals	61	5.8	47	6.8	2	4.5	49	6.6	26	6.7
21 Misc, manufacturing	23	2.2	15	2.2	0	0.0	17	2.3	8	2.1
22 Soap & toiletries	11	1.0	10	1.4	0	0.0	11	1.5	6	1.5
24 Computing software	159	15.0	42	6.0	8	18.2	65	8.8	30	7.7
25 Telecommunications	21	2.0	9	1.3	5	11.4	9	1.2	7	1.8
26 Wholesale trade	26	2.5	14	2.0	0	0.0	16	2.2	5	1.3
27 Business services	16	1.5	9	1.3	1	2.3	10	1.3	6	1.5
29 Mining	13	1.2	11	1.6	0	0.0	11	1.5	6	1.5
30 Construction	19	1.8	12	1.7	0	0.0	11	1.5	4	1.0
31 Transportation services	6	0.6	4	0.6	1	2.3	4	0.5	3	0.8
32 Utilities	21	2.0	20	2.9	1	2.3	18	2.4	11	2.8
33 Trade	7	0.7	2	0.3	0	0.0	2	0.3	0	0.0
34 Fire, Insurance, Real Estate	2	0.2	0	0.0	0	0.0	0	0.0	0	0.0
35 Health services	4	0.4	2	0.3	0	0.0	2	0.3	2	0.5
36 Engineering services	38	3.6	26	3.7	1	2.3	28	3.8	9	2.3
37 Other services	10	0.9	6	0.9	0	0.0	7	0.9	3	0.8
Total	1061	100.0	695	100.0	44	100.0	741	100.0	390	100.0

Table A.4. Distribution of R&D, patents and software patents by industry

2.5 digit industry classes (1060 firms)

	R&D		**EP patents**		**EP software patents**		**US patents**		**US software patents**	
2.5 digit industry class	Mil EUR	%	n	%	n	%	n	%	n	%
01 Food & tobacco	24875	3.5	1752	2.5	0	0.0	3534	2.6	103	1.1
02 Textiles, apparel & footwear	658	0.1	103	0.1	0	0.0	175	0.1	4	0.0
03 Lumber & wood products	52	0.0	1	0.0	0	0.0	3	0.0	0	0.0
04 Furniture	2402	0.3	162	0.2	1	0.4	264	0.2	2	0.0
05 Paper & paper products	2170	0.3	444	0.6	0	0.0	477	0.3	12	0.1
06 Printing & publishing	1243	0.2	4	0.0	0	0.0	18	0.0	9	0.1
07 Chemical products	73977	10.5	10964	15.6	0	0.0	15701	11.5	262	2.8
08 Petroleum refining & prods	25109	3.6	1822	2.6	0	0.0	3610	2.6	165	1.8
09 Plastics & rubber prods	5515	0.8	1291	1.8	1	0.4	1115	0.8	54	0.6
10 Stone, clay & glass	5215	0.7	1627	2.3	0	0.0	2137	1.6	79	0.9
11 Primary metal products	2594	0.4	349	0.5	0	0.0	765	0.6	13	0.1
12 Fabricated metal products	2134	0.3	790	1.1	0	0.0	1824	1.3	44	0.5
13 Machinery & engines	16343	2.3	2984	4.2	0	0.0	4707	3.4	137	1.5
14 Computers & comp, equip,	3185	0.5	171	0.2	1	0.4	700	0.5	181	2.0
15 Electrical machinery	93255	13.2	19372	27.6	139	51.3	35529	25.9	2930	31.8
16 Electronic inst, & comm, eq,	93435	13.3	6605	9.4	33	12.2	26183	19.1	2657	28.8
17 Transportation equipment	22424	3.2	409	0.6	1	0.4	579	0.4	33	0.4
18 Motor vehicles	145932	20.7	8922	12.7	3	1.1	17272	12.6	1130	12.3
19 Optical & medical instruments	5580	0.8	670	1.0	17	6.3	1316	1.0	185	2.0
20 Pharmaceuticals	116961	16.6	4852	6.9	2	0.7	11501	8.4	404	4.4
21 Misc, manufacturing	1503	0.2	108	0.2	0	0.0	275	0.2	4	0.0
22 Soap & toiletries	8972	1.3	2532	3.6	0	0.0	2722	2.0	42	0.5
24 Computing software	9645	1.4	205	0.3	7	2.6	474	0.3	183	2.0
25 Telecommunications	16885	2.4	1089	1.6	65	24.0	1524	1.1	337	3.7
26 Wholesale trade	493	0.1	16	0.0	0	0.0	21	0.0	3	0.0
27 Business services	3701	0.5	28	0.0	1	0.4	94	0.1	18	0.2
29 Mining	1894	0.3	375	0.5	0	0.0	1012	0.7	14	0.2
30 Construction	2645	0.4	116	0.2	0	0.0	140	0.1	10	0.1
31 Transportation services	3697	0.5	1473	2.1	0	0.0	1690	1.2	46	0.5
32 Utilities	8445	1.2	719	1.0	0	0.0	1273	0.9	125	1.4
33 Trade	178	0.0	0	0.0	0	0.0	0	0.0	0	0.0
34 Fire, Insurance, Real Estate	10	0.0	0	0.0	0	0.0	0	0.0	0	0.0
35 Health services	217	0.0	54	0.1	0	0.0	60	0.0	2	0.0
36 Engineering services	2192	0.3	181	0.3	0	0.0	289	0.2	12	0.1
37 Other services	287	0.0	27	0.0	0	0.0	88	0.1	13	0.1
Overall	703823	100.0	70217	100.0	271	100.0	1E+05	100.0	9213	100.0

*This is the total over all years of the sample, in constant year 2000 euros.

Table A.5. Distribution of R&D expenditures by country and sector

		R&D expenditure in millions of euros						As a share of total expenditure				HTT sample relative to	
Country	**Year**	**Business Sector**	**Govt Sector**	**HEI Sector**	**Other**	**Total R&D**	**HTT sample**	**Business Sector**	**Govt Sector**	**HEI Sector**	**Other**	**Business sector**	**Total R&D**
Austria	2002	3131	266	1266	21	4684	65.1	66.8%	5.7%	27.0%	0.4%	2.1%	1.4%
Belgium	2000	3589	312	1005	58	4964	907.7	72.3%	6.3%	20.2%	1.2%	25.3%	18.3%
Bulgaria	2000	15	49	7	0	71	0.0	21.4%	68.6%	9.8%	0.2%	0.0%	0.0%
Switzerland	2000	5065	90	1566	132	6852	8794.5	73.9%	1.3%	22.9%	1.9%	173.7%	128.3%
Cyprus	2000	5	11	6	2	25	0.0	21.3%	46.6%	24.8%	7.3%	0.0%	0.0%
Czech Rep.	2000	446	188	106	4	744	0.0	60.0%	25.3%	14.2%	0.5%	0.0%	0.0%
Germany	2000	35600	6873	8146	0	50619	28094.8	70.3%	13.6%	16.1%	0.0%	78.9%	55.5%
Denmark	2000	2596	492	770	34	3892	979.8	66.7%	12.6%	19.8%	0.9%	37.7%	25.2%
Estonia	2000	8	9	19	1	37	1.0	22.5%	23.1%	52.4%	1.9%	11.4%	2.6%
Spain	2000	3069	905	1694	51	5719	0.0	53.7%	15.8%	29.6%	0.9%	0.0%	0.0%
Finland	2000	3136	468	789	30	4423	731.3	70.9%	10.6%	17.8%	0.7%	23.3%	16.5%
France	2000	19348	5361	5804	439	30954	14557.8	62.5%	17.3%	18.8%	1.4%	75.2%	47.0%
Greece	2001	278	188	383	3	852	55.1	32.7%	22.1%	44.9%	0.4%	19.8%	6.5%
Croatia	2002	115	60	95	0	271	50.5	42.7%	22.2%	35.1%	0.0%	43.8%	18.7%
Hungary	2000	180	106	97	23	405	35.4	44.3%	26.1%	24.0%	5.6%	19.7%	8.7%
Ireland	2000	842	96	238	0	1176	403.8	71.6%	8.1%	20.2%	0.0%	47.9%	34.3%
Iceland	2000	142	64	41	5	251	0.0	56.4%	25.5%	16.2%	1.9%	0.0%	0.0%
Italy	2000	6239	2356	3865	0	12460	37.0	50.1%	18.9%	31.0%	0.0%	0.6%	0.3%
Lithuania	2000	16	31	27	0	73	0.0	21.5%	41.9%	36.5%	0.0%	0.0%	0.0%
Luxembourg	2000	337	26	1	0	364	1.7	92.6%	7.1%	0.2%	0.0%	0.5%	0.5%
Latvia	2000	15	8	14	0	38	0.0	40.3%	22.1%	37.6%	0.0%	0.0%	0.0%
Malta	2002	3	2	7	0	12	0.0	24.7%	16.4%	58.8%	0.1%	0.0%	0.0%
Netherlands	2000	4458	974	2120	75	7626	8370.4	58.5%	12.8%	27.8%	1.0%	187.8%	109.8%
Norway	2001	1814	444	780	0	3037	321.3	59.7%	14.6%	25.7%	0.0%	17.7%	10.6%
Poland	2000	432	386	377	2	1197	10.1	36.1%	32.2%	31.5%	0.1%	2.3%	0.8%
Portugal	2000	258	222	348	100	927	0.0	27.8%	23.9%	37.5%	10.8%	0.0%	0.0%
Romania	2000	103	28	18	0	149	0.0	69.4%	18.8%	11.8%	0.0%	0.0%	0.0%
Russia	2000	2087	721	134	7	2948	0.0	70.8%	24.4%	4.5%	0.2%	0.0%	0.0%
Sweden	2001	8118	297	2085	10	10511	7119.9	77.2%	2.8%	19.8%	0.1%	87.7%	67.7%
Slovenia	2000	167	77	49	3	297	0.0	56.3%	25.9%	16.6%	1.2%	0.0%	0.0%
Slovakia	2000	94	35	14	0	143	0.0	65.8%	24.7%	9.5%	0.0%	0.0%	0.0%
Turkey	2000	464	86	839	0	1389	0.0	33.4%	6.2%	60.4%	0.0%	0.0%	0.0%
UK	2000	18884	3672	5985	529	29070	17214.8	65.0%	12.6%	20.6%	1.8%	91.2%	59.2%
Europe	2000	121054	24902	38694	1528	186177	87752.0	65.0%	13.4%	20.8%	0.8%	72.5%	47.1%
EU15	2000	109883	22508	34499	1351	168239	78539.2	65.3%	13.4%	20.5%	0.8%	71.5%	46.7%
EU25	2000	111365	23436	35233	1385	171417	78585.7	65.0%	13.7%	20.6%	0.8%	70.6%	45.8%
US	2000	216552	29926	33221	10218	289917	0.0	74.7%	10.3%	11.5%	3.5%	0.0%	0.0%
Japan	2000	109181	15217	22354	7108	153860	0.0	71.0%	9.9%	14.5%	4.6%	0.0%	0.0%

(Source: Eurostat and Stan, OECD, 2007)

Table B.1. Weights implied by estimated cumulative lag distributions for EPO patents

cited year	lag	CHEM	DRUG	ELEC	IND	MECH	OTHR	INST
2004	1	25.743	25.656	26.754	27.755	27.581	26.453	27.786
2003	2	12.613	12.574	12.629	12.828	12.723	12.374	12.970
2002	3	8.367	8.343	8.255	8.300	8.226	8.058	8.429
2001	4	6.272	6.255	6.146	6.148	6.092	5.992	6.255
2000	5	5.023	5.010	4.906	4.894	4.849	4.783	4.983
1999	6	4.194	4.184	4.090	4.073	4.037	3.989	4.148
1998	7	3.604	3.596	3.513	3.495	3.465	3.428	3.558
1997	8	3.162	3.155	3.082	3.065	3.039	3.011	3.118
1996	9	2.819	2.814	2.749	2.733	2.711	2.688	2.779
1995	10	2.545	2.540	2.484	2.469	2.450	2.431	2.509
1994	11	2.322	2.317	2.268	2.254	2.238	2.222	2.288
1993	12	2.135	2.131	2.088	2.075	2.061	2.048	2.105
1992	13	1.977	1.974	1.936	1.925	1.913	1.902	1.951
1991	14	1.842	1.840	1.806	1.796	1.786	1.776	1.819
1990	15	1.726	1.723	1.694	1.685	1.676	1.668	1.705
1989	16	1.623	1.621	1.596	1.588	1.580	1.573	1.605
1988	17	1.533	1.531	1.509	1.502	1.496	1.490	1.517
1987	18	1.453	1.452	1.433	1.427	1.421	1.416	1.439
1986	19	1.381	1.380	1.364	1.359	1.354	1.350	1.370
1985	20	1.317	1.316	1.302	1.298	1.294	1.291	1.307
1984	21	1.259	1.258	1.247	1.243	1.240	1.237	1.250
1983	22	1.206	1.205	1.196	1.193	1.191	1.188	1.199
1982	23	1.157	1.157	1.150	1.148	1.146	1.144	1.152
1981	24	1.113	1.113	1.108	1.106	1.105	1.103	1.109
1980	25	1.072	1.072	1.069	1.068	1.067	1.066	1.070
1979	26	1.035	1.035	1.033	1.033	1.032	1.032	1.034
1978	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B.2. Weights implied by estimated cumulative lag distribution for US patents

cited year	lag	CHEM	DRUG	ELEC	IND	MECH	OTHR	INST
2004	1	31.692	36.501	28.857	33.062	27.891	33.167	33.167
2003	2	13.617	15.548	13.224	13.977	12.151	14.284	14.284
2002	3	8.454	9.580	8.516	8.584	7.623	8.874	8.874
2001	4	6.114	6.882	6.288	6.165	5.558	6.415	6.415
2000	5	4.799	5.368	4.995	4.816	4.392	5.030	5.030
1999	6	3.961	4.404	4.150	3.963	3.647	4.145	4.145
1998	7	3.381	3.739	3.555	3.376	3.130	3.533	3.533
1997	8	2.957	3.252	3.114	2.949	2.751	3.084	3.084
1996	9	2.634	2.880	2.774	2.624	2.461	2.741	2.741
1995	10	2.379	2.587	2.503	2.368	2.233	2.470	2.470
1994	11	2.172	2.350	2.283	2.162	2.048	2.251	2.251
1993	12	2.002	2.155	2.100	1.993	1.896	2.070	2.070
1992	13	1.860	1.991	1.946	1.851	1.768	1.918	1.918
1991	14	1.738	1.852	1.814	1.730	1.659	1.789	1.789
1990	15	1.634	1.732	1.701	1.626	1.565	1.678	1.678
1989	16	1.543	1.627	1.601	1.536	1.484	1.581	1.581
1988	17	1.463	1.535	1.514	1.457	1.413	1.496	1.496
1987	18	1.393	1.454	1.436	1.387	1.349	1.420	1.420
1986	19	1.330	1.382	1.367	1.325	1.293	1.353	1.353
1985	20	1.273	1.317	1.305	1.270	1.243	1.293	1.293
1984	21	1.223	1.258	1.249	1.219	1.198	1.239	1.239
1983	22	1.177	1.205	1.198	1.174	1.157	1.190	1.190
1982	23	1.135	1.157	1.151	1.133	1.120	1.145	1.145
1981	24	1.097	1.112	1.109	1.095	1.086	1.104	1.104
1980	25	1.062	1.072	1.069	1.061	1.055	1.066	1.066
1979	26	1.030	1.035	1.033	1.029	1.026	1.032	1.032
1978	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000

An Empirical Analysis of Patent Litigation in the Semiconductor Industry

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January 2007

Abstract[*]

Semiconductor firms sell products that embed hundreds if not thousands of patented inventions, elevating concerns about patent-related hold-up in this sector. This paper examines the incidence and nature of patent lawsuits involving 136 dedicated U.S. semiconductor firms between 1973 and 2001. By supplementing patent litigation data with information drawn from archival sources, we estimate the probability that firms will be involved in patent lawsuits, either as enforcers of exclusionary rights or as targets of litigation filed by other patent owners. We further distinguish between disputes that involve product-market rivals and those that do not. Overall, we find little evidence that semiconductor firms have adopted a more aggressive stance towards patent enforcement since the 1970s, despite the effective strengthening of U.S. patent rights in the 1980s and widespread entry by small firms. In fact, their litigation rate as *enforcers* of patents remains relatively stable over the past two decades once we control for factors such as the number of patents they own and changes in R&D spending. In striking contrast, we find an escalation in their baseline risk as *targets* of litigation brought by outside patent owners.

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[*] Preliminary version prepared for the 2007 American Economic Association annual meeting, Chicago, IL, 4-7 January. We thank the STEP Board of the National Research Council and the General Electric Innovation Fund of the Wharton School's Reginald H. Jones Center for Management Policy, Strategy and Innovation for grants used to purchase and compile data for this research. Matt Daniels, Faria Jabbar, Owen Smith, Leslie Schafer and Yelena Slutskaya provided exceptional research assistance.

An Empirical Analysis of Patent Litigation in the Semiconductor Industry

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1. Introduction

The U.S. patent system is under fire. Record numbers of patents are being awarded in areas ranging from semiconductors and computer software to business methods and gene sequences, raising concerns about the costs and feasibility of navigating through overlapping claims in these areas (Shapiro, 2001). At the same time, the past two decades have witnessed a noticeable rise in patent litigation (Merz and Pace, 1994; Landes and Posner, 2003) as well as an escalation in the costs associated with patent enforcement (AIPLA, 2005). Calling for reform, legal scholars and economists are questioning whether the direct and indirect costs associated with obtaining and enforcing US patent rights are imposing an implicit tax on innovation in vital segments of the economy (e.g., Barton, 2000; Jaffe & Lerner, 2004).

If there is an “innovation tax” arising from patents, it is expected to be especially salient in sectors where products are complex and combine many patentable technologies that may be owned by a number of different parties. As suggested by a number of researchers (e.g., see Grindley and Teece 1997) and as shown by Arora et al. (2003), Information and Communication Technology (ICT) sectors, including semiconductors, are likely to fall in this class of sectors. Such firms typically require access to a “thicket” of external intellectual property to advance technology or to legally manufacture and sell products, elevating concerns about patent-related hold-up problems. According to an estimate from Intel, for example, by 2002 over 90,000 US patents related to central processing unit technologies had been awarded to more than 10,000 firms, universities, government labs, and independent inventors (Detkin 2002).

In prior studies, we examined the effects of a "pro-patent" shift in U.S. policy attributed to the 1982 formation of the Court of Appeals for the Federal Circuit (CAFC) on the innovative activities of firms in this sector (Hall and Ziedonis, 2001; Ziedonis 2004). On one hand, evidence from our prior study suggests that the patent reforms led capital-intensive firms in this sector to "ramp up" their patent portfolios more aggressively—largely to reduce litigation risks and to improve their bargaining positions in negotiations with external patent owners.[1] On the other hand, the strengthening of U.S. patent rights in the 1980s also may have facilitated entry into the industry by firms specializing in chip design. Interviews with representatives from design firms suggest that these firms (often relatively small in size) enforce their patent rights quite aggressively in court, primarily to establish proprietary rights in niche product markets (Hall and Ziedonis, 2001). In line with this view, Ziedonis (2003) finds that chip design firms enforce roughly 4 out of every 100 patents they own—a patent enforcement rate comparable to that reported in Lerner (1995) in the context of specialized biotechnology firms but somewhat lower than that reported in Lerner (2006) for financial sector patents.

In this paper, we examine factors that affect the probability that dedicated semiconductor firms will be involved in patent litigation—either as enforcers of exclusionary rights or as targets of litigation filed by other patent owners. We also explore the extent to which the incidence and

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[1] Similarly, Cohen et al. (2000) report that the most prominent motives for patenting in technologically "complex" industries (including semiconductors) include the prevention of lawsuits and use of patents in license negotiations. Hall (2005) shows an escalation in the patent propensities of ICT firms more generally following the 1980s patent reforms.

nature of patent-related disputes in this sector changed following the CAFC's formation. We start with a sample of "potential litigants" that includes an unbalanced panel of 136 publicly traded U.S. firms that compete primarily in semiconductor-related product markets. As Lanjouw and Schankerman (2001) show, the main database used in patent litigation studies (Litalert by Derwent) has an under-reporting bias that is more pronounced prior to the mid-1980s. Because we want to capture patterns of litigation involving firms in our sample prior to the CAFC's establishment, we supplement Litalert data with information drawn from archival 10-K filings, news articles, trade journals such as the EETimes, and company press releases. In total, we identify over 500 patent lawsuits involving sample firms between 1973 and 2001. Not all firms are involved in patent-related litigation. Roughly 67% of the sample encounters one or more patent lawsuits during this three-decade period while the remainder of the sample does not. In 2000, sample firms collectively generated over $88 billion in revenues, spent $12 billion in R&D, and owned roughly 31,000 US patents.

With the exception of Lerner (1995) and Bessen and Meurer (2006), prior studies have estimated patent-related "litigation risk" primarily using matched pairs of litigated and non-litigated patents (e.g., Lanjouw and Schankerman, 2001; Somaya, 2003; Allison et al., 2004; Lerner, 2006). We prefer to estimate litigation probabilities at the level of firms rather than patents for several reasons. First, interpreting patent-level litigation risk is quite difficult within the information technology sector. If the number of patents firms file is causally related to litigation risk, as suggested above, it is unclear whether a reduction in lawsuits filed per patent reflects diminished or heightened concerns of patent hold-up. In addition, a firm-level analysis allows exploration of the relationship between litigation probability and patent portfolio size and characteristics, which is desirable given the importance of overall firm patent strategy in this context.

Shifting attention to litigation probabilities of firms also enables us to examine the role that different firms play in disputes over patents, while controlling for firm-level characteristics such as R&D spending, size, and patent propensity. Consistent with Bessen and Meurer (2006), we characterize a firm as a “patentee litigant” when they enforce patents against others and as a “target” when other parties assert patent rights against them. Our study differs from Bessen and Meurer’s cross-industry analyses, however, in that we observe “pre-CAFC” litigation. We also draw on industry-specific data to assess the relationships between litigants in semiconductor-related product markets in the years of dispute.

Overall, we find little evidence that semiconductor firms have adopted a more aggressive stance towards patent enforcement since the 1970s, despite the effective strengthening of U.S. patent rights in the mid-1980s and widespread entry by specialized firms. In fact, their litigation rate as *enforcers* of patents remains relatively stable over the past two decades once we control for factors such as the number of patents they own and changes in R&D spending. In striking contrast, we find an escalation in their baseline risk as *targets* of litigation brought by outside patent owners. While the majority of lawsuits launched against sample firms are made by rivals in semiconductor product markets, our estimates suggest that the probability that these firms will be sued by non-rivals nonetheless has increased over the past decade.

The remainder of this paper is organized as follows. In Section 2, we briefly discuss the changing U.S. patent landscape during the 1980s and its implications for patent enforcement within the semiconductor industry. Section 3 presents our data sources, summary statistics and methodology. Results are given in Section 4, which is followed by a discussion of the limitations of this study and the extensions we envision.

2. *The Changing Patent Landscape*[2]

The patent system has long been recognized as an important policy instrument used to promote innovation and technological progress. Two fundamental mechanisms underpin the system. First, an inventor discloses to the public a “novel”, “useful”, and “nonobvious” invention. In return, the inventor receives the right to exclude others from using that patented invention for a fixed period of time (20 years from the date of patent application in the United States). By providing exclusionary rights for some period of time and a more conducive environment in which to recoup R&D investments, the patent system aims to encourage inventors to direct more of their resources toward R&D than would otherwise be the case. At the same time, detailed information about the invention is disclosed to the public when the patent application is published.

The creation of the Court of Appeals for the Federal Circuit in 1982 is often credited with ushering in an era that generally afforded stronger legal protection for patent owners in the United States (Jaffe, 2000). Although the driving force behind the legal reform was a need to unify U.S. patent doctrine, the CAFC put in place a number of procedural and substantive rules that collectively favored patent owners. For example, the new court increased the evidentiary standards required to invalidate patents (Lerner, 1995; Henry and Turner, 2006), was more willing to halt allegedly infringing actions early in the dispute by granting preliminary

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[2] This section is drawn from Ziedonis (2003).

injunctions (Lanjouw and Lerner, 2001), and was more willing to sustain large damage awards (Merges, 1997).

Not surprisingly, the use and importance of U.S. patents in semiconductors was affected by this changing landscape. By the early 1980s, a broad range of semiconductor technologies had diffused widely across the industry (Levin, 1982). Due to consent decrees with U.S. antitrust authorities signed in the 1950s, the "technological giants" in semiconductor production, largely IBM and AT&T, were effectively curtailed from enforcing patent rights against rival firms throughout the 1960s and 1970s. Instead, IBM & AT&T instituted liberal licensing policies that are widely credited with the rapid growth and pace of innovation in the early phase of the industry's development (Levin, 1982). Nonetheless, Tilton (1971, p. 76) concludes:

> "Certainly, the great probability that other firms were going to use the new technology with or without licenses is another reason for the liberal licensing policy. Secrecy is hard to maintain in the semiconductor field because of the great mobility of scientists and engineers and their desire to publish. Moreover, semiconductor firms, particularly the new, small ones, have demonstrated over and over again their disposition to infringe on patents."

Although cross-licensing remains an important mechanism with which firms trade access to one another's patents within the industry, the terms of these agreements changed (not surprisingly) during the "pro-patent" regime. Firms with large patent portfolios, such as Texas Instruments, IBM, and AT&T, adopted a more aggressive licensing strategy to profit directly from their patent portfolios—both by seeking licenses from a larger number of firms and by increasing royalty rates on use of their inventions. For example, Texas Instruments launched an aggressive patent licensing program in the mid-1980s, initially against Japanese competitors in markets for memory chips, earning more than $2 billion from licensing rights to its semiconductor patents between 1986 and 1993 (Grindley and Teece, 1997). Similarly, IBM's revenues from patent licensing increased from $646 million in 1995 to over $1.5 billion by 2000 (Ziedonis, 2003).

Recent controversy regarding patent hold-up problems in the industry centers on the licensing and litigation activities of so-called "patent trolls". While definitions vary, "trolls" are generally defined as individuals or patent holding companies that obtain patents of dubious merit and then use lawsuits to extract settlements, sometimes long after technologies have become standard or widely adopted within an industry (FTC, 2003). The recent conflict between Research-in-Motion (RIM), the maker of Blackberry hand-held devices, and NTP Inc, a patent holding company, represents a well-publicized example. After four years of legal wrangling and faced with a possible halt in sales on the U.S. market, Research-in-Motion paid NTP more than $600 million to settle its claims of patent infringement.[3] Lerner (2006) finds partial support for this "trolls hypothesis" in a recent study of litigated patents related to financial products and services: While litigated patents are disproportionately those awarded to individuals and small, private entities, they are not necessarily "low quality" as measured by citations-based indicators. Below, we define "trolls" quite broadly as entities that sue focal companies in our sample but that do not compete in semiconductor-related product markets in the year of the dispute.

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[3] This settlement occurred in spite of the fact that 4 of the 5 patents held by NTP had already been rejected under a preliminary re-examination at the USPTO. Of these four, one had already received a final rejection under re-exam at the time of the settlement. Nonetheless, the Court refused to delay the case until the remainder decisions were final, so RIM was forced to settle. This case illustrates the extent to which assertion of even doubtful patents can be successful.

3. Data and sample statistics

Our data come from several different sources: Standard and Poor's Compustat for firm level balance sheet and income statement data, Derwent for patent data, and Derwent and additional sources, including news stories and press releases, for patent litigation data. The sample of firms with which we began was updated from that used in Hall and Ziedonis (2001) and Ziedonis (2003): it consists of 136 specialized U.S. semiconductor firms that are engaged in the manufacturing and/or design of semiconductor products and were observed during the years 1973-2001. We updated the financial and patent data for these firms through 2003 and augmented the 287 patent litigation cases used in Ziedonis (2003) with an additional 148 cases gleaned from Derwent and various press sources. The appendix provides more information about construction of the data.

In this paper, we restrict the years analyzed to 1973-2001, so that the panel eventually analyzed consists of 136 firms observed for periods of 1 to 29 years. 12 firms are there for the entire period, but almost half the firms are observed for periods of 10 years or less, reflecting the relatively young age of the sector.[4] Figures 1 and 2 show the trends in patenting by these firms. Because of the omission of large players such as IBM and the Japanese manufacturers, our sample accounts for a relative small share of total patenting in semiconductor technologies (about 20 per cent in the later years). However Figure 2 shows that they are indeed specialized in electronics and to a lesser extent in semiconductor technologies. Patenting by our firms began

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[4] The 12 survivors include the largest firms: AMD, Analog Devices, Diodes Inc, Intel, Intl Rectifier, Natl Semiconductor, Semtech, Siliconix, Solitron Devices, Standard Microsystems, Texas Instruments, and White Electronic Designs. In 1982, the year of the CAFC's establishment, there were 41 firms in the sample.

growing first in 1984, as suggested by the analysis in Hall and Ziedonis (2001), and shifted into high gear in the mid-1990s. The median number of patents granted per employee was less than one until the mid-1980s and rose steadily to about eight by 2000-2001.

To study the questions raised in the introduction to this paper, we classified the case filings into those where the firm held the patent being litigated (either was a plaintiff in an infringement suit or a defendant in a validity suit) and those where the firm was a target in patent litigation (the opposite two situations). As the appendix makes clear, there are a number of complications such as ownership changes that arise in making these classifications, and many of them were therefore hand-coded based on litigation histories. We then further classified the litigation where the firm was a target into those where the opponent was a rival in the product market and those where the opponent was non-rival. Table 1 presents a summary of the number of cases that fell into each category and Figures 3 and 4 give an indication of the trends. It is important to understand the distinction between the first two columns of Table 1: the first column gives the total number of disputes involving at least one of our sample firms, whereas the second column is the total number of times that our firms appear in disputes. The difference is due to disputes *between* two firms in our sample; because our analysis is firm-level, these disputes will appear twice in the analysis.

Figure 3 shows that litigation has risen along with the increase in patenting, and also that there has been a substantial increase in suits involving non-rival entities during the past ten years, supporting the claims of some in the industry (FTC, 2003). Figure 4 shows how litigation probability for our firms has changed over time. As suggested by interviews reported in Hall and Ziedonis (2001), the overall probability of litigation on a per-patent basis rose steeply after the creation of the CAFC and the strengthening of patent enforcement that followed. However, it then falls again to the pre-1982 level, possibly because of the success of the defensive portfolio strategy in reducing litigation between rivals.

Table 2 reports summary statistics for firms in our sample, broken down into two groups: those with manufacturing facilities and firms that specialize in the design but not the fabrication of semiconductor devices. The latter group is generally considerably smaller and younger but has much higher R&D and patent stock per employee. Surprisingly, they are also more capital intensive, where capital is measured as the net book value of property, plant and equipment. This may reflect the relative lower level of employment in these firms. In both groups, the firms involved in patent litigation are much larger than the others, as well as being more R&D and patent-intensive. Interestingly, firms that litigate their own patents or are the target of patentholders that are also product market rivals are very similar to each other, whereas the targets of non-rival firms are much larger, as well as more capital, R&D, and patent intensive. This fact suggests that the motives of the non-rival firms may be related to a desire to target firms with deep pockets. It could also suggest, however, that firms where sunk costs are large and therefore hold-up is more costly may be more likely to settle than to fight a dispute.

4. Methodology and main results

To explore the changes in litigation trends and their determinants further, we estimated a series of probit regressions that predict whether or not a firm is involved in a particular type of patent litigation in any year as a function of its characteristics.[5] The model is the following:

$$\Pr(patentlitigation \mid X_{it}) = \Phi(X_{it}\beta) \qquad (1.1)$$

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[5] We also experimented with an ordered probit regression where the dependent variable was the number of cases initiated in a year. The results were qualitatively similar to those from the simpler probit regression.

where *i* indexes firms and *t* indexes years. $\Phi(.)$ denotes the standard normal distribution. In the tables we show average of the derivative of this probability with respect to each right hand side variable X^j which is implied by the estimates:

$$\frac{\partial \Pr(patentlitigation \mid X_{it})}{\partial X_{it}^{j}} = \beta_j \varphi(X_{it}\beta) \tag{1.2}$$

The firm characteristics *X* that we include in the estimation equation are the following:

Whether or not the firm specializes in design – the raw data suggested that such firms were more likely to be involved in litigation, possibly because their intangible knowledge assets are more central to their value-creation strategies (see also, Ziedonis 2003). In contrast, manufacturers are able to rely on sunk capital costs to protect themselves from entry (although not from hold-up).

Size of the firm - log of the number of employees. Clearly larger firms are more likely to be involved in more suits, simply by reason of their size.

Capital intensity of the firm – log of the ratio of net plant and equipment to the number of employees. Our earlier work found that this was an important predictor of patenting post-1984, due to the fear of hold-up of these assets in litigation. Thus it is unclear how this variable will enter an equation that predicts the probability of being involved in litigation. If the patent portfolio race strategy is successful, we might expect that this variable would be negatively correlated with the probability of being involved in litigation.

R&D intensity of the firm – log of the ratio of current R&D spending to employees. This is a measure of the importance of knowledge assets to the firm that is independent of whether or not they have patents attached to them.

Patent yield of the firm – log of the ratio of a patent stock (annual patent grants by application date, cumulated to a stock using the usual 15% depreciation rate) to R&D spending. This measure captures the relative importance of patents in the firm's strategy and the success of their R&D program. We also included a dummy for those firms with no patents, but it was never significant.

Texas Instruments – a separate dummy was included for this firm. Our earlier work found that TI was an important first mover in patent litigation and in the patent portfolio race in this sector, and so we allowed a separate mean for TI's litigation probability.

Year effects – six dummies for five-year periods (1973-77, 1978-82, 1983-87, 1988-92, 1993-97, 1998-2001). We grouped the years for greater precision in the estimates because of the volatility shown in the individual data years that is visible in Figure 3.

Table 3 shows the results of the probability estimation using three different definitions of the dependent variable: 1) whether or not the firm had a new case involving patent litigation filed in that year; 2) whether or not the firm was either the defendant in an infringement suit or the plaintiff in a validity suit (that is, the firm was a target); 3) whether or not the firm was either a plaintiff in an infringement suit or the defendant in a validity suit (that is, the firm had a patent litigated). All the regressions have reasonable explanatory power, with R-squares above 0.2. Design firms are about 6 per cent more likely to be involved in patent litigation, other things equal; the increase in probability is equally split between being a target and being a litigant. Doubling a firm's size also increases its probability of involvement by about 6 per cent, again more often as a target. Texas Instruments is 4 per cent less likely to be involved in patent litigation, but that is entirely due to the fact that it is less likely to be a target.

An interesting result is that although capital intensity helps to predict patent litigation (regressions not shown), it is highly correlated with R&D intensity in the sample. Once we include R&D intensity, the capital intensity effect vanishes. Recall that capital intensity does predict patenting, other things equal. Performing R&D and having patents both increase the probability of patent litigation. Controlling for R&D, having more patents per R&D dollar increases the probability slightly, but the effect comes entirely from the increased probability of litigating patents, which is not surprising. On the other hand, doing R&D increases the probability of being a target, whereas patenting intensity has a very weak impact on being a target. Thus even though capital-intensive firms are engaging in patent portfolio races and are therefore no more likely to be involved in patent litigation than other firms, there is still a very small residual positive effect of having a portfolio on being a target.

Table 4 breaks things down even further and examines the impact of firm characteristics on the probability of being the target of rival or non-rival entities. The definition of a rival entity is one that has integrated circuit sales during the year in question according to ICE (1976-2002). The results for rivals are basically the same as those for all targets (litigation with rivals is about two thirds of all patent litigation where the firm is a target). However, nothing other than firm size and (to a lesser extent) R&D intensity predicts non-rival litigation. A firm that doubles in size is predicted to experience a one per cent increase in litigation probability from non-rival entities. Our firms range in size from about 5 employees to 90,000, with an interquartile range of 146 to 1300. This implies that a firm which moves from the first quartile to the third quartile of size experiences an increase in non-rival litigation probability of 10 per cent, which is not insignificant. However, it is dwarfed by the increase in rival litigation probability (about 30 per cent).

Turning to the year effects, we note that they show a substantial increase in the probability of being a target of litigation in any one year, even controlling for changes in firm characteristics, but no corresponding increase in the probability of litigating one's own patents. Figures 5 and 6 show the time trends from the probability regression that controls for firm characteristics. The increase in the probability that a firm is involved in litigation is almost entirely due to the increased probability that it will be a target. From Figure 6 we can see that the increase in target probability is driven by rival litigation until the 1997/1998 period. The final period in this figure suggests that the increase in target probability is being increasingly driven by increases in non-rival litigation. We are in the process of exploring these results further in order to more fully characterize rivals and non-rivals, because many of the putative rivals appear to be firms that are in the process of exiting semiconductor product markets.

5. Discussion and conclusions

Semiconductor firms sell products that embed hundreds if not thousands of patented inventions, elevating concerns about patent-related hold-up in this sector. This paper examines the incidence and nature of patent lawsuits involving 136 firms in the semiconductor industry between 1973 and 2001. By supplementing patent litigation data with information drawn from archival sources, we estimate the probability that firms will be involved in patent lawsuits, either as enforcers of exclusionary rights or as targets of litigation filed by other patent owners. We further distinguish between disputes that involve product-market rivals and those that do not.

Overall, we find little evidence that dedicated US. semiconductor firms adopted a more aggressive stance towards patent enforcement since the 1970s, despite the effective strengthening of U.S. patent rights in the mid-1980s and widespread entry by small firms. In fact, their litigation rate as *enforcers* of patents remains relatively stable over the past two decades once we control for factors such as the number of patents they own and changes in R&D spending. In sharp contrast, we find an escalation in their baseline risk as *targets* of litigation brought by outside patent owners. Despite widespread concerns about lawsuits filed by “trolls”, or non-producing entities, we find that the increased probability that semiconductor firms will be a target of litigation during the “pro-patent” era is primarily due to lawsuits filed by other firms competing in semiconductor-related product markets. We do, however, observe a noticeable increase in “non-rival” disputes filed against these firms since the mid-1990s.

It is interesting to compare our results with those of Bessen and Meurer (2006), who use a much larger sample of patent litigation suits in all sectors (~16,500 suits filed 1984-2000) drawn from Derwent. For comparability to their specifications we computed logit and Poisson regressions (where the dependent variable is the number of suits in a year) using our data.[6] Where they can be compared, our results are not that different from theirs. We found that the probability of being a target goes up somewhat more rapidly with size and R&D intensity for semiconductor firms than for firms as a whole. In these characteristics the semiconductor firms were somewhat between the Chemical/pharmaceutical (henceforth chemicals) sector and the “thickets” industries sector in Bessen and Meurer, although the differences are probably not significant. The one major difference is that capital intensity does not depress the litigation probability the way it does in the chemicals sector, a result which is consistent with the idea that the holdup threat is greater for capital intensive firms.

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[6] These regressions are not shown, but they are available from the authors on request.

The probability of litigating one's own patents also goes up somewhat more rapidly with size and R&D intensity, with the result again lying somewhere between that for chemicals and thicket industries. For the chemicals sectors, Bessen and Maurer found that capital intensity significantly depressed patent litigation probabilities and R&D intensity significantly increased them, whereas neither had an effect on the probability of initiating a suit in thickets industries. In our Poisson regression, we found that the latter was true for semiconductor firms, although in the logit regression R&D intensity had a small positive impact. The conclusion is that semiconductor firms behave like other firms in thickets industries with respect to their own litigation, but compared to other thickets industries, as targets their size and their large sunk technology costs make them look more like firms in chemicals.

This is a preliminary version of the paper and it raises a number of questions. Perhaps most importantly, a closer examination of the rivals who target our sample firms with patent litigation reveals that many of them are not true "rivals," but instead are firms that are in the process of exiting the industry in one way or another.[7] For example, long after struggling in computer and semiconductor-related product markets, Wang Laboratories launched an aggressive patent enforcement campaign against dedicated semiconductor producers prior to filing bankruptcy in 1992. Since our data sources report internal chip production for Wang in the focal litigation years, we treat the dispute as one between "rivals" when in fact Wang's threat as a viable competitor in the related product markets had long eroded. Unisys and its enforcement of patented encryption technologies is a related example. This suggests that a more nuanced

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[7] This idea is supported by the probability regressions, where missing or low q is a strong predictor of the probability of litigating a patent, other things equal. In a revised version of this paper we will explore this result more fully.

description of the litigants may be appropriate, using the actual level and rate of change of IC sales, and possibly more information on their patent portfolio composition.

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Figure 1

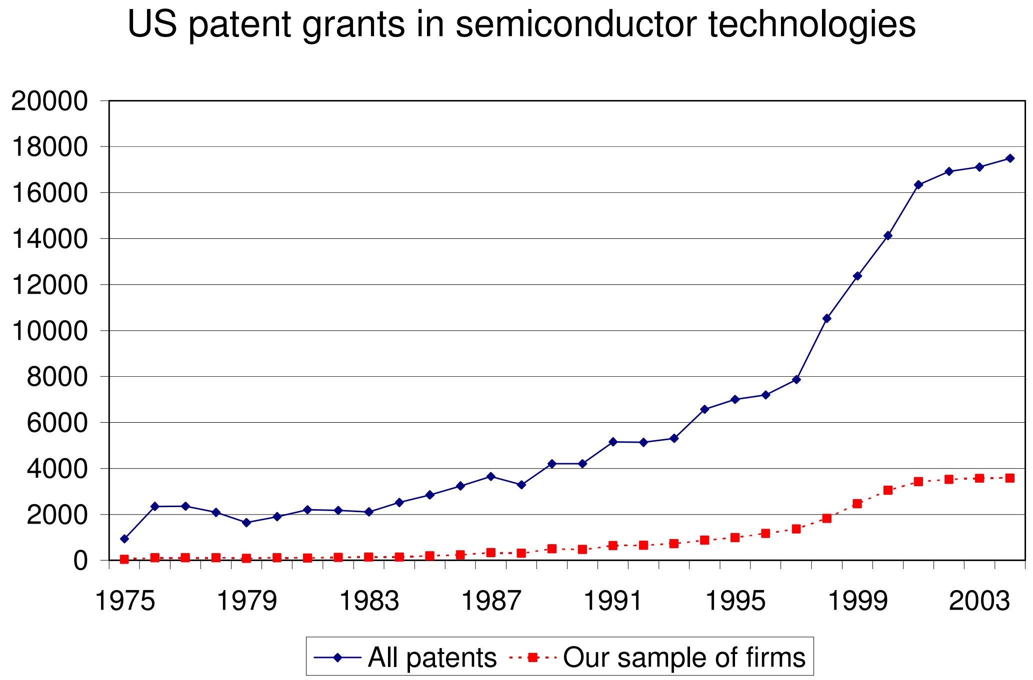

Figure 2

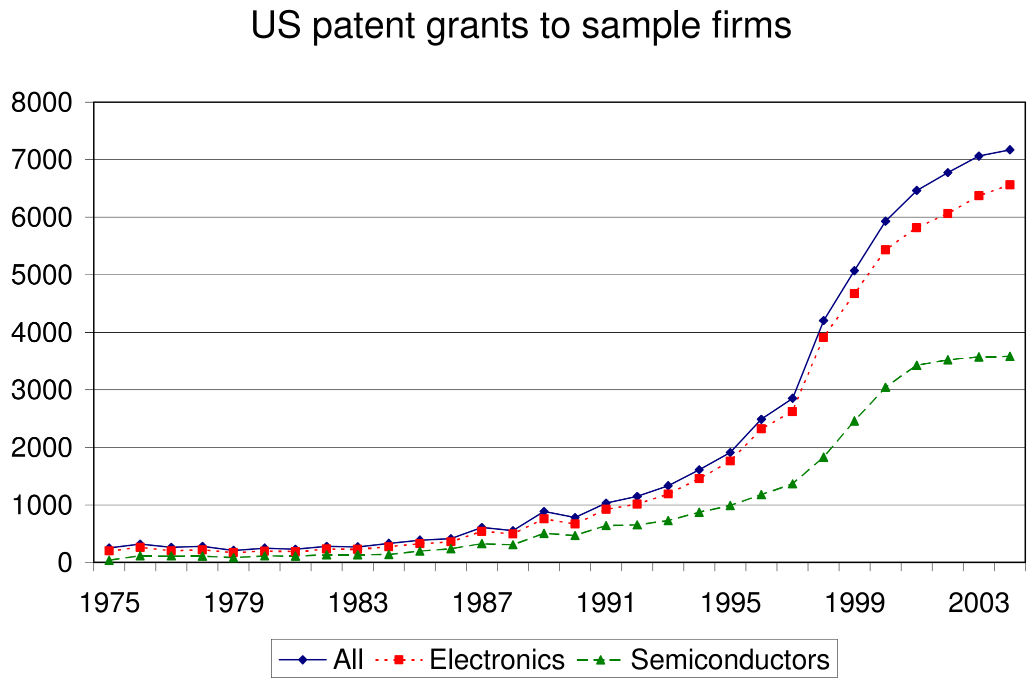

Figure 3

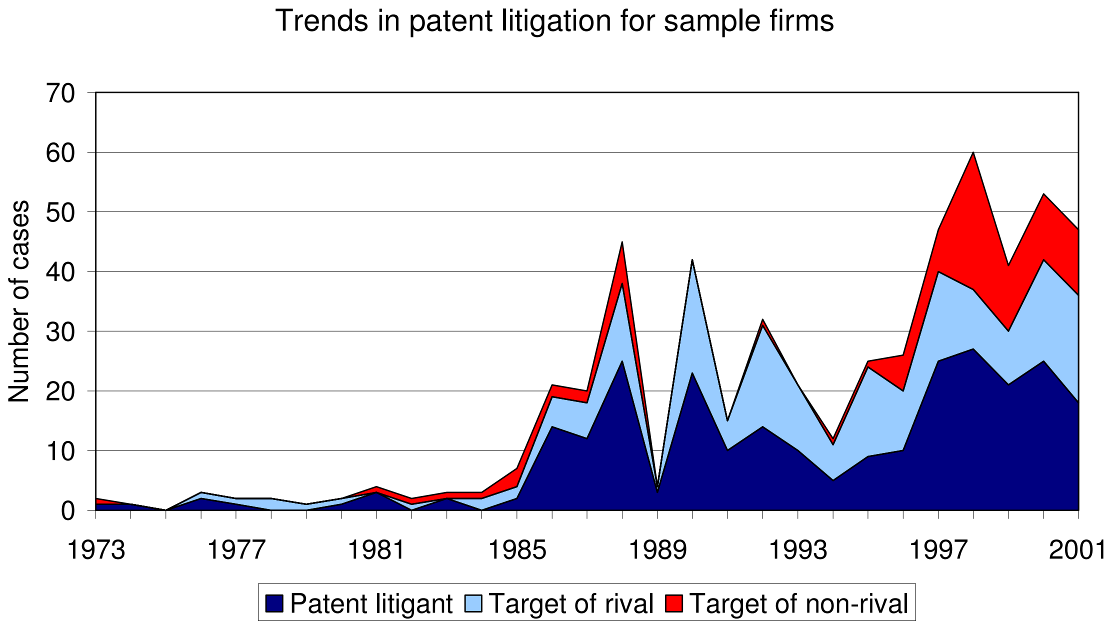

Figure 4

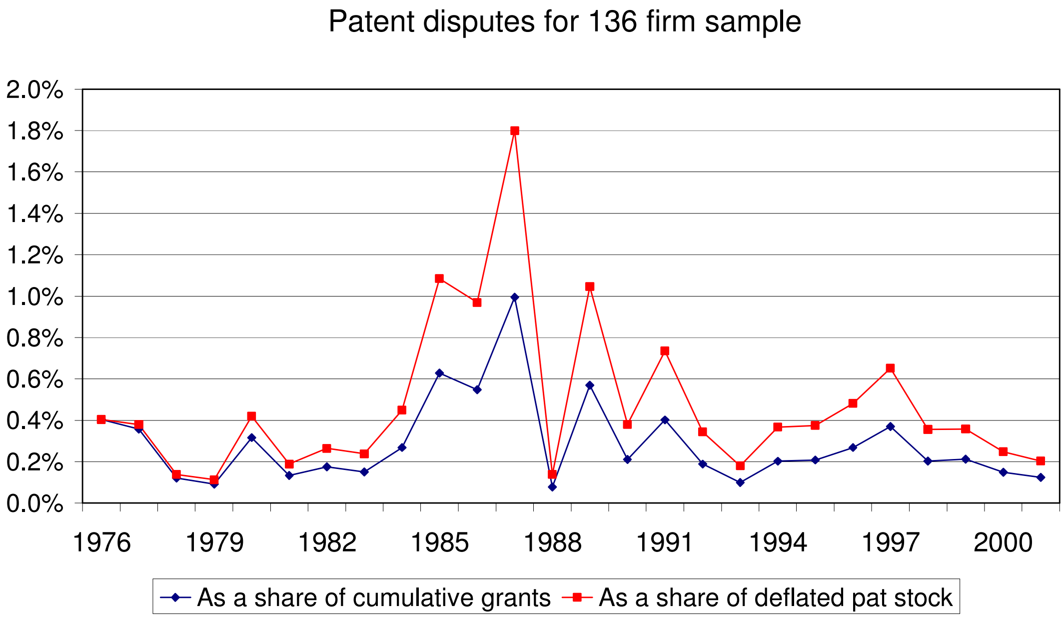

Figure 5

Relative probability of litigation over time, controlling for firm size, type, capital, R&D, and patent stock (136 semiconductor firms)

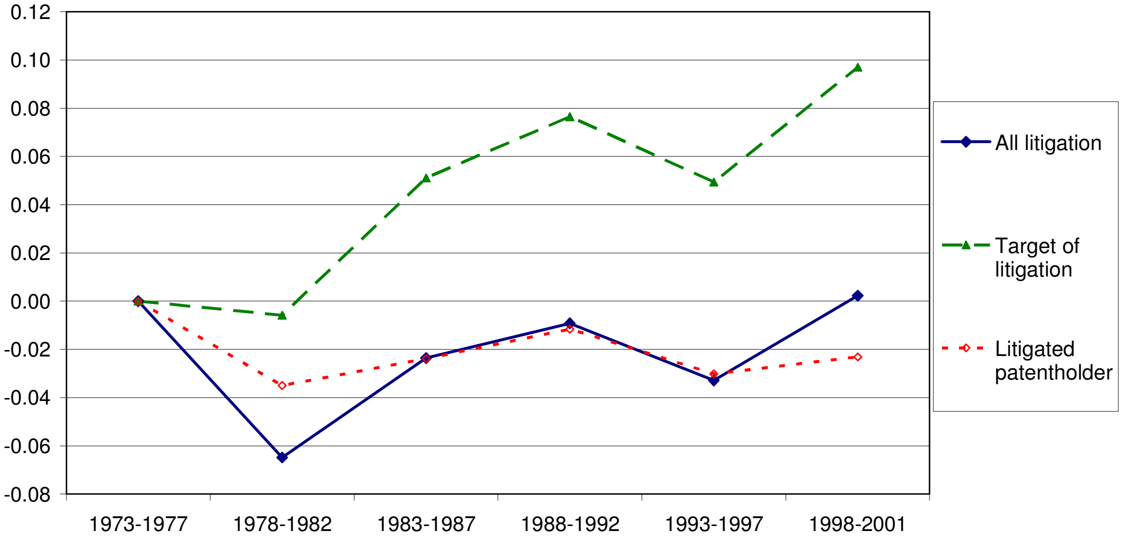

Figure 6

Relative probability of litigation over time, controlling for firm size, type, capital, R&D, and patent stock (136 semiconductor firms)

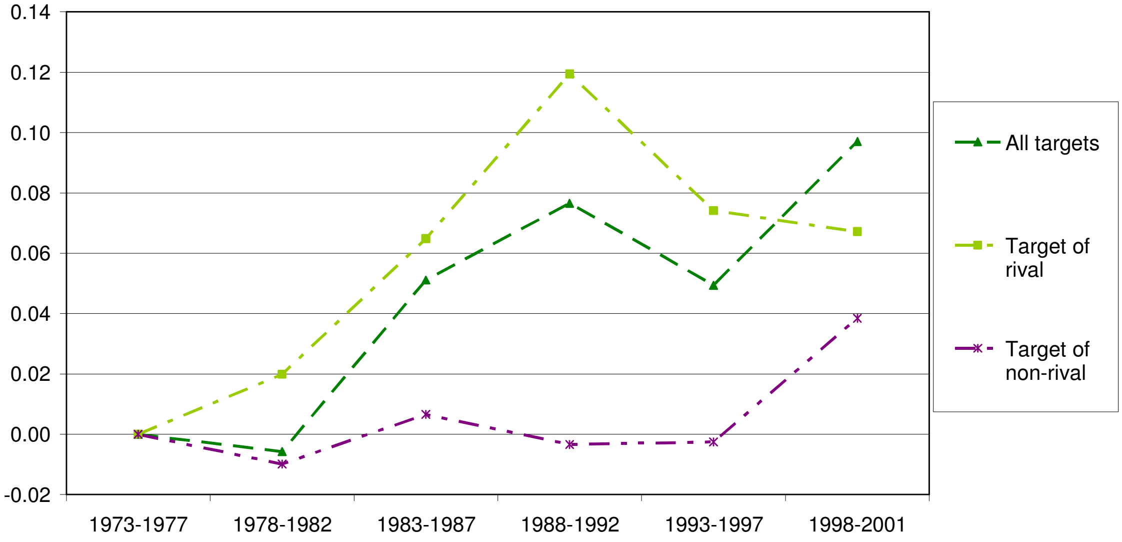

Table 1
Patent case filings for 136 semiconductor firms

Period	Total disputes	Total number in which appear	As patent litigant	As target	As target of rival	As target of non-rival
1973-1982	17	19	9	10	7	3
1983-1992	140	192	105	87	70	17
1993-2001	278	336	150	182	111	71
All years	435	547	264	279	188	91

Data for a population of 136 U.S. specialized semiconductor firms

All cases involve one or more patents. If patents are held by a sample firm, case is classified as patent litigant. If held by the opponent, they are classified as target cases. Note that some cases appear twice if they are between two firms in our sample; this is indicated by the difference between column 1 and 2.

Table 2
Sample Medians: 136 U.S. Semiconductor Firms (1973-2001)
(1819 firm-year observations)

	All	Litigants	Non-Litigants	Targets	Litigated patentholders	Targets of rivals	Targets of non-rivals
Panel A: Manufacturers (n = 84)							
Observations	1344	189	1152	136	97	93	55
Year founded	1969	1969	1968	1969	1969	1969	1969
Employment	577.5	3750	468	4418	4300	3690	7200
Capital per employee	$24,090	$61,226	$20,401	$66,325	$60,151	$60,027	$93,436
R&D per employee	$7,118	$20,076	$5,433	$20,952	$18,321	$20,431	$28,815
Patent stk per $M R&D	2.16	2.18	2.15	1.92	2.61	1.77	2.05
Undeflated patent stock	15	197	11	197	272	166	425
Share with no patents	13.2%	1.6%	15.1%	0.7%	2.1%	0.0%	1.8%
Share with no R&D	7.0%	0.0%	8.2%	0.0%	0.0%	0.0%	0.0%
Panel B: Design Firms (n = 52)							
Observations	475	93	384	66	42	49	19
Year founded	1984	1984	1984	1984	1984	1984	1984
Employment	184	348	159.5	431	365	348	440
Capital per employee	$36,030	$39,670	$35,384	$36,867	$39,105	$34,552	$45,187
R&D per employee	$53,789	$63,539	$52,882	$61,809	$57,389	$52,786	$73,267
Patent stk per $M R&D	1.37	1.27	1.38	1.29	1.33	1.46	1.16
Deflated patent stock	18	40	15	33	59	33	35
Share with no patents	5.3%	0.0%	6.5%	0.0%	0.0%	0.0%	0.0%
Share with no R&D	0.4%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%

Table 3
Probability of being involved in litigation in a year
136 semiconductor firms, 1973-2001 (1819 observations, 282 obs with 547 litigation events)

	All		**Targets**		**Litigated patents**	
# Litigation Events (obs)	**547 (282)**		**279 (202)**		**268 (140)**	
	dF/dx	**Std. err.**	**dF/dx**	**Std. err.**	**dF/dx**	**Std. err.**
D (design)	**0.055**	**0.027**	*0.032*	*0.020*	**0.039**	**0.019**
Log (employment)	**0.060**	**0.005**	**0.038**	**0.005**	**0.026**	**0.004**
Log (assets/employee)	0.010	0.012	0.000	0.008	0.009	0.009
Log (R&D/employee)	**0.049**	**0.009**	**0.028**	**0.007**	**0.019**	**0.007**
Log (pat app stock/R&D)	**0.023**	**0.007**	*0.008*	*0.004*	**0.015**	**0.004**
Missing patents	-0.028	0.035	-0.038	0.017	0.000	0.026
D (Texas Instruments)	**-0.035**	**0.014**	**-0.035**	**0.007**	-0.006	0.013
1973-1977	0		0		0	
1978-1982	-0.065	0.022	-0.006	0.030	-0.035	0.009
1983-1987	-0.024	0.045	0.051	0.059	-0.024	0.017
1988-1992	-0.009	0.050	0.077	0.057	-0.012	0.026
1993-1997	-0.033	0.047	0.049	0.050	-0.030	0.025
1998-2001	0.002	0.055	0.097	0.069	-0.023	0.023
Chi-squared (vars only)	**698.2**		**516.1**		**397.3**	
deg of freedom	7		7		7	
pseudo R-squared	0.261		0.238		0.237	
Log-likelihood*2	823.8		607.2		467.6	
# variables	12		12		12	
*2*LogL (year dummies only)*	*125.6*		*91.1*		*70.3*	
#vars	*5*		*5*		*5*	

The method of estimation is maximum likelihood on a probit model. Robust standard errors clustered on firms are shown. The average derivative of the estimated probability with respect to each variable and its standard error are shown in the table. For the dummy variables, the change in probability for a move from 0 to 1 is shown. Changes in probability that are significant at the 5% (10%) level are shown in bold (italics).

Table 4
Probability of being a target in suits by rivals vs. non-rivals in a year

136 semiconductor firms, 1973-2001 (1819 firm-year observations)

	Targets		**Targets vs. Rivals**		**Targets v. Non-Rivals**	
# Litigation Events (obs)	**279 (202)**		**188 (141)**		**91 (75)**	
	dF/dx	**Std. err.**	**dF/dx**	**Std. err.**	**dF/dx**	**Std. err.**
D (design)	*0.037*	*0.023*	*0.031*	*0.018*	0.003	0.009
Log (employment)	**0.045**	**0.004**	**0.031**	**0.003**	**0.011**	**0.002**
Log (assets/employee)	0.000	0.009	-0.004	0.006	0.003	0.004
Log (R&D/employee)	**0.033**	**0.008**	**0.025**	**0.006**	**0.007**	**0.003**
Log (pat app stock/emply)	**0.011**	**0.005**	*0.007*	*0.004*	0.002	0.002
D (Texas Instruments)	**-0.042**	**0.008**	**-0.035**	**0.005**	-0.002	0.007
1973-1977	0		0		0	
1978-1982	-0.006	0.035	0.020	0.041	-0.010	0.009
1983-1987	0.056	0.064	0.065	0.069	0.007	0.022
1988-1992	0.085	0.062	0.119	0.076	-0.003	0.015
1993-1997	0.057	0.055	0.074	0.058	-0.003	0.016
1998-2001	0.110	0.074	0.067	0.061	0.038	0.041
Chi-squared (vars only)	**660.4**		**272.6**		**184.7**	
deg of freedom	6		6		6	
pseudo R-squared	0.232		0.181		0.255	
Log-likelihood*2	823.8		342.0		322.9	
# variables	11		11		11	
*2*LogL (time only)*	*163.4*		*69.4*		*138.2*	
#vars	*5*		*5*		*5*	

The method of estimation is maximum likelihood on a probit model. Robust standard errors clustered on firms are shown. The average derivative of the estimated probability with respect to each variable and its standard error are shown in the table. For the dummy variables, the change in probability for a move from 0 to 1 is shown. Changes in probability that are significant at the 5% (10%) level are shown in bold (italics).

Appendix A. Construction of Litigation Database

This paper builds on an earlier database used in Ziedonis (2003), which identified U.S. patent lawsuits filed from January 1973 through July 2000 for the same sample of 136 firms. To construct the initial sample, names, former names, and majority-controlled subsidiaries were identified for each firm using business directories such as Hoover's Business Directory and *The Directory of Corporate Affiliations*. Name searches were conducted using two patent litigation databases: (1) Derwent's Litalert database[8] of patent lawsuits filed in U.S. District Courts and (2) the International Trade Commission's database of section 337 patent infringement cases.[9] In total, 287 cases were identified that involved sample firms as plaintiffs, defendants, or patent assignees.[10] Of these, 259 were filed in US District Courts and 28 were filed with the ITC.

We extend the Ziedonis (2003) database in two main ways. First, in light of underreporting biases in Litalert (discussed in the text), we compiled archival 10-K filings for each firm in years that they were publicly traded. We used information reported about patent lawsuits in each 10-k filing to identify cases previously unreported in Litalert. We also used it to enhance information

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[8] The Litalert database is the most common database used in patent litigation studies, largely due to the fact that (unlike alternative data available from the Federal Judicial Center) it identifies patents involved in the disputes and lists multiple parties in each dispute. See Lanjouw and Schankerman (2001) for additional discussion.

[9] Under Section 337 of the Tariff Act of 1970, a firm can challenge the importation of products that infringe its US patent rights. Since ITC cases involve a separate administrative and judicial process than cases filed in US courts (Mutti and Yeung 1996), we include them in the sample as separate cases. Cases were searched and downloaded from the ITC website at: http//info.usitc/gov/337.

[10] In initial Litalert sample, we removed two duplicative records (where identical information was filed under different case numbers) and 57 sequential cases (where a change in venue or an outcome of a previously filed case was announced but the patents and litigated parties involved in the lawsuit were the same).

about existing cases, including the nature of the dispute, the relationships between the parties, and the patents involved (if reported). We conducted similar searches using news directories, trade journals such as *EETimes* and *Semiconductor Business News*, and company press releases. Finally, we updated the sample (using all sources mentioned above) to include cases filed in the second half of 2000 through 2001.

In combination, this process added 148 patent litigation events to initial sample of 287 disputes from Ziedonis (2003). Of the final set of 435 litigated disputes, 133 (31%) were ones added from the archival 10-k and news searches that were not otherwise reported in Litalert. The qualitative information we compiled about the cases enabled us to identify the nature of the dispute in all but three cases. Consistent with statistics reported in Lanjouw and Schankerman (2001) and Bessen and Meurer (2006), patent infringement lawsuits represent the overwhelming majority (85%) of disputes in our final sample.

Does IPR protection affect high growth entrepreneurship? A cross-country empirical examination

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September 18, 2007
Working draft‡

Abstract

The objective of this paper is to determine whether a country's level of intellectual property rights (IPR) protection influences high expectation entrepreneurship. Based on the Baumol's assumption that entrepreneurs, as an allocatable resource, can be reallocated from one domain to another by changing the relative profit prospects offered by the available economic activity vis-a-vis others, we examine whether and how IPR protection affects the local entrepreneurship prevalence. Using a new entrepreneurship dataset from the Global Entrepreneurship Monitor (GEM), we undertake cross-country empirical investigation to answer the following questions: (i) does IPR protection affect the expectations of high growth entrepreneurship level; and (ii) whether a change in IPR protection affects developing and developed countries differently. We find interesting results in the differences of IPR impact on developed versus developing countries. Further examination is required.

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[‡] We are grateful to Heiko Bergmann from the University of St. Gallen, Switzerland, for providing us with the Global Entrepreneurship Monitor data on high expectation entrepreneurship. We would also like to thank the participants of The Economics of Technology Policy held at Monte Verità, Switzerland on June 17-22, 2007, particularly Manuel Trajentenberg for his valuable comments and feedback on an earlier version of this paper.

1 Introduction

How does intellectual property rights (IPR) protection affect local economies? Given the impending deadline for the implementation of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) by the year 2016, scrutiny of the effects of this global IPR protection system is required. This harmonized minimum IPR protection standard, in addition to the various World Trade Organization (WTO) agreements, narrows the policy space for governments in developing countries to build and develop their own capacities for innovation along similar lines of developed countries. We study the impact of IPR protection on local entrepreneurial activities to improve our understanding of how this policy affects developing countries and their innovative activities. We attempt to show that TRIPS is an institutional factor that impacts local entrepreneurial activities according to levels of economic development.

Examining how IPR system affects entrepreneurial activities is not a new research question. Direct empirical relationship between IPR protection and entrepreneurial activity has not been established particularly due to the difficulty of attributing the exploitation of entrepreneurial activities to the strengthened property rights (Shane, 2003). Using a new entrepreneurship dataset from the Global Entrepreneurship Monitor (GEM), we run cross-country empirical investigation to answer the following questions: i) does IPR protection affect local entrepreneurial activities; and ii) whether this impact varies across levels of economic development. Our study is timely because the cutoff date for TRIPS implmentation allows us to carry out a natural experiment to examine the impact of IPR protection, especially on developing and least developed countries (LDCs).

This paper is divided into 5 parts. In the following section we set the foundation for our investigation, briefly describing TRIPS and its economic arguments, and expounding on the theories of Baumol on the allocatability of entrepreneurs across economic activities. The third section provides information on the data collected for the empirical study and discusses specific aspects of the data. The penultimate section discloses, analyses and discusses the results of the empirical study. And finally the last section concludes with a brief summary of the paper.

2 TRIPS and its impact on entrepreneurship

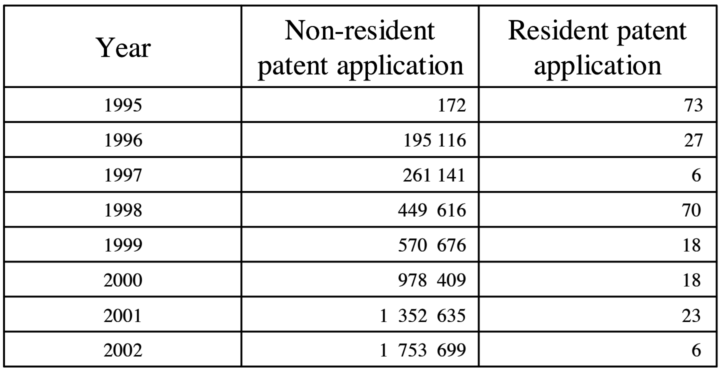
In this section we build our case for pursuing our research question. First, we provide a brief outline of the TRIPS agreement as well as the current discussion on global IPR protection. We then utilize Baumol's argument that entrepreneurs can be allocated across economic activities by changing the reward structure to show how TRIPS can impact countries of differing levels of economic development. Finally, we set forth the propositions to carry out our empirical investigation.

2.1 TRIPS: global IPR protection regime

TRIPS was part of the Uruguay Round of negotiations' single package agreement signed in 1994 by members of the then-GATT (General Agreement on Tariffs and Trade) organization.[1] It is an internationally binding agreement that sets out minimum standards for the granting and protection of IPR in areas such as copyrights, trademarks and patents. The agreement contains margin of flexibility for member countries to implement its provisions in line with their own legal system and practice (TRIPS, Art. 1.1), and according to certain transitional arrangements (TRIPS, Art. 65). In general, member countries are obliged to implement the agreement in its entirety one year after the date of entry into force of WTO agreements. However, developing countries are allocated an additional four years[2] to implement them, and an additional five years for countries that have to introduce product patent protection in technological areas not in existence before, such as pharmaceutical products. During the Doha Ministerial, members of the WTO extended the transitional arrangement for LDCs until 2013.[3]

Global IPR protection is a highly controversial matter. For one, it has not been clearly established whether IPR has played a crucial role in economic development, even in countries with long traditions of IPR protection (Granstrand, 1999). Rather, historical examinations of economic growth in those countries show that IPR protection were strengthened and weakened according to national interests and needs (Khan, 2002; Granstrand, 1999).

Secondly, developing countries tend to be technologically dependent. Global IPR system could exacerbate fundamental asymmetry between countries with few or no innovative capacities and those innovating at the technological frontier. Table 1 below highlights this asymmetry. The increasing gap between patent filings of non-residents and residents of LDCs from 1995–2002 proxy innovation levels in LDCs and shows how innovation in these countries lag behind the rest of the world.



Year	Non-resident patent application	Resident patent application
1995	172	73
1996	195 116	27
1997	261 141	6
1998	449 616	70
1999	570 676	18
2000	978 409	18
2001	1 352 635	23
2002	1 753 699	6

Table 1: Patent application by residents and non-residents in LDC (Source: WIPO, 2006)

Adoption of stronger IPR protection in developing countries makes it more costly and difficult to access knowledge in vital areas such as health and education sectors, and to catch-up with the world's technological frontier. Countries like Hong Kong, Singapore, South Korea and Taiwan have managed to catch-up with the world's technological frontier by having a "soft" IPR regime, which enabled them to adopt, adapt and assimilate technologies from developed nations (Kumar, 2002).

Finally, it is not clear if extending IPR protection globally would increases society's welfare. In their theoretical analysis of examining the welfare implications of global IPR protection, Deardoff (1992), Grossman and Lai (2002), and Chin and Grossman (1990) argue that the gains from adopting global IPR regime would accrue only to inventing countries, at the expense of the world. Stylized facts also raise questions as to whether the implementation of IPR regime globally would be beneficial. Developed countries, or countries innovating at the technological frontier, would gain from the extension of IPR protection in form of increased market size for their innovations. However, the benefit for developing countries would vary according to several factors, notably their innovation capacity framework. The World Bank (2001) points out that: (1) LDCs usually do not have resources to devote to innovative activity and thus existence of any IPR regime is unlikely to benefit local innovation; (2) developing countries with some technological capabilities tend engage in adaptive innovation through reverse engineering; and (3) developing countries with more sophisticated technology capabilities gravitate toward higher IPR protection levels. However, with the non-discriminatory application of TRIPS agreement in its entirety, developing countries may not have the policy space to build their innovative capacity so as to benefit from the agreement's implementation. Other factors such as openness, market size, and macroeconomic policies also play a crucial role in determining how IPR affects the countries in question (Correa, 2000; Bank, 2001). Furthermore it seems that IPR only enhances countries' welfare for some sectors, some innovations and under certain circumstances (Ferrantino, 1993; Helpman, 1993; Lall, 2003; Falvey et al., 2006).

Nevertheless, some gains can be attributed to global IPR protection. Inventing countries would be able to recoup their investments in research and development, and welfare increasing innovative activities could be stimulated. The table below outlines the static and dynamic costs and benefits for a given country resulting from stronger IPR system.[4]

Stronger IPR	Static	Dynamic
Cost	Knowledge purchased at monopoly price (above marginal cost of production), possible welfare loss	Barriers to access modifiable technologies increase
Benefits	Knowledge sold at monopoly price allows firms to recoup their R&D investments and capture economic rents	Innovative activities become more profitable, attracting more competitors in this domain.

Table 2: Cost and benefits of a stronger patent system

Need paragraph for transition

2.2 Effects of IPR on entrepreneurship

Recent literatures on the impact of IPR protection on developing countries have provided some insights on how it affects trade (Fink and Braga, 1999; Maskus and Penubarti, 1995), foreign direct investment (Smarzynska Javorcik, 2004; Lee and Mansfield, 1996; Mansfield, 1994), and economic growth (Thompson and Rushing, 1999; Rapp and Rozek, 1990), to name a few. We have undertaken to pursue research work in this area by shifting the focus of IPR study from the macroeconomic variable such as trade and FDI to microeconomic one, in particular the entrepreneurial firm. Our rationale for concentrating on entrepreneurial firms is because: i) entrepreneurs tend to spot changes in economic environment quickly enabling them to respond to these changes swiftly; and ii) as Shane (2003) states, "[a]lmost every explanation for business and, for that matter, capitalism itself, relies on entrepreneurship as a cornerstone." Thus we choose to focus on entrepreneurial firms due to their importance as "movers" and "shakers" of the economy and their inherent trait in identifying opportunities for gain.

The link between IPR protection and entrepreneurship is a clear one, albeit not directly proven (Shane, 2003). IPR protection provides a mechanism for entrepreneurs to appropriate her returns to innovation. However the effectiveness of IPR protection and the extent to which the innovator can fully capture the returns varies according to the type of protection used and the nature of innovation (Teece, 1986). Once an innovator creates a novel product or service, she can either produce and commercialize it herself via firm formation à la Schumpeter (1942), or contract this innovation out to another firm with the necessary complementary assets to produce it either through licensing or a joint venture. A study by Shane (2001) reaffirms the link between IPR protection level and firm formation. Using patent data assigned to Massachusetts Institute of Technology between 1980 and 1996, Shane finds that the effectiveness of patents increases the probability that the new technology will be exploited through firm formation.For this research study, we focus on the link between IPR protection and firm formation.

William Baumol proposes a nice theory which can help us conceptualize the link between IPR protection and entrepreneurship. Baumol (1993) argues persuasively that entrepreneurs can be allocated across economic activities by changing the structure of rewards of those activities.[5] He points out that entrepreneurs exist in any economy and tend to operate in domains that promise greatest monetary returns, although not necessarily in the innovative domain. He states that, "there are a variety of roles among which entrepreneur's effort can be reallocated; and some of those roles do not follow the constructive and innovative script that is conventionally attributed to them" Baumol (2002). Thus the areas in which the entrepreneurs function given the socio-economic system depends on the economy's payoff structure. Baumol further contends that entrepreneurs, when faced with a given set of alternative economic activities, can be reallocated from one activity to another by a change in the relative profit prospect from undertaking that particular activity *ceteris paribus*. When the reward structure in an economy changes either through institutional or market–reasons, entrepreneurs will be the first few economic agents to respond to this perceptible change.

Given the inherent characteristics of the entrepreneur, when the reward structure in an economy changes either due to political, institutional or market reasons, entrepreneurs will be the first few economic agents who would identify the opportunities from these changes and respond to them. As such, studying entrepreneurs' reaction to strengthening of IPR protection would show the direct effect of IPR protection on the economy.

Historical evidences from the United States give support Baumol's theory. Among the recent IPR changes in the United States include (cf. Sampat (2001)): i) widening patentability fields to include living organisms, software and business methods; ii) implementation of the Bayh-Dole Act which enables federally-funded research work to apply for patents; iii) court decisions in the 1980s and 1990s in favor of widening the scope of patents; and iv) the importance of patents to new innovative firms to be eligible on the NASDAQ. Technological advances, effective knowledge infrastructure and these IPR-friendly institutional changes have prompted an influx of entrepreneurs towards these innovative activities. For example, Shane (2004) examining the effect of Bayh-Dole Act on university patenting in the United States confirms that the introduction of the Act provided incentives for universities to increase patenting, especially in fields where "licensing provides an effective mechanism for acquiring new technical knowledge".

We apply Baumol's theory to link the relationship between entrepreneurship and IPR protection. We argue that strengthening IPR protection in a given country would change the payoff structure of the economy by increasing potential returns from undertaking innovative activities. This change in the payoff structure relative to other economic activities would then induce the reallocation of entrepreneurs accross different economic domains, leading to a concentration of entrepreneurs in the innovation and technological areas.

2.3 Research questions

Using Baumol's theory, we attempt to establish a relationship IPR protection and entrepeneurship and examine whether this relationship differs across different levels of economic development, given the necessary preconditions. These necessary preconditions include sustainable national innovative capacity framework, stable macroeconomic conditions, openness and effective legal infrastructure. National innovative capacity, which includes education system, ensures that the entrepeneurs would have the necessary skills and infrastructure support to carry out innovative activities (Lall, 2003). Stable macroeconomic conditions and effective legal infrastructure provides the environment for entrepreneurs to operate their firms effectively. And finally openness enables exchanges of new knowledge, allowing the entrepeneurs to learn and thus improve existing technologies.

Firm formation is a viable option for entrepreneurs to commercialize their innovation. Given that IPR protection is a mechanism that facilitates innovative activities, strengthening this policy should encourage more entrepreneurs to commercialize their products through establishing a firm. Thus, the implementation of the TRIPS agreement introduces and strengthen IPR protection level in a country with previously weak or nonexistent IPR protection system, making legal innovative activities attractive and illegal imitative activities such as piracy more costly to undertake for economic actors. Theoretically, this would encourage the entry of more entrepeneurs in innovative activities. Put in another way, stronger IPR protection should encourage the presence of higher levels of entrepreneurial opportunities and thus facilitate the undertaking of more entrepreneurial activities in this field.

Proposition 1 *Stronger IPR protection encourages more entrepreneurial activities.*

Most of the analyses examining the effects of IPR protection on countries differentiate between high and low development level countries, and we follow this correctly identified assumption in our research as well. Several studies find different effects of IPR protection for different development levels. Falvey et al. (2006) conducted an empirical analysis of the link between

IPR and economic growth and finds that low and high income countries are positively and significantly affected by IPR protection but not for middle income countries. They conclude that middle income countries "may have offsetting losses from reduced scope for imitation." This suggests that there is a U-shaped relationship between IPR protection and economic development. Interestingly, Smith (1999) in her examination US exports to developing countries find that the strength of IPR protection had a stronger impact on exports to developing countries with strong absorptive capacity. Thus, the impact of IPR protection on entrepeneurship would differ according to their levels of economic development. This leads us to our second testable hypothesis:

Proposition 2 *The effect of IPR protection on entrepreneurial activities differs according to income levels.*

In the following section, we explain our methodology for carrying out our test of the hypotheses.

3 Methodology

Outside the confines of developed economies, the effect of IPR protection on creating entrepreneurial opportunities and encouraging the exploitations of these opportunities is not clear. This is due to difficulty in finding a proxy to capture this activity. Firstly not all developing countries have had IPR protection or have adequately enforced IPR until the recent TRIPS agreement. Thus the usual measure of entrepreneurial activity via firm formation, along the lines of Shane (2001) of using patent data, is not feasible. Secondly cross-country comparison of entrepreneurship activities has been made difficult due to differing definitions of entrepreneurship and the method of collection. This is why we resort to using high expectation entrepreneurship data and refrain from exploiting the patent data.

3.1 Data

We examine high expectation entrepreneurship data collected from GEM consortium for 55 countries over the time period of 2002 – 2006. High expectation entrepreneurship refers to the subset of entrepreneurs who expect their businesses to employ at least 20 employees over the next 5 years. This measure is preferable over the patent data for two reasons: (i) it allows for cross-country comparison of entrepreneurial activities across various income levels and (ii) it does not depend on the enforcement of IPR protection in order to capture the exploitation of opportunities via firm formation.

3.1.1 Dependent variable

Schumpeter's entrepreneur is both an innovator and part of the engine of economic growth. It has been difficult to adequately capture a measure of entrepreneurship that proxies Schumpeter's entrepreneur. We choose to focus on high expectation entrepreneurship variable as our dependent variable. This variable proxies the prevalence of high growth entrepreneurship, thus it captures the kind of entrepreneurial activity that generates employment crucial for economic development. Autio (2005) examines this measure in detail and argues that high expectation entrepreneurial activity accounted for "the bulk of expected new jobs by startups and newly formed businesses" (p. 8). He further concludes that policies designed to encourage knowledge transfer from universities or R&D firms to spin-offs could have a positive impact on high expectation entrepreneurship (p.11).

There is another variable collected by the GEM consortium that may reflect the kind of entrepreneurial activities that we would like to capture better. This variable is referred to as the *high growth potential entrepreneurship* which is defined as new ventures that expect to have: i) high growth intentions (proxied by plan to employ more at least 20 employees in the next five years); ii) innovativeness in product or service (captured by looking at expected market expansion impact); iii) international distinctiveness (measured by percentage of customers living abroad); and iv) employs new technological base in its production (technology cannot be widely avaible more than a year before). However, there are several empirical drawbacks to using this data, particularly in regards to its reliability and its measurement over the years that we are interested in.

We collect annual aggregated data from the Global Entrepreneurship Monitor on various measure of entrepreneurship. The database collection began in 1998, but we choose the time period of 2002 to 2006 based on the availability of widest possible range of country income levels in the database. The data covers approximately 55 countries but not all data is available for all countries in the time frame selected for this study.

The GEM survey asks individuals if they are in the process of establishing a new business, referred to as nascent entrepreneurship, or owning/managing a baby business, termed as baby business. Of the individuals who have responded affirmatively to either one of these entrepreneurship activities, they are further asked if they expect their business to employ at least 20 employees in the next 5 years. This is the definition of high expectation entrepreneurship.

3.1.2 Predictor variable

The other variable of interest, besides the high expectation growth entrepreneurship variable, is the intellectual property rights (IPR) protection variable. There have been two approaches in quantifying the strength of IPR protection: legislation- and survey-based approaches, both approaches have been criticized because of their respective collection and quantification methods. The legislation-based approach, exemplified by Ginarte and Park (1997), has been criticized for overestimating the level of protection accorded because it had only taken into consideration the enforcement element of IPR protection. On the other hand the survey-based approach, typified by the Yale survey from Levin et al. (1987) and Lee and Mansfield (1996), is considered subjective, perhaps reflecting some "ideological tendencies" of those who built the survey and those who answered it (Kauffman et al., 2004).

We use the IPR enforcement index collected by the World Economic Forum (WEF) as a measure of IPR strength because of its coverage of countries over the time period of investigation. This index is built based on answers from local professionals and is bi-annually published in the WEF annual Global Competitiveness Report. Furthermore, this index captures the enforcement component of IPR protection which reflects the current law perspectives and practices on its protection. The survey asked whether, "[I]ntellectual property protection in your country is: (1=weak or nonexistent, 7=equal to the world's most stringent)." Responses from the experts are tabulated and averaged for each country in question.

3.2 Control variables

We include factors other than IPR protection that have been found to be a significant factor in the determination of entrepreneurship activities. By doing so, we control for factors that could influence IPR protection and ensure that the variable that we am concerned with, IPR protection, influences the high expectation entrepreneurship beyond what previous researchers have found. The variables we employ here are to control for macroeconomic determinants of entrepreneurship. All of the control variables are from the World Bank's World Development Indicator 2007. A list of their definition can be found in the appendix.

Entrepreneurship rates have been found to be higher during economic boom periods and decline during economic recessions. We chose the variable GDP growth rate to proxy for economic growth of the economy.

High inflation rate tend to indicate times of economic instability, wherein which it has been found that entrepreneurship activity decreases. We use the inflation rate as measured by the GDP deflator of a country to control for times of economic instability.

Highfield and Smiley (1987) argue that low unemployment rate positively influence firm formation. However, they stipulate that under "opportunistic" competition, high unemployment rate positively influence firm formation because the cost of attracting and hiring qualified workers would be lower.

It is more difficult to open a new firm when the cost of borrowing money is high. Audretsch and Acs (1994) in their study on the relationship between new firm startups and macroeconomic fluctuations, use the average three-month interest rate paid on the U.S. Treasury Bills. However, given that we do not have access to all of the government bond rates for each country in our study, we use real interest rate as a proxy to measure the cost of capital.

We are aware that there are other control variables that could be included in the model that could help control for other factors such as existence of complementary assets, level of competition and types of industry sectors. But given our small sample size, we choose to focus on the macroeconomic variables that could best capture the economic framework in a parsimonious manner.

3.3 Descriptive statistics

We have 55 countries in our sample, both developed and developing countries between 2002 and 2006. However, we end up with an unbalanced panel dataset due to the missing data in some years. We also had to drop our observation on Chinese Taipei due to the lack of data reported by the World Bank on the macroeconomic variables.

Table 3 summarizes the variables in this study. Note that the mean for high expectation entrepreneurship is approximately 1 percent. This indicates that on average only 1 percent of the total working population in the countries studied are engaging in high expectation type of entrepreneurship. The highest high expectation entrepreneurship percentage of the total working population is found in Chile with 4.5 percent in 2002, China with 3.8 and 3.1 percent in 2002 and 2006 respectively, and Colombia with 3.4 percent in 2006. Further examination of this entrepreneurship variable for developing countries shows that the mean of high expectation entrepreneurship rate is 1.3 percent of the population, slightly higher than for the whole sample. Just for comparison, range of high expectation entrepreneurship variable for the United States is from 1.04 to 2.18 percent of the population.

Variable	Obs	Mean	Std. Dev.	Min	Max
High expectation entrepreneurship	174	1.021	0.835	0.000	4.530
Economic growth rate	269	3.959	3.238	-11.032	17.855
Real interest rate	186	5.824	9.617	-9.710	84.050
Inflation rate	269	4.937	6.213	-6.347	44.134
Unemployment rate	153	8.477	5.017	1.500	30.700
IPR	271	4.499	1.255	2.200	6.600

Table 3: Descriptive statistics

Table 2 is a correlation table between the important variables we collected for this study. As the table shows, the highest correlation between any two independent variables is -0.54 between IPR proxy and the inflation rate. While the table shows that there is no problem of multicollinearity, or high correlation problem, it does suggest that the factors that we are using in our investigation are not completely independent of one another.

Simple Pearson pairwise correlation of high expectation entrepreneurship variable and economic growth proxy measured by GDP growth rate show a positive and significant correlation, reaffirming Autio's earlier argument that this variable may positively influence economic growth. Notice that the Pearson pairwise correlation between the high expectation entrepreneurship variable and the IPR protection variable is negative and significant; however the variable "IPR*dev" which is found by interacting the IPR protection variable with the dummy for developing countries (*dev*), the correlation is positive and significant. This indicates that there is different effect when we consider the sample as a whole and when we consider developing countries only.

	1	**2**	**3**	**4**	**5**	**6**	**7**
1. High expectation entrepreneurship	1						
2. Growth rate	0.1917*	1					
3. Real interest rate	0.0257	-0.2896*	1				
4. Inflation rate	0.3049*	0.0409	0.0465	1			
5. Unemployment rate	-0.1306	-0.1414*	0.2538*	0.3324*	1		
6. IPR	-0.2606*	-0.3248*	-0.1042	-0.5391*	-0.3899*	1	
7. IPR* dev	0.2096*	0.3253*	0.1799*	0.3452*	0.4176*	-0.6397*	1

Table 4: Correlation table

4 Analysis

The purpose of this study is to examine whether a country's level of IPR protection influences local entrepreneurial activity across countries of differing economic development activities. We test the two following hypotheses: i) *stronger IPR protection encourages more entrepreneurial activities;* and ii) *the effect of IPR protection on entrepreneurial activities differs according to income levels.*

4.1 Regression method

We collect data for 55 countries over the period 2002 and 2006 but are left with an unbalanced panel set of approximately 134 observations. We test for heteroskedasticity and reject the null hypothesis that there is no cross-section heteroskedasticity in our panel set. Thus, we correct for the groupwise heteroskedasticity and the correlation of the error term over time by running normal Ordinary Least Square (OLS) regression clustering by country with robust standard errors. We also run Generalized Least Square (GLS) regression, correcting for panel heteroskedasticity. We report and analyze the results in the following subsections. Given our panel heteroskedasticity assumption, the GLS estimation is more efficient and preferred over the OLS with cluster by country estimation. We report both OLS with cluster and the GLS regression for completeness. The OLS with cluster regression although not efficient in the case of panel heteroskedasticity is reported because its estimates will be correct in either case of with or without panel heteroskedasticity.

4.2 Results

4.2.1 Proposition 1

Our first hypothesis is that stronger IPR protection encourages more entrepreneurial activities. We run the test using the following model:

$$y_{it} = \alpha + \beta_{it} x_{it} + \varepsilon_{it}$$

where x_{it} represent all the explanatory variables, including the IPR measure. Table 5 reports our findings from a normal OLS regression, clustering robust standard errors by countries. The F-statistics test finds that all the coefficients in the models are significant.[6] The R-square values improve the as we move from the baseline model to Model 4.[7]

Model 1 shows that the coefficients of GDP growth rate and inflation rate are positively related to the entrepreneurship variable, and are statistically significant from zero. Interestingly the unemployment rate is negatively related to the dependent variable, and statistically significant from zero. Model 2 adds the intellectual property rights variable. As in Model 1, the coefficients GDP growth rate and inflation rate are positively related to the entrepreneurship variable, and is statically significant from zero. However, the IPR variable is negatively related to the entrepreneurship variable but is statistically insignificant from zero.

4.2.2 Proposition 2

We test the second hypothesis, i.e. whether the impact of IPR protection on entrepreneurship differs according to levels of economic development. We create a dummy variable called *dev*, which differentiates countries that are developed from those who are developing following the World Bank classifications. The dummy takes a value of 1 if the country in question is a developing or least developed country and 0 if otherwise. The regressions for this hypothesis is shown in both Tables 5 and 6 as Models 3 and 4.

Models 3 and 4 are replicas of models 1 and 2 but with the interaction terms of developing countries. We test:

$$y_{it} = \alpha + \beta_{it} x_{it} + \delta_{it} x_{it} * dev + \varepsilon_{it}$$

where "dev" is a dummy variable that takes on the value 1 if the country is a developing nation and 0 otherwise. All the coefficients for the whole sample in Model 3 are insignificant except for unemployment rate, which is negatively related to the entrepreneurship variable and statistically significant from zero. In Model 4, the unemployment rate is negative and statistically significant from zero for the whole sample. The growth rate interaction and the unemployment interaction terms are positive and statistically significant from zero. IPR variable, for developing countries, is negative and statistically significant from zero.

Checking for robustness, we test whether the coefficients between the two samples (whole sample and developing countries' sample) are the same and reject the null hypothesis that they are. This implies that IPR level and strength affects countries with different income levels differently.

	Model 1	**Model 2**	**Model 3**	**Model 4**
GDP growth rate	0.0701***	0.0620**	0.0605	0.0168
	(0.023)	(0.026)	(0.051)	(0.053)
Real interest rate	-0.00179	-0.00259	0.0237	0.0277
	(0.011)	(0.011)	(0.019)	(0.018)
Inflation rate	0.0609***	0.0544***	0.0398	0.032
	(0.014)	(0.018)	(0.04)	(0.042)
Unemployment rate	-0.0363***	-0.0382***	-0.0721*	-0.111**
	(0.0091)	(0.01)	(0.041)	(0.046)
IPR		-0.0473		0.0553
		(0.095)		(0.11)
GDP growth rate*dev			0.0785	0.168**
			(0.061)	(0.068)
Real interest rate*dev			-0.00105	-0.000862
			(0.00077)	(0.00055)
Inflation rate*dev			-0.081	-0.0592
			(0.064)	(0.068)
Unemployment rate*dev			0.0342	0.0939*
			(0.033)	(0.047)
IPR *dev				-0.253**
				(0.12)
Constant	0.724***	1.025	0.839**	0.913
	(0.14)	(0.62)	(0.39)	(0.85)
N	86	85	56	55
R-squared	0.24	0.24	0.42	0.47

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: OLS regression with heteroskedastic panel

	Model 1	**Model 2**	**Model 3**	**Model 4**
GDP growth rate	0.0740***	0.0676***	0.0762***	0.0445***
	(0.0092)	(0.014)	(0.018)	(.017)
Real interest rate	0.00521	0.000795	0.0198*	0.0200*
	(0.0053)	(0.0074)	(0.011)	(0.011)
Inflation rate	0.0662***	0.0616***	0.0396***	0.0333**
	(0.0061)	(0.0091)	(0.014)	(0.014)
Unemployment rate	-0.0379***	-0.0349***	-0.0709***	-0.0940***
	(0.0037)	(0.0055)	(0.012)	(0.012)
IPR		-0.0197		0.0874*
		(0.038)		(0.051)
GDP growth rate*dev			0.0592*	0.135***
			(0.032)	(0.035)
Real interest rate*dev			-0.000833***	-0.000998**
			(0.00029)	(0.00042)
Inflation rate*dev			-0.0577*	-0.0304
			(0.03)	(0.033)
Unemployment rate*dev			0.0301**	0.0842***
			(0.012)	(0.017)
IPR *dev				-0.259***
				(0.059)
Constant	0.633***	0.751***	0.766***	0.557**
	(0.06)	(0.27)	(0.099)	(0.27)
N	86	85	56	55
ID	41	40	36	35
Log-likelihood	-35.42894	-37.44926	-11.39054	-10.21097

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: GLS regression with heteroskedastic panel

4.2.3 Discussion of the results

The results from our regressions are interesting but preliminary. The results show that for developed countries, increases in the IPR regime positively affect the formation of high expectation entrepreneurship but negatively for the developing countries. This suggests that for developed countries marginal strengthening of IPR protection level facilitates more entrepreneurial activities, partially confirming our application of Baumol's theory. By strengthening IPR protection, innovative activities become more rewarding and there is a surge in this particular type of entrepreneurship. However, based on the evidences that we currently have, we cannot confirm whether there is a shift of entrepreneurs from one domain to another.

As for the developing countries, this marginal increase in IPR protection leads to decrease in the current entrepreneurial activities, contradicting Baumol's theory. There are two possible explanations for this interesting result. The first possible explanation is that there is no reallocation process in developing countries particularly because there is no scope for this process to take place. For example, it could be the case that the national innovative framework has been insufficient to facilitate the types of entrepreneurial activities that are IPR-sensitive. Even if the national innovative framework is conducive to IPR-sensitive entrepreneurial activities, it is likely that these type of entrepreneurs can neither be spontaneously generated nor shift from one entrepreneurial acitivity instantaneouly. Thus a longer time period is required to carefully study this reallocation effect so as to circumvent this time consistentcy problem. A second possible explanation has to do with the legality of the entrepreneurial activity. Perhaps what we are witnessing with the decrease in entrepreneurial activity given the strengthening of IPR protection is an exit of entrepreneurial firms due to the "illegality" of their activity. Stated in a different way, strengthening IPR protection increases the cost of undertaken this "illegal" activity and thus firms would have to exit or prefer not to enter that particular activity. Consider India's case as an example. Prior to TRIPS, India allowed process patenting but not product patenting. This enabled Indian generic producers to copy a drug and re-engineer it using a different processes. Post-TRIPS, this type of innovative activity is now "illegal" and the producers would have to stop their infringement of the product patent. If the second explanation is the case, then this interesting result for developing countries would also partially confirm Baumol's theory. Again, we are not able to deduce that there is a reallocation effect due to the limitations of the data that we have gathered. Figure 1 below summarizes the possible explanation for the results we obtain for developing countries.

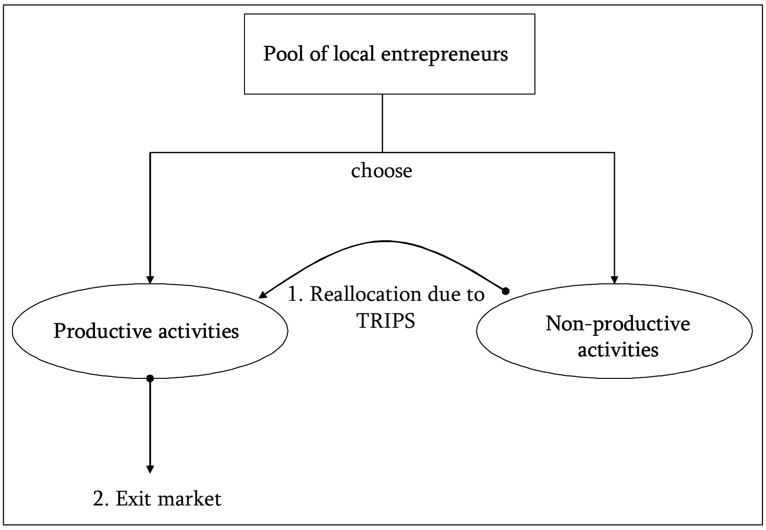


Figure 1: Explanation for developing countries' results

Our empirical model suffers from data problems. In particular, due to the methodology and collection of the dependent variable, we are not privy to know whether the entrepreneurial firms are IPR-sensitive or not. This brings several drawbacks to our investigation. Arguably, the entrepreneurial firms in developed countries are IPR-sensitive and as such would respond positively to the strengthened IPR system. However, the same cannot be said for entrepreneurial firms captured by the data for developing countries. As mentioned earlier, we could've circumvented this data problem by using the high growth potential entrepreneurship variable, which seems to track innovativeness of the firm. However, because we cannot confirm the reliability and consistency of this variable, we choose not to use it.

Further research investigation is needed in this subject matter. It would be useful to have a longer time period to properly assess the allocation effect of entrepreneurs in an economy. Furthermore, capturing the sectors in which these entrepreneurs participate would allow us to better assess the applicability of Baumol's theory in practice.

5 Conclusion

Our examination of the impact of IPR protection on high expectation entrepreneurship yields interesting results. High expectation entrepreneurship responds positively to IPR protection in developed countries but negatively in developing countries. For developed countries the result partially concurs with Baumol's theory. An increase in IPR protection makes IPR-sensitive activities more attractive as these activities now yield higher payoffs in comparison to other activities. While the Baumol's theory may partially apply in developed countries, our result shows the contrary for developing countries. The negative relationship suggest that strengthening IPR protection is costly for their local high expectation entrepreneurs. As we have discussed in our previous section, two possible explanations can justify this interesting results. For one, developing countries may not have adequate supply of entrepreneurs who can readily participate in IPR-sensitive activities. Thus, the problem for developing countries can be attributed to problem of production rather than problem of allocation of entrepreneurship. Secondly, it is possible that the types of entrepreneurial activities captured by high expectation entrepreneurship variable may have been "legal" prior to TRIPS and "illegal" post-TRIPS. Therefore an exit of high expectation entrepreneurs is likely given the costliness of participating in this "illegal" activity.

Our research adds to the discussion of how TRIPS impact developing countries. Given our preliminary research finding, TRIPS may not be beneficial for developing countries. However this may reflect certain supply-side constraints, such as human capital, that responds negatively to this institutional change. It is clear that TRIPS is not a magical solution to entrepreneurial, R&D and innovation deficit in developing countries. Sufficient and sustainable national innovative capacity framework as well as other institutional framework should be in place to support the developmental growth of the economy. Our research sheds light on the importance of examining strategic complementarities between various institutional changes and processes. For example, studying the evolution of IPR regime and the transformation of education system would perhaps generate a better view of how these institutional changes affect economic activities. Milgrom and Roberts (1990) underline the importance of mutual complementarities of institutional changes that should be adopted together to enhance the positive impact that these changes would bring to the economy. There is, thus, potential for systemic transformation that results entirely from the positive feedback effects that each institutional change has on the other changes. When properly managed, such strategic complementarities among institutions can account for the emergence of a persistent pattern of change.

However, further study should be undertaken to better assess the situation.

Notes

[1] The Marrakesh agreement stipulated that the GATT organization would be replaced by the World Trade Organization, and that all the agreements negotiated during the Uruguay Round of negotiations would be administered by the WTO.

[2] Except for obligations regarding the WTO's national- and most-favored nation treatments, in which case the initial one year deadline is applicable.

[3] Compliance with pharmaceutical patenting was also extended to 2016.

[4] The cost of building a legal system is not considered in Table 2, which can be prohibitively high for countries where such system does not exist yet, or where the legal system functions ineffectively.

[5] We refer to *entrepreneurs* here generically, i.e. economic agents that can identify, evaluate and exploit profit opportunities in the economy through arbitrage, speculation or innovation.

[6] The F statistics tests that the coefficients on the regressors listed in the table are all jointly zero.

[7] The R^2 is usually improves when one adds more variables, and so a more adequate measure to capture whether the variables added improves the model is the adjusted R^2. However, we do not report the adjusted R^2 because it is not available.

A Variable description

Measure	Proxy	Units	Source
Entrepreneurship	High expectation entrepreneurship	% of total working population	GEM
Economic growth	GDP growth	% change annually	WDI
Cost of capital	Real interest rate	%	WDI
Economic stability	Inflation rate	% change annually	WDI
Ease of hiring	Unemployment rate	Total unemployment as a % of total labor force	WDI
IPR protection	IPR index	1 to 7 scale	WEF

Table 6: Variables collected

Variable	Obs	Mean	Std. Dev.	Min	Max
High expectation entrepreneurship	63	1.319	1.016	0.058	4.530
Economic growth rate	129	5.093	3.719	-11.032	17.855
Real interest rate	101	7.323	12.579	-9.710	84.050
Inflation rate	129	7.914	7.549	-3.855	44.134
Unemployment rate	76	10.637	6.010	1.500	30.700
IPR	127	3.428	0.783	2.200	5.100

Table 7: Descriptive statistics for developing countries

Variable	Obs	Mean	Std. Dev.	Min	Max
High expectation entrepreneurship	111	0.852	0.660	0.000	3.911
Economic growth rate	140	2.913	2.277	-1.198	11.900
Real interest rate	85	4.043	3.067	-4.050	12.120
Inflation rate	140	2.193	2.476	-6.347	14.286
Unemployment rate	77	6.345	2.328	2.900	11.400
IPR	144	5.444	0.718	3.800	6.600

Table 8: Descriptive statistics for developed countries

B List of countries in the sample set[8]

United Arab Emirates
Australia
Belgium
Canada
Chile*
Chinese Taipei
Czech Republic
Germany
Spain
France
Greece
Croatia
Indonesia*
Ireland
Israel
Jamaica*
Jordan*
Latvia*
Malaysia*
Norway
Peru*
Poland*
Russia*
Slovenia*
Thailand*
Uganda*
United States
South Africa
Argentina*
Austria
Brazil*
Switzerland
China*
Colombia*
Denmark
Ecuador*
Finland
United Kingdom
Hong Kong
Hungary
India*
Iceland
Italy
Japan
South Korea
Mexico
Netherlands
New Zealand
Philippines*
Portugal
Singapore
Sweden
Turkey*
Uruguay*
Venezuela*

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R&D Competition and Strategic Trade Restrictions in the Market for Technology[*]

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August 29, 2007

Abstract

What type of "currency" should firms choose when they trade intellectual property (IP)? Looking at the empirical evidence, it is not obvious that cash is the most preferable method of payment. Rather, it seems that firms pay with their own IP in exchange for other firms' technology. This paper suggests that the choice of cash versus IP affects the R&D activity of firms. We show that a commitment to an IP-for-IP strategy can be a profitable means to alter the allocation of R&D and thus soften R&D competition. However, this strategy forgoes potential gains from trade when IP is distributed asymmetrically. By providing a simple model of the trade-offs involved, this paper shows that IP-for-IP is profitable in industries (1) where firms differ in their commercialization abilities; (2) where patent complementarities are less pronounced.

JEL classification: O32, O31, L11
Keywords: Intellectual Property, R&D competition, Technology Trade

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[*] We owe thanks to Matthias Blonski, Ulf von Lilienfeld-Toal, Konrad Stahl, Uwe Walz, as well as conference and seminar participants in Guanajuato, Halifax, Mannheim, and Strasbourg for helpful comments.

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1 Introduction

What type of "currency" should firms choose when they trade intellectual property (IP)? Looking at the empirical evidence, it is not obvious that cash is the most preferable method of payment. Rather, it seems that firms pay with their own IP in exchange for other firms' technology. This is most evident in the empirical discussion of so-called cross-licensing agreements. Put simply, cross-licensing implies granting reciprocal access to IP or patents by firms. Evidence suggests that cross-licensing is more than a simple, reciprocal seller-buyer-relation but is part of a long-term strategy. Intel's formerly proclaimed "IP-for-IP" strategy is a case in point. This strategy involved that Intel committed itself to grant access to its IP only to firms who gave Intel access to their own IP.[1] Hence, Intel purposely restricted its own trade of IP to non-monetary transactions.

This paper suggests that the choice of currency (cash versus IP) affects the R&D activity of firms. We show that a commitment to an IP-for-IP strategy can be a profitable means to alter the allocation of R&D investments and thus soften R&D competition. However, such a strategy involves costs as it forgoes potential gains from trade when IP is distributed asymmetrically in the market. By providing a simple model of the trade-offs involved, this paper shows that IP-for-IP has ex ante impacts on firms' innovative activities (in addition to affecting post-innovation issues such as litigation, as suggested by prior literature).

We consider two firms that are engaged in the same two R&D projects. This implies that each firm has to decide about its overall R&D budget as well as the allocation across projects. The projects stochastically yield IP that can be commercialized, each in a different market. However, firms differ in their ability to commercialize IP across these different markets. This allows them to capture gains from trade when a firm with lower commercialization ability sells its IP to the one with higher ability. At the same time, gains from trade also raise the incentives to pursue R&D in projects outside firm's key markets, thus increasing R&D competition.

By committing to an IP-for-IP strategy, firms may restrict R&D competition. This creates a positive level-effect on R&D expenditures. Our analysis suggests that strategies of restricting trade in technologies to reciprocal exchange can be profit-enhancing. This is particularly the case in industries (1) where firms differ in their commercialization abilities; (2) where patent complementarities (that is

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[1] According to Shapiro (2002), "[T]he FTC alleged that Intel [...] was acting anti-competitively by refusing to license certain trade secrets to firms that would not enter into cross-licenses with Intel." For further details refer also to Shapiro (2001), Shapiro (2004), and the FTC's documentation at http://www.ftc.gov/os/caselist/d9288.shtm.

the value added by additional patents) are less pronounced.

There is a growing body of literature that studies the impact of technology licensing and intellectual property design on market structure and welfare. Inter alia, this literature emphasizes the special role of cross-licensing agreements in promoting freedom to design and manufacture products in the presence of patent thickets and thus in enhancing efficiency in high-tech industries such as semiconductors and electronics. According to Grindley and Teece (1997, p.23), "[t]o obtain access to needed technologies, Hewlett-Packard needs patents to trade in cross-licensing agreements. [This IP portfolio] is also invaluable as leverage to ensure access to outside technology." The same authors argue that IBM acquires necessary outside IP rights "primarily by trading access to its own patents, a process called 'cross-licensing'." Referring to conversations with semiconductor firms, Hall and Ziedonis (2001, p.107) argue that "many manufacturers had decided to 'harvest' more patents from their R&D [...] to assist them in winning favorable terms in cross-licensing negotiations with other firms in the industry."[2] This treatment of cross-licensing agreements in the literature raises the question whether there is more to cross-licensing than the mere composition of two distinct licensing deals. Put differently, many articles in that field do not explicitly explain why a firm's own IP (cross-licensing) is a different currency than cash (one-way licensing) when seeking access to outside technology. In a more general context, Prendergast and Stole (1996) address the potential economic implications of monetary versus non-monetary trade (i.e. barter) in assets. Our model contributes to this literature by highlighting why the type of currency in the market for technology might matter in the context of firms' R&D activities.

Our model contains the features of a patent race and is therefore closely related to the traditional patent race literature. The symmetric models incorporated in Loury (1979) and Lee and Wilde (1980) show that patent races among a fixed number of firms lead to overinvestment in R&D compared to the cooperative solution.[3] The major reason for the existence of overinvestment is the difference between the private and the social value of a patent. However, unlike in our model, these models are not concerned with project choice in R&D. There is also a literature focusing on project choice rather than the level of investments in R&D. As Anderson and Cabral (2007) put it, "[...] from a manager's point of view, the decision is not just how much to spend on R&D but also how to spend it". This paper and others (e.g. Bhattacharya and Mookherjee, 1986; Dasgupta and Maskin,

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[2] In a similar way, The Economist (2005) writes that "[u]nless firms have patents of their own to assert so they can reach a cross-licensing agreement (often with money changing hands too), they will be in trouble."

[3] For a survey on these and additional models on patent races, see Reinganum (1989).

1987; Cabral, 2003; Gerlach, Ronde, and Stahl, 2005) are primarily interested in the choice of risk that firms take in R&D competition given a fixed R&D budget. In our paper we do not consider risk-taking behavior by firms. Rather, firms' allocation of R&D across investment projects is driven by the trading environment in the market for technology.

Looking at multiple research projects highlights two different motives for firms to undertake R&D. Apart from the obvious value of an innovation in its use at the inventor, an innovation may be valuable as a tradeable good (provided property rights are well specified). This latter value often features in the management literature on innovation. However, the value of technology as a tradeable good depends on the terms of trade. An IP-for-IP strategy affects this value and thus alters the relative weight of firms' R&D motives. The paper shows how this changes incentives to undertake R&D across different types of projects.

This paper is organized as follows. Section 2 introduces the key assumptions of the model. Section 3 first analyzes R&D competition under free trade versus IP-for-IP and compares the outcomes of these two regimes and then focuses on the profitability of an IP-for-IP based strategy. Extensions to the basic model are presented in section 4. Finally, section 5 concludes.

2 Model

We consider two firms ($i = A, B$) that are potentially engaged in two research projects ($j = 1, 2$). Each project stochastically yields at most one patent which covers the whole R&D output of a project.[4] This R&D process is sufficiently uncertain such that the outcome is non-contractible. Firms are homogenous with respect to their unconditional success probabilities for both projects. The maximum (market) value of either patent is symmetric and given by V. However, firms have heterogenous commercialization abilities regarding both patents. We assume that firm A (firm B) can fully exploit the value of patent 1 (2) whereas it might face a commercialization disability regarding patent 2 (1). The commercialization disability is captured in a discount factor, $\delta \in [0, 1]$.

2.1 Timing and Solution Concept

The time structure of the game is as follows:

t=0 Firms simultaneously set their terms of trade.

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[4] We initially rule out complementary patent relationships within a certain project. This assumption is relaxed in section 4. Moreover, patent protection is assumed to be perfect, i.e. it is not possible to invalidate a granted patent in court.

t=1 Firms simultaneously decide about their R&D expenditures.

t=2 Nature determines the allocation of patents (conditional on R&D expenditures)

t=3 Trade takes place if the terms of trade of both firms allow it. All payoffs are realized hereafter.

We are looking at subgame perfect equilibria of the game in order to determine when trade restricting strategies (see below) may be part of firms' equilibrium behavior. The key part of the analysis will be to examine the decision on R&D expenditures in t=1, where we restrict the analysis to symmetric Nash equilibria.

We assume that firms are able to commit to their terms of trade set in t=0 when they enter the trading stage. As will be clear below, firms might want to change these terms in the last stage of the game. Hence, we assume that firms are able to restrict their ability to change their initial decision. This might be achieved by posting a bond which is forfeited upon deviation from their initial choice or by delegating the decision in t=0 to a (central) manager who maximizes expected profits and incurs costs if he were to deviate from his initial decision.[5] We will discuss at the end of section 3 how our results may be rationalized in an infinitely repeated game framework.

2.2 Trade in Technology

Once firms have obtained patents they are potentially free to trade these. By doing so, firms can realize gains from trade in cases where $\delta < 1$. If trade takes place then it is assumed that firms bargain with equal bargaining power over the price of the patent to be exchanged.[6] In our model, the terms of trade in technology chosen in t=0 play a crucial role. Firms may choose between two scenarios. In the first scenario, labeled "free trade", firms can exchange patents without any restrictions. This enables them to realize all gains from trade. In contrast, we consider a second scenario where firms are restricted in their trade opportunities. We refer to this case as "IP-for-IP". Under the terms of IP-for-IP firms are not able to use money for the purchase of a patent from another firm. Rather, a firm may only use its own IP as currency for the IP of the other firm. That is, in the IP-for-IP scenario, trade in technology has to take place on a reciprocal basis. Contrary to the free trade case, with IP-for-IP firms may not be able to exploit

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[5] See e.g. the discussion in Maskin and Tirole (1999) about how renegotiation can be avoided.

[6] The basic model only considers barter (or, put differently, exclusive licensing) and therefore neglects licensing deals which involve simultaneous usage of a patent by both firms. We examine multiple usage of patents in section 4.

all potential gains from trade. As this scenario is more restrictive than the free trade scenario and since trade only occurs if both firms agree to it, the IP-for-IP scenario always applies if it is chosen by at least one firm in t=0.

2.3 R&D Technology

The unconditional success probability of firm A for project j ($j = 1, 2$) is $1 - e^{-a_j}$ where $a_j \geq 0$ represents the R&D expenditures of firm A on project j. Likewise, firm B is successful on project j with probability $1 - e^{-b_j}$ with $b_j \geq 0$ being the R&D expenditures of firm B on project j. Furthermore, if both firms are successful on a certain project then each firm obtains the respective patent with probability $\frac{1}{2}$.[7] This type of success probability implies that the overall success probability on a certain project does only depend on the total level of R&D expenditures but not on its allocation over firms.

3 Analysis

In the following, we consider equilibrium R&D expenditures under the free trade (section 3.1) and the IP-for-IP (section 3.2) scenario. In section 3.3, the optimal choice of the terms of trade is characterized.

Generally, firms' profits depend on the pre-trade allocation of patents by nature and the trading environment which determines the final allocation of a patent. Let $\omega_j \in \Omega \equiv \{\emptyset, A, B\}$ denote the post-R&D, *pre-trade* owner of patent j. Then there are nine possible pre-trade allocations of patents (ω_1, ω_2). Let $p(\omega_1, \omega_2)$ be the probability of an allocation and $\pi_i(\omega_1, \omega_2)$ firm i's *post-trade* payoff from this allocation. Then firm i's expected profit in the R&D stage is

$$E[\pi_i] = \sum_{\omega_1 \in \Omega} \sum_{\omega_2 \in \Omega} p(\omega_1, \omega_2) \pi_i(\omega_1, \omega_2) \tag{1}$$

Finally, the payoffs $\pi_i(\omega_1, \omega_2)$ depend on the trade scenario and will be specified below.

3.1 Free Trade

When there are no restrictions to trading technology, each firm will ex post be allocated the patent it values most. The price at which patents are traded is determined by bargaining such that the parties split the gains from trade equally. Table 1 provides the probabilities and payoffs to the two firms for all possible

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[7] This implies that, for example, the probability of firm A obtaining a patent in market 1 conditional on firm B's expenditures is $(1 - e^{-a_1})\frac{1}{2}(1 + e^{-b_1})$.

patent allocations. Consider for example allocation $(\emptyset, A)$: in this case, firm A gains the patent for market 2 and values it at δV. As firm B's valuation is higher, they trade and split the gains, $(1-\delta)V$, equally. Similarly, for allocation (B, B), firm B sells the patent for market 1 to firm A. And in case of allocation (B, A), the two firms exchange the patents gained in R&D, without money changing hands due to symmetric valuations.[8]

Cooperative solution: For benchmark purposes we first derive the optimal cooperative solution regarding the R&D investments per project. Joint profits are

$$E[\pi_A + \pi_B] \quad = \quad V(2 - e^{-(a_1+b_1)} - e^{-(a_2+b_2)}) - a_1 - a_2 - b_1 - b_2. \tag{2}$$

This is maximized at $a_1 + b_1 = a_2 + b_2 = \ln V$ with $V \geq 1$ to ensure non-negative investment levels.

Non-cooperative solution: We now turn to firms' individual, non-cooperative, R&D investment decisions in case of free trade. Individual expected profits are given in (1) and table 1. Maximization of expected profits yields in the symmetric equilibrium $(a_1 = b_2, a_2 = b_1)$ the following relations[9]

$$e^{a_1} = e^{b_1} + 2\frac{(1-\delta)}{(1+\delta)} \tag{3}$$

$$e^{b_2} = e^{a_2} + 2\frac{(1-\delta)}{(1+\delta)}, \tag{4}$$

where $\frac{(1-\delta)}{(1+\delta)} \in [0,1]$. These relations show that a firm invests more in a project than its rival if this firm is enjoying a higher commercialization ability regarding the R&D output of the project. If $\delta = 1$ then firms invest identical amounts in either project. Under free trade the two research projects are not strategically linked with each other as trading patent 1 is not affected by the trade of patent 2. That is, free trade leads to R&D competition over two distinct patents. Within a certain research project, one of the firms enjoys a comparative advantage over the other firm as it has a higher commercialization ability regarding the R&D output of the project. It is thus not surprising that the firm with the higher commercialization ability invests more in the respective R&D project than its competitor.

Proposition 1 *Let $V \geq 3$. Under free trade, the symmetric equilibrium regarding firms' R&D expenditures is unique and characterized by overinvestment compared to the cooperative solution. The level of overinvestment is increasing in δ.*

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[8] We consider asymmetric valuations in section 4.

[9] For a derivation see A.1

Proof: See A.2.

Proposition 1 restores the standard result of R&D overinvestment in the patent race literature. Here, the patent race is asymmetric as firms have different commercialization abilities across the two projects.

3.2 IP-for-IP

Under IP-for-IP, gains from trade can only be realized if trade takes place on a reciprocal basis. The payoffs in this scenario differ from the free trade payoffs in some but not all states of the world as long as firms have different commercialization ability regarding the two patents (i.e. as long as $\delta < 1$). Table 1 shows the post-trade payoffs of the two firms for all possible patent allocations. Consider again the three previous examples, $(\emptyset, A)$, (B, B), and (B, A): in the first case, firm A is the owner of the only patent. Even though B would value the patent more, there is no possibility to barter, so firm A uses the patent itself at the reduced value of δV. A similar situation arises under (B, B) for firm B. As it holds both patents, there is no possibility to barter, so it keeps both patents even though patent 1 would be valued more highly at firm A. Finally, in case of (B, A), the two firms are able to reciprocally exchange their patents and realize their full value.

Firms' individual expected profits are as defined in (1), with the payoffs given in table 1. Again, we are interested in the symmetric equilibria of R&D competition under an IP-for-IP regime, i.e. in equilibria where $a_2 = b_1$ and $b_2 = a_1$.

Lemma 1 *For $\delta = 1$, first order conditions under IP-for-IP are identical to those under free trade implying that the respective IP-for-IP equilibrium is the same as under free trade.*

Proof: See A.3

For $\delta = 1$ firms can commercialize either patent at full value. This makes trade irrelevant as in this case there are no gains from trade. This, in turn, implies that IP-for-IP based trade restrictions are ineffective if $\delta = 1$. However, for all $\delta < 1$, IP-for-IP changes the nature of R&D competition between firms A and B as it changes the structure of expected payoffs. If δ is smaller than one then a firm might be forced to commercialize a patent at value δV while trade would have been desirable. This lowers the expected private value of the patent that can not be fully exploited. This in turn weakens the R&D incentives regarding one of the two projects. The introduction of IP-for-IP based trade restrictions strategically interlinks both research projects since the ability to trade a certain patent depends on the distribution of patents over both projects.

Proposition 2 *(i) For all $\delta \in [0,1]$ there exists an R&D equilibrium that is characterized by R&D overinvestment in comparison to the cooperative solution. (ii) For all $\delta \in [0, \frac{2}{V+1}]$ there exists an additional equilibrium in firms' R&D expenditures. This equilibrium also leads to overinvestment as long as $\delta < \frac{2}{V+1}$. At $\delta = \frac{2}{V+1}$ it coincides with the cooperative solution.*

Proof: See A.4

According to proposition 2, for all $\delta < 1$ except $\delta = \frac{2}{V+1}$, firms overinvest in R&D compared to the cooperative solution. The strategic interrelation between both projects under IP-for-IP leads to two equilibria as long as δ is sufficiently small. One equilibrium (henceforth called "high expenditure equilibrium") exists over the full range of δ whereas the second equilibrium ("low expenditure equilibrium") does not exist if $\delta > \frac{2}{V+1}$.[10] At $\delta = \frac{2}{V+1}$ the low expenditure equilibrium leads to perfect coordination between the firms, i.e. both firms' equilibrium behavior coincides with the cooperative solution. That is, firm A (firm B) invests $\ln V$ (zero) in project 1 and zero ($\ln V$) in project 2.

Corollary 1 *(i) Let $\delta = 1$. Then, a marginal reduction in δ lowers firms' total R&D expenditures in both the free trade scenario and under IP-for-IP. However, the decrease in total R&D expenditures is larger under IP-for-IP than under free trade. (ii) Consider the low expenditure IP-for-IP equilibrium at $\delta = \frac{2}{V+1}$ (where $a_1 = b_2 = \ln V$ and $b_1 = a_2 = 0$). Then, a marginal reduction in δ lowers a_1 and b_2, raises a_2 and b_1, and leads to an increase in overall R&D expenditures.*

Proof: See A.5

Corollary 1 illustrates the structure of the IP-for-IP equilibria in relation to the equilibrium under free trade. At $\delta = 1$, a decrease in δ leads to a stronger reduction in total R&D expenditures under IP-for-IP than under free trade suggesting that firms' total investment is smaller under IP-for-IP than under free trade. At $\delta = \frac{2}{V+1}$, both IP-for-IP equilibria exist, with total R&D expenditures inversely related to δ in the low expenditure equilibrium. Figure 1 presents again the results derived so far. It shows the R&D expenditures per firm in the symmetric equilibria for $V = 16$. For $\delta \leq [\frac{2}{V+1} = 2/17]$ it shows both IP-for-IP equilibria (for $\delta > 2/17$, there is only the high-expenditure equilibrium). Both are characterized by lower

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[10] Note that apart from potential asymmetric equilibria, there exists also a third symmetric equilibrium where firm A (firm B) only invests in market 1 (market 2). This equilibrium reproduces the cooperative solution for all $\delta \leq \frac{2}{V+1}$. However, this equilibrium is due to the finite marginal productivity of R&D when expenditures are zero. If the success probability is adjusted such that marginal productivity is infinite at zero expenditures, this third equilibrium does not exist any more, while the other two prevail. However, due to tractability of the analysis, the finite marginal productivity form is used in the paper.

investments than under free trade. At $\delta = 2/17$ the low expenditure equilibrium coincides with the cooperative solution.

3.3 Choosing the Terms of Trade

Assessing the optimality of free trade versus IP-for-IP involves summing up the costs and benefits of each scenario. The major trade-off involved in the decision of free trade versus IP-for-IP can be described as dampened R&D competition in terms of lower investment levels versus potentially forgone gains from trade. The costs of forgone gains from trade depend on δ in two aspects. Firstly, δ directly determines the proportion of V that a firm can commercialize if trade is desirable but not possible due to trade restrictions. Secondly, equilibrium investment levels depend on δ which alters the probability that a situation occurs where gains from trade remain unexploited.

Lemma 2 *For $\delta = 1$, the costs of IP-for-IP are zero. At $\delta = \frac{2}{V+1}$, IP-for-IP causes strictly positive costs in the high expenditure equilibrium and zero costs in the low expenditure equilibrium. There exists no further value of δ where the costs of IP-for-IP are zero in either of the two equilibria.*

Proof: See A.6

The combination of proposition 2 and lemma 2 implies that for $\delta = \frac{2}{V+1} > 0$, R&D competition under IP-for-IP yields the cooperative profit level for each firm. Figure 2 illustrates the expected profits under each scenario. In the high-expenditure equilibrium, IP-for-IP leads to lower expected profits than under free trade as long as $\delta < 1$. For $\delta = 1$ IP-for-IP based trade restrictions are ineffective and yield the same expected profits as under free trade. In the low-expenditure equilibrium, an IP-for-IP strategy is more profitable than free trade for $\delta = \frac{2}{V+1}$.

Proposition 3 *For $\delta = \frac{2}{V+1}$, choosing the IP-for-IP scenario and the low expenditure equilibrium R&D levels is a subgame perfect equilibrium.*

Proof: See A.7

This result suffices to show that firms may gain from committing to what appear to be ex post inefficient terms of trade. Given the results from our numerical analysis (as represented in figure 2), we are able to provide even further characterizations of firms' optimal choice of trading scenarios: (1) There exists a critical $\delta_0 < \frac{2}{V+1}$ such that for all $\delta \in (\delta_o, \frac{2}{V+1}]$ IP-for-IP is the most profitable strategy.[11] Hence, there is a parameter range for δ where IP-for-IP and the low expenditure

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[11] Numerical calculations show that for higher values of V, δ_o is negative.

equilibrium form a subgame perfect equilibrium. (2) As the high expenditure equilibrium produces lower profits than either the free trade scenario (except for $\delta = 1$) or the low expenditure equilibrium, we can also conclude that choosing free trade and corresponding R&D expenditure levels is a subgame perfect equilibrium for all levels of δ. (3) Unless there exists an asymmetric equilibrium in the free trade scenario which yields even lower profits than the high expenditure equilibrium under IP-for-IP, the choice of the latter is not a subgame perfect equilibrium, as it would be dominated by the free trade equilibrium.[12] As a consequence, the choice of IP-for-IP by any firm in t=0 of the game acts as a signal which coordinates the two firms to play the low expenditure equilibrium in the ensuing R&D game (see e.g. van Damme, 1989).

Lastly, the above results can be used to construct equilibria in a repeated game version of the model: Consider a repeated extensive game that starts with R&D investment decisions and where firms announce their trading intentions after patents have been allocated. For values of δ where the low expenditure IP-for-IP equilibrium yields higher profits than free trade, the following strategy supports restricting oneself to IP-for-IP and the corresponding low expenditure equilibrium investments for discount factors sufficiently close to one: each player invests according to the low expenditure equilibrium and only suggests trade if it is reciprocal (barter). Players continue to do so in all following repetitions unless the competitor suggests a one-sided cash trade. Once a competitor suggested to trade for cash, each player invests according to the free trade equilibrium and always suggests to trade if gains from trade exist. This free trade equilibrium is played in all repetitions of the game thereafter. As the gains from playing IP-for-IP outweigh those from deviation (realizing gains from trade once and realizing free trade payoffs thereafter), IP-for-IP may be supported in a repeated game instead of assuming a commitment mechanism.

4 Extensions

In what follows, we consider two extensions to our model that incorporate two important aspects of the market for technology. First, we allow for joint usage of a patent by both firms such that "trade" of IP now implies cross-licensing instead of a full sale of IP. Second, we introduce firm heterogeneity by allowing the two firms to differ in their commercialization abilities. Both extensions are solved

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[12] IP-for-IP and the high expenditure equilibrium form a Nash equilibrium of the complete game only if choice of free trade produces even lower profits. This violates the requirements of subgame perfection unless the above-mentioned asymmetric equilibrium exists. We were unable to find such an equilibrium in our simulations.

numerically.

4.1 Cross-licensing: Feature Complementarity

The empirical motivation of the paper mainly stems from the literature on cross-licensing deals. However, in our base model, transactions take the form of outright sale of IP from one firm to another. To capture (cross-)licensing, that is the use of a patent by the inventing firm and at least one other firm, we assume that patent 2 contains a feature that complements patent 1, and vice versa. By using both patents, a firm may thus capture an enhanced maximum value of γV, where $\gamma \geq 1$, from each patent. The payoffs from using a single patent, however, remain the same. This is illustrated in table 2 which shows the post-trade payoffs under free trade and IP-for-IP for the base model and the extensions.[13] Payoffs only differ from the base model in case both patents exist. Under free trade, firms now realize twice the full value of a patent plus the complementary value $(1-\gamma)V$. Under IP-for-IP and asymmetric pre-trade patent allocation, the firm owning the patents realizes the fully enhanced value only in one market and the reduced value of $\delta\gamma V$ in the other market.

The structure of the equilibria under free trade and IP-for-IP remains as in the base model. The key effect of feature complementarity is to increase the value of both patents existing. This raises R&D incentives for the firms in both R&D projects. Consequently, it is also harder for a firm to keep its competitor out of a project. Figure 3 shows the resulting net gain for a firm from choosing IP-for-IP (and low expenditure equilibrium investments) versus free trade. Starting from no complementary value ($\gamma = 1$, i.e. the base model), an increase in γ leads to a shift of the net payoff curve to the left. In sum, the introduction of cross-licensing via feature complementarity requires firms to differ more in term of commercialization abilities in order for IP-for-IP to be attractive.

4.2 Asymmetric Firms

SO far, the model has assumed that both firms are symmetric in all respects. Given one of our motivations in the introduction – Intel's IP-for-IP strategy – one may wonder if firms are indeed symmetric in reality. Therefore, in this part of the analysis we are interested in an asymmetric setting where one of the two firms enjoys an exogenous competitive advantage over the other firm. As our core model focuses on the commercialization ability of both firms (δ), we drive a wedge between both firms' abilities to commercialize patents. More precisely, we now

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[13] Where payoffs differ from the base model, table cells are highlighted by shading.

assume that $\delta_A > \delta_B = 0$. That is, firm B is unable to commercialize patent 1 whereas firm A still obtains a strictly positive value from patent 2. Given this modification, firm B's motives to invest in project 1 are reduced to obtaining patent 1 as a trading good (either in exchange for cash or IP). Under an IP-for-IP strategy, if firm A does not hold patent 2 then the value of patent 1 is zero for firm B as the latter is unable to commercialize patent 1 and trade is ruled out.[14] In contrast, firm A still obtains a positive value from patent 2 when trade is not possible.[15] This type of asymmetry gives firm A an advantage over firm B under an IP-for-IP strategy. Our numerical results show that firm A has higher incentives to employ an IP-for-IP trade restriction than firm B (see figure 4). Moreover, in our simulations there still exist multiple equilibria under IP-for-IP implying that the multiplicity of equilibria under IP-for-IP is robust to the introduction of asymmetry with respect to δ.

5 Concluding Remarks

The model in this paper argues that the type of "currency" used in technology transactions may have an impact on R&D competition between firms. In the simplest set-up, the model has two firms allocating their research budget over two R&D projects. Firms' R&D technologies are homogeneous across both projects. However, firms have heterogeneous commercialization abilities regarding the output of the two projects which enables them to realize potential gains from trade upon the completion of R&D activity. We have analyzed the effects that arise from a trade restricting strategy which restrains firms from using cash when trading technology. The model has shown that the introduction of such an IP-for-IP strategy causes a trade-off. On the one hand, firms forego potential gains from trade as in some cases desirable trade does not take place because it would require cash transactions. On the other hand, these trade restrictions drive a wedge between the two projects and thus soften R&D competition. That is, under an IP-for-IP strategy, both firms concentrate their R&D effort on the project where they have a higher commercialization ability. The model has shown that IP-for-IP can be a profitable strategy as long as the difference between firms' commercialization abilities is sufficiently high.

This model has shown that the way IP is traded in the market for technology has an impact on the market for the creation of technology. Thus, it gives one (ex-ante orientated) explanation why cash might be a different currency than IP in the

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[14] As before, in this part of the analysis we assume that an IP-for-IP strategy rules out any cash payments.

[15] See table 2 for the full payoff structure.

market for technology. This suggests that firms may influence R&D competition by modifying the terms of trade in the market for technology. However, in order to gain more insight in this topic, the model could be extended in various directions. One straightforward extension would be to take into account potential product market interactions between the two firms instead of assuming, as is done in this paper, that firms operate in distinct product markets.

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A Appendix

A.1 Derivation of equations (3) and (4)

The first order conditions for the maximization of firms' individual profits under the assumption of symmetry ($a_2 = b_1, b_2 = a_1$) for project 1 are

$$\frac{V}{4}(e^{-a_1}((1+\delta)+(3-\delta)e^{-b_1}))-1=0 \tag{5}$$

and

$$\frac{V}{4}\,(\delta+1)\,e^{-b_1}(1+e^{-a_1})-1=0\;. \tag{6}$$

The combination of these two first order conditions yields equation (3). The same procedure applies to the derivation of equation (4).

A.2 Proof of proposition 1

First order conditions with respect to a_1 and b_1 can be expressed as

$$\frac{1}{e^{a_1}}=\frac{4}{(1+\delta)V}-\frac{(3-\delta)}{(1+\delta)}\frac{1}{e^{a_1+b_1}} \tag{7}$$

and

$$\frac{1}{e^{b_1}}=\frac{4}{(1+\delta)\,V}-\frac{1}{e^{a_1+b_1}}\;, \tag{8}$$

respectively. The unique defined mutual solution to these first order conditions is given by

$$a_1=\ln\frac{V(1+\delta)^2+8(1-\delta)+\sqrt{V^2(1+\delta)^4+32V\,(1+\delta)^2+64(1-\delta)^2}}{8(1+\delta)} \tag{9}$$

and

$$b_1=\ln\frac{V(1+\delta)^2-8(1-\delta)+\sqrt{V^2(1+\delta)^4+32V\,(1+\delta)^2+64(1-\delta)^2}}{8(1+\delta)}\;. \tag{10}$$

In order to ensure non-negative individual investment levels it is required that $V \geq 3$. The sum of non-cooperative investments is thus

$$a_1+b_1=\ln\frac{(V(1+\delta)^2+\sqrt{V^2(1+\delta)^4+32V\,(1+\delta)^2+64(1-\delta)^2})^2-64(1-\delta)^2}{64(1+\delta)^2} \tag{11}$$

which is greater than $\ln V$ for $V \geq 3$ and increasing in δ.

A.3 Proof of lemma 1

First order conditions for the IP-for-IP case are given by

$$\begin{aligned} a_1 &: e^{-a_1}\frac{1}{2}(1+e^{-b_1}-\frac{1}{2}(1-\delta)\left(1-e^{-b_1}\right)\left(1-e^{-a_2}\right)(1+e^{-b_2}))=\frac{1}{V} && (12)\\ a_2 &: e^{-a_2}\frac{1}{4}\left(1+e^{-b_2}\right)(2\delta+(1-\delta)\left(1-e^{-b_1}\right)(1+e^{-a_1}))=\frac{1}{V} && (13)\\ b_1 &: e^{-b_1}\frac{1}{4}\left(1+e^{-a_1}\right)(2\delta+(1-\delta)\left(1-e^{-a_2}\right)(1+e^{-b_2}))=\frac{1}{V} && (14)\\ b_2 &: e^{-b_2}\frac{1}{2}(1+e^{-a_2}-\frac{1}{2}(1-\delta)\left(1-e^{-a_2}\right)\left(1-e^{-b_1}\right)(1+e^{-a_1}))=\frac{1}{V} && (15) \end{aligned}$$

If $\delta = 1$ the these first order coincide with those under free trade and reduce to

$$\begin{aligned} a_1 &: e^{-a_1}\frac{1}{2}(1+e^{-b_1})=\frac{1}{V} && (16)\\ a_2 &: e^{-a_2}\frac{1}{2}\left(1+e^{-b_2}\right)=\frac{1}{V} && (17)\\ b_1 &: e^{-b_1}\frac{1}{2}\left(1+e^{-a_1}\right)=\frac{1}{V} && (18)\\ b_2 &: e^{-b_2}\frac{1}{2}(1+e^{-a_2})=\frac{1}{V}. && (19) \end{aligned}$$

A.4 Proof of proposition 2

By focussing on symmetric equilibria, the first order conditions in (12) to (15) reduce to (substitute $a_2 = b_1$ and $b_2 = a_1$):

$$e^{-a_1}\frac{V}{2}(1+e^{-b_1}-\frac{1}{2}(1-\delta)\left(1-e^{-b_1}\right)^2(1+e^{-a_1}))-1=0 \quad (20)$$

$$e^{-b_1}\frac{V}{4}\left(1+e^{-a_1}\right)(2\delta+(1-\delta)\left(1-e^{-b_1}\right)(1+e^{-a_1}))-1=0 \quad (21)$$

In what follows, we will mostly analyze these equilibrium loci in terms of the "failure probabilities" $a \equiv e^{-a_1} \leq 1$ and $b \equiv e^{-b_1} \leq 1$:

$$\begin{aligned} \psi_a &\equiv a\frac{V}{2}(1+b-\frac{1}{2}(1-\delta)(1-b)^2(1+a))-1=0 && (22)\\ \psi_b &\equiv b\frac{V}{4}(1+a)(2\delta+(1-\delta)(1-b)(1+a))-1=0 && (23) \end{aligned}$$

The proof then proceeds in four steps: (a) characterize the two equilibrium loci; (b) show that the equilibrium loci always intersect for some $b < 1$; (c) show that any equilibrium with $b < 1$ implies overinvestment; (d) show that there is a critical delta where the cooperative solution applies. (e) show that for δ below the critical level, there exist additional equilibria with overinvestment.

(a) Characterization of equilibrium loci: Let ψ_{ax} (ψ_{bx}) be the partial derivative of ψ_a (ψ_b) with respect to x (and correspondingly for higher-order derivatives), and let $(.)|_{\psi_i}$ denote an analysis along the equilibrium locus ψ_i.

Then (22) defines an equilibrium locus with the following properties:

- $b(a)|_{\psi_a}$ is (weakly) decreasing in δ:

$$\left.\frac{db}{d\delta}\right|_{\psi_a} = -\frac{\psi_{a\delta}}{\psi_{ab}} \tag{24}$$

$$= -\frac{\frac{V}{4}a(1-b)^2(1+a)}{\frac{V}{2}a(1+(1-\delta)(1-b)(1+a))} \leq 0 \tag{25}$$

- For $\delta = 0$ and $b < 1$, $b(a)|_{\psi_a}$ has a minimum at $a = \frac{1+b}{(1-b)^2} - \frac{1}{2}$:

$$\left.\frac{db}{da}\right|_{\psi_a,\delta=0} = -\left.\frac{\psi_{aa}}{\psi_{ab}}\right|_{\delta=0} \tag{26}$$

$$= -\frac{\frac{V}{2}(1+b-(1-b)^2(\frac{1}{2}+a))}{\frac{V}{2}a(1+(1-b)(1+a))} \tag{27}$$

  which is equal to zero at $a^{min} \equiv \frac{1+b}{(1-b)^2} - \frac{1}{2}$. This is a minimum:

$$\left.\frac{d^2b}{da^2}\right|_{\psi_a,\delta=0,a=a^{min}} = -\left.\frac{\psi_{aaa}}{\psi_{ab}}\right|_{\delta=0,a=a^{min}} > 0 \tag{28}$$

  as $\psi_{aaa} = -(1-b)^2V/2 < 0$.

- For $\delta = 1$, $b(a)|_{\psi_a}$ is decreasing in a:

$$\left.\frac{db}{da}\right|_{\psi_a,\delta=1} = -\left.\frac{\psi_{aa}}{\psi_{ab}}\right|_{\delta=1} \tag{29}$$

$$= -\frac{\frac{V}{2}(1+b)}{a\frac{V}{2}} < 0 \tag{30}$$

- $a(b)_{\psi_a}$ has a lower boundary at $1/V$ for $b \in [0,1]$: for $\delta = 1$, inserting the boundary yields $b(a = 1/V)|_{\psi_a,\delta=1} = 1$. As $b(a)|_{\psi_a}$ is (weakly) decreasing in δ, $a(b)|_{\psi_a} \geq 1/V$ for any $\delta \in [0,1]$.

In sum, the function $b(a)$ defined by (22) has a maximum support of $[1/V, 1]$, has a lower boundary for $\delta = 1$, has an upper boundary for $\delta = 0$, is decreasing in a for $\delta = 1$ and is u-shaped for $\delta = 0$.

Next, we can characterize the equilibrium locus defined by (23):

- $a(b)|_{\psi_b}$ is decreasing in δ:

$$\left.\frac{da}{d\delta}\right|_{\psi_b} = -\frac{\psi_{b\delta}}{\psi_{ba}} \tag{31}$$

$$= -\frac{b\frac{V}{4}(1+a)(2-(1+a)(1-b))}{b\frac{V}{2}(\delta+(1-\delta)(1-b)(1+a))} < 0 \tag{32}$$

- For $\delta = 0$ and $b \in (0,1)$, $a(b)|_{\psi_b}$ has a minimum at $b = 1/2$:

$$\left.\frac{da}{db}\right|_{\psi_b,\delta=0} = -\left.\frac{\psi_{bb}}{\psi_{ba}}\right|_{\delta=0} \tag{33}$$

$$= -\frac{\frac{V}{4}(1+a)^2(1-2b)}{b\frac{V}{2}(1-b)(1+a)} \tag{34}$$

  is equal to zero for $b = 1/2$. To confirm that this is a minimum, we need to show that

$$\left.\frac{d^2a}{db^2}\right|_{\psi_b,\delta=0,b=1/2} = -\left.\frac{\psi_{bbb}\psi_{ba} - \psi_{bab}\psi_{bb}}{(\psi_{ba})^2}\right|_{\delta=0,b=1/2} > 0 \tag{35}$$

  which is true because

$$-(\psi_{bbb}\psi_{ba} - \psi_{bab}\psi_{bb})|_{\delta=0,b=1/2} = \frac{V^2}{16}(1+a)^3 > 0 \tag{36}$$

- For $\delta = 1$, $a(b)|_{\psi_b}$ is decreasing in b:

$$\left.\frac{da}{db}\right|_{\psi_b,\delta=1} = -\left.\frac{\psi_{bb}}{\psi_{ba}}\right|_{\delta=1} \tag{37}$$

$$= -\frac{\frac{V}{2}(1+a)}{\frac{V}{2}b} < 0 \tag{38}$$

- $b(a)|_{\psi_b}$ has a lower boundary at $1/V$ for $a \in [0,1]$: for $\delta = 1$, inserting the boundary yields $a(b = 1/V)|_{\psi_b\delta=1} = 1$. As $a(b)|_{\psi_b}$ is decreasing in δ and in b, any $\delta < 1$ implies $b(a)|_{\psi_b} > 1/V$.

In sum, the function $a(b)$ defined by (23) has a maximum support of $[1/V, 1]$, has a lower boundary for $\delta = 1$, has an upper boundary for $\delta = 0$, is decreasing in b for $\delta = 1$ and is u-shaped for $\delta = 0$.

(b) There exists always an equilibrium with $b < 1$: We will next show that, for V sufficiently large, the equilibrium loci always intersect at some interior point $(a,b) \in (1/V,1)^2$.

- The equilibrium loci never intersect for $a \in [a^{min}, 1]$: For $a = 1$, $b(a = 1)_{\psi_a,\delta=0} = \frac{3}{2} \pm \frac{1}{2}\sqrt{9 - 8/V}$; the (relevant) lower solution always lies below $1/V$, which is the lower boundary of $b(a)_{\psi_b}$: $\frac{3}{2} - \frac{1}{2}\sqrt{9-8/V} - \frac{1}{V}$ is increasing in V and approaches zero asymptotically (from below).

- For $\delta = 0$ and $b \in (0,1)$, the minimum of $a(b)|_{\psi_b}$ lies below $1/V$ if $V > 14$:

$$a(b = 1/2)|_{\psi_b,\delta=0} = \frac{4}{\sqrt{V}} - 1 \tag{39}$$

  which is lower than $1/V$ if $V > 7 + 4\sqrt{3}$. Hence, $V > 14$ is a sufficient condition for $a(b = 1/2)|_{\psi_b,\delta=0} < 1/V$.

These two features are sufficient for an intersection of the two equilibrium loci with $(a,b) \in (1/V,1)^2$.

(c) For all equilibria with $b \in [1/V, 1)$, there is overinvestment: Overinvestment relative to the cooperative solution exists if $a_1 + b_1 > \ln V$. Along the equilibrium locus defined by (20), the cooperative level of investment is reached for $b_1 = 0$. If, for any $b_1 \in [0, \ln V]$, the implied function of a_1 (at its lower bound, ie for $\delta = 0$) decreases by less than one, then there is overinvestment for any $b_1 > 0$. Totally differentiating (20) yields (along the equilibrium locus):

$$\frac{da_1}{db_1} \quad = \quad - \frac{-e^{-a1} e^{-b1} \frac{V}{2} (1 + (1 - e^{-b1})(1 + e^{-a1}))}{-e^{-a1} \frac{V}{2} (1 + e^{-b1} - (1 - e^{-b1})^2 (\frac{1}{2} + e^{-a1}))} \tag{40}$$

The absolute value of this slope has to be less than one, which requires (replacing again e^{-a1} with a and e^{-b1} with b)

$$b(1 + (1 - b)(1 + a)) < 1 + b - (1 - b)^2 (\frac{1}{2} + a) \;, \tag{41}$$

or

$$a < \frac{1 + b^2}{2(1 - b)} \tag{42}$$

Note that for $V \geq 16$, the equilibrium a is bounded from above at $a = 1/2$: $a(b = 0)_{\psi_a, \delta = 0} = \frac{1}{2}(1 \pm \sqrt{1 - 16/V})$, where the lower solution applies as it lies below the minimum of $a(b)_{\psi_a, \delta = 0}$. Hence, (42) is always fulfilled if $\frac{1+b^2}{2(1-b)} > \frac{1}{2}$, which is true for all $b > 0$. This proofs that there is overinvestment for any $b_1 > 0$ and concludes the proof of (i).

(d) For $\delta = \frac{2}{V+1}$ the cooperative solution is an equilibrium: For $b = 1$, $a(b)|_{\psi_a}$ always yields $a = 1/V$. This can only be an equilibrium if (23) also holds, which is true only for $\delta = \frac{2}{V+1}$.

(e) For $\delta < \frac{2}{V+1}$ there exist multiple overinvestment equilibria: Because $a(b)|_{\psi_b}$ is decreasing in δ (see (a)) and has its minimum below $1/V$ (see (b)), the two equilibrium loci have to intersect twice for $\delta \leq \frac{2}{V+1}$. For $\delta < \frac{2}{V+1}$, $b < 1$ for both equilibria. Given the argument in (d), the latter implies that there is overinvestment in both equilibria. This concludes the proof of (ii).

A.5 Proof of corollary 1

The results follow from comparative static analyses of the equilibrium conditions (22) and (23) for the IP-for-IP case and (5) and (6) for the free trade scenario. In order to simplify the exposition, the analysis is done in "failure probabilities" $a \equiv e^{-a_1} \leq 1$ and $b \equiv e^{-b_1} \leq 1$ with superscript IP and FT indicating the two scenarios, respectively. Re-writing (5) and (6) yields

$$\phi_a \equiv \frac{V}{4}a(1+\delta+(3-\delta)b)-1=0 \tag{43}$$

$$\phi_b \equiv \frac{V}{4}(1+\delta)b(1+a)-1=0\ . \tag{44}$$

Using the same notation as in the proof of proposition 2, we can define the following comparative static effects:

$$\frac{da^{FT}}{d\delta} = \frac{\phi_{ab}\phi_{b\delta}-\phi_{bb}\phi_{a\delta}}{\phi_{aa}\phi_{bb}-\phi_{ab}\phi_{ba}} \tag{45}$$

$$\frac{db^{FT}}{d\delta} = \frac{\phi_{ba}\phi_{a\delta}-\phi_{aa}\phi_{b\delta}}{\phi_{aa}\phi_{bb}-\phi_{ab}\phi_{ba}} \tag{46}$$

$$\frac{da^{IP}}{d\delta} = \frac{\psi_{ab}\psi_{b\delta}-\psi_{bb}\psi_{a\delta}}{\psi_{aa}\psi_{bb}-\psi_{ab}\psi_{ba}} \tag{47}$$

$$\frac{db^{IP}}{d\delta} = \frac{\psi_{ba}\psi_{a\delta}-\psi_{aa}\psi_{b\delta}}{\psi_{aa}\psi_{bb}-\psi_{ab}\psi_{ba}} \tag{48}$$

(i) then follows from (note that at $\delta=1$, $a^{FT}=b^{FT}=a^{IP}=b^{IP}=a$)

$$\begin{aligned}\left.\frac{d[a^{FT}b^{FT}]}{d\delta}\right|_{\delta=1} &= \left. b\frac{da^{FT}}{d\delta}+a\frac{db^{FT}}{d\delta}\right|_{\delta=1} \\ &= -\frac{a^2}{1+2a}<0 \qquad (49)\\ \left.\frac{d[a^{IP}b^{IP}]}{d\delta}\right|_{\delta=1} &= \left. b\frac{da^{IP}}{d\delta}+a\frac{db^{IP}}{d\delta}\right|_{\delta=1} \\ &= -\frac{a^2+a^5}{1+2a}<0 \qquad (50)\end{aligned}$$

and

$$\left.\frac{d[a^{IP}b^{IP}]}{d\delta}\right|_{\delta=1} - \left.\frac{d[a^{FT}b^{FT}]}{d\delta}\right|_{\delta=1} = -\frac{a^5}{1+2a}<0 \tag{51}$$

(ii) follows from (note that at $\delta=2/(V+1)$, $b=1$ and $a=1/V$ in the cooperative equilibrium)

$$\left.\frac{da^{IP}}{d\delta}\right|_{\delta=2/(V+1)} = \frac{1+V}{4V-V^2}<0 \tag{52}$$

$$\left.\frac{db^{IP}}{d\delta}\right|_{\delta=2/(V+1)} = \frac{2(1+V)}{V-4}>0 \tag{53}$$

and

$$\left.\frac{d[a^{IP}b^{IP}]}{d\delta}\right|_{\delta=2/(V+1)} = \frac{1+V}{V^2-4V}>0 \tag{54}$$

where all signs hold for $V>4$.

A.6 Proof of lemma 2

Firm A's expected costs of IP-for-IP in the symmetric case are

$$\frac{(1-\delta)}{4} V \alpha_B \left(2-\alpha_A\right)\left(2-2\alpha_B+\alpha_A\alpha_B\right) \tag{55}$$

where $\alpha_A \equiv 1-e^{-a_1}$ and $\alpha_B \equiv 1-e^{-b_1}$. These costs can only become zero if (i) $\delta = 1$, or (ii) $\alpha_B = 0$ ($\Leftrightarrow b_1 = 0$). The latter case holds if $\delta = \frac{2}{V+1}$. The term $(2-2\alpha_B+\alpha_A\alpha_B)$ cannot become zero as $\alpha_B < 1$ but $\alpha_A \geq 0$.

A.7 Proof of proposition 3

Given the investment levels at the cooperative level (proposition 2) and zero cost of choosing IP-for-IP (lemma 2) choice of the IP-for-IP scenario and the low expenditure equilibrium levels of R&D spending yields the highest profits achievable for the two firms.

(ω_1, ω_2)	$p(\omega_1, \omega_2)$	$\pi_i(\omega_1, \omega_2)$	
		Free trade	IP-for-IP
$(\emptyset, \emptyset)$	$(e^{-a_1}e^{-b_1}) \cdot (e^{-a_2}e^{-b_2})$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$
$(A, \emptyset)$	$[(1-e^{-a_1})(e^{-b_1}) + \frac{1}{2}(1-e^{-a_1})(1-e^{-b_1})] \cdot (e^{-a_2}e^{-b_2})$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$
$(B, \emptyset)$	$[(1-e^{-b_1})(e^{-a_1}) + \frac{1}{2}(1-e^{-a_1})(1-e^{-b_1})] \cdot (e^{-a_2}e^{-b_2})$	$\pi_A = \frac{1-\delta}{2}V$ $\pi_B = \frac{1+\delta}{2}V$	$\pi_A = 0$ $\pi_B = \delta V$
$(\emptyset, B)$	$[(1-e^{-b_2})(e^{-a_2}) + \frac{1}{2}(1-e^{-b_2})(1-e^{-a_2})] \cdot (e^{-a_1}e^{-b_1})$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$
$(\emptyset, A)$	$[(1-e^{-a_2})(e^{-b_2}) + \frac{1}{2}(1-e^{-b_2})(1-e^{-a_2})] \cdot (e^{-a_1}e^{-b_1})$	$\pi_A = \frac{1+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = \delta V$ $\pi_B = 0$
(A, A)	$[(1-e^{-a_1})(e^{-b_1}) + \frac{1}{2}(1-e^{-a_1})(1-e^{-b_1})] \cdot \left[(1-e^{-a_2})(e^{-b_2}) + \frac{1}{2}(1-e^{-a_2})(1-e^{-b_2})\right]$	$\pi_A = \frac{3+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = (1+\delta)V$ $\pi_B = 0$
(B, B)	$[(1-e^{-b_1})(e^{-a_1}) + \frac{1}{2}(1-e^{-a_1})(1-e^{-b_1})] \cdot \left[(1-e^{-b_2})(e^{-a_2}) + \frac{1}{2}(1-e^{-a_2})(1-e^{-b_2})\right]$	$\pi_A = \frac{1-\delta}{2}V$ $\pi_B = \frac{3+\delta}{2}V$	$\pi_A = 0$ $\pi_B = (1+\delta)V$
(B, A)	$[(1-e^{-b_1})(e^{-a_1}) + \frac{1}{2}(1-e^{-b_1})(1-e^{-a_1})] \cdot \left[(1-e^{-a_2})(e^{-b_2}) + \frac{1}{2}(1-e^{-b_2})(1-e^{-a_2})\right]$	$\pi_A = V$ $\pi_B = V$	$\pi_A = V$ $\pi_B = V$
(A, B)	$[(1-e^{-a_1})(e^{-b_1}) + \frac{1}{2}(1-e^{-a_1})(1-e^{-b_1})] \cdot \left[(1-e^{-b_2})(e^{-a_2}) + \frac{1}{2}(1-e^{-a_2})(1-e^{-b_2})\right]$	$\pi_A = V$ $\pi_B = V$	$\pi_A = V$ $\pi_B = V$

Table 1: Patent allocations and payoffs

(ω_1, ω_2)	Base Model $\pi_i(\omega_1, \omega_2)$		Feature Complementarity $\pi_i(\omega_1, \omega_2)$		Asymmetric Firms $\pi_i(\omega_1, \omega_2)$	
	Free trade	IP-for-IP	Free trade	IP-for-IP	Free trade	IP-for-IP
$(\emptyset, \emptyset)$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$	$\pi_A = 0$ $\pi_B = 0$
$(A, \emptyset)$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$	$\pi_A = V$ $\pi_B = 0$
$(B, \emptyset)$	$\pi_A = \frac{1-\delta}{2}V$ $\pi_B = \frac{1+\delta}{2}V$	$\pi_A = 0$ $\pi_B = \delta V$	$\pi_A = \frac{1-\delta}{2}V$ $\pi_B = \frac{1+\delta}{2}V$	$\pi_A = 0$ $\pi_B = \delta V$	$\pi_A = \frac{1}{2}V$ $\pi_B = \frac{1}{2}V$	$\pi_A = 0$ $\pi_B = 0$
$(\emptyset, B)$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$	$\pi_A = 0$ $\pi_B = V$
$(\emptyset, A)$	$\pi_A = \frac{1+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = \delta V$ $\pi_B = 0$	$\pi_A = \frac{1+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = \delta V$ $\pi_B = 0$	$\pi_A = \frac{1+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = \delta V$ $\pi_B = 0$
(A, A)	$\pi_A = \frac{3+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = (1+\delta)V$ $\pi_B = 0$	$\pi_A = \frac{3+\delta}{2}\gamma V$ $\pi_B = \frac{1-\delta}{2}\gamma V$	$\pi_A = (1+\delta)\gamma V$ $\pi_B = 0$	$\pi_A = \frac{3+\delta}{2}V$ $\pi_B = \frac{1-\delta}{2}V$	$\pi_A = (1-\delta)V$ $\pi_B = 0$
(B, B)	$\pi_A = \frac{1-\delta}{2}V$ $\pi_B = \frac{3+\delta}{2}V$	$\pi_A = 0$ $\pi_B = (1+\delta)V$	$\pi_A = \frac{1-\delta}{2}\gamma V$ $\pi_B = \frac{3+\delta}{2}\gamma V$	$\pi_A = 0$ $\pi_B = (1+\delta)\gamma V$	$\pi_A = \frac{1}{2}V$ $\pi_B = \frac{3}{2}V$	$\pi_A = 0$ $\pi_B = V$
(B, A)	$\pi_A = V$ $\pi_B = V$	$\pi_A = V$ $\pi_B = V$	$\pi_A = \gamma V$ $\pi_B = \gamma V$	$\pi_A = \gamma V$ $\pi_B = \gamma V$	$\pi_A = (1+\frac{\delta}{2})V$ $\pi_B = (1-\frac{\delta}{2})V$	$\pi_A = V$ $\pi_B = V$
(A, B)	$\pi_A = V$ $\pi_B = V$	$\pi_A = V$ $\pi_B = V$	$\pi_A = \gamma V$ $\pi_B = \gamma V$	$\pi_A = \gamma V$ $\pi_B = \gamma V$	$\pi_A = V$ $\pi_B = V$	$\pi_A = V$ $\pi_B = V$

Table 2: Patent allocations and alternative payoffs

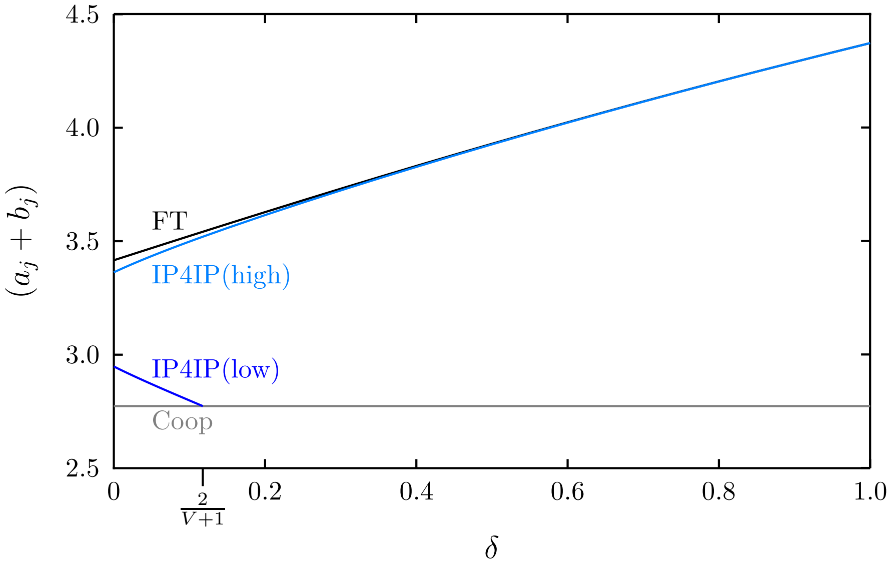

Figure 1: R&D budgets ($V = 16$)

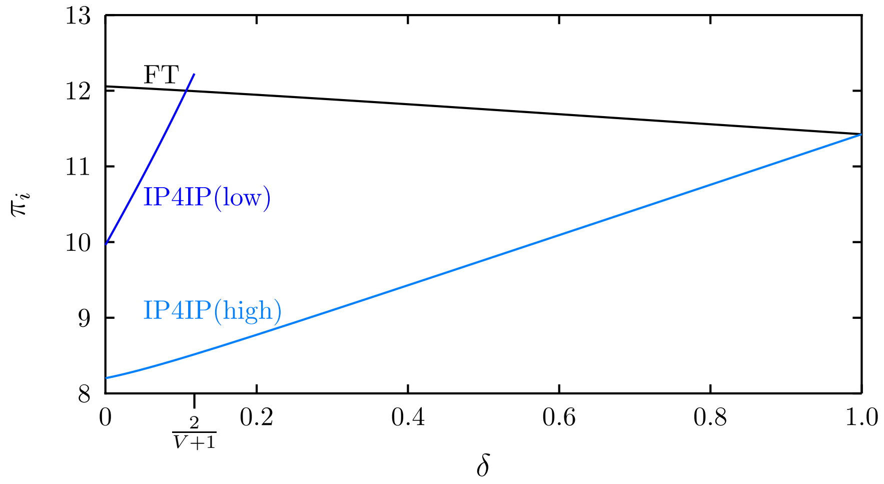

Figure 2: Expected profits ($V = 16$)

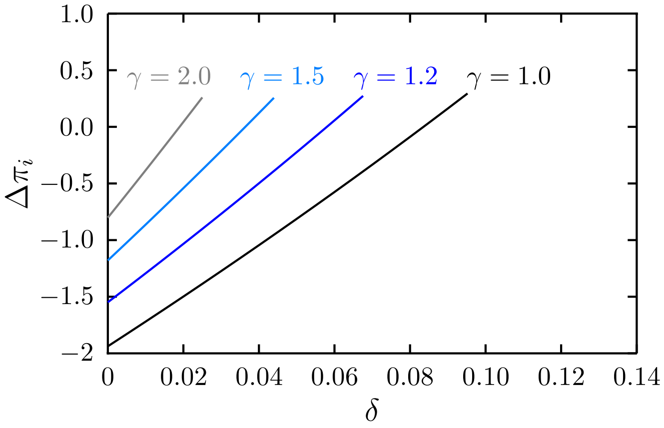

Figure 3: Feature complementarity: Profitability of IP-for-IP strategy ($V = 20$)

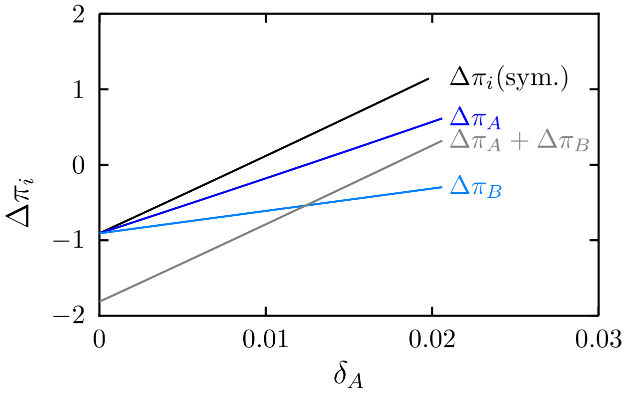

Figure 4: Asymmetric firms: Profitability of IP-for-IP strategy ($V = 100$)

A Closer Look at Inventive Output - The Role of Age and Career Paths

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July 2007

Abstract

Against the background of the aging of the economically active population accompanied by the current opinion of a decreasing productive efficiency with age, this paper is analyzing the age-output relationship of inventors. To do so, this study integrates both inventor related characteristics and external factors that may influence observable inventive output. Results of a fixed effects panel regression estimation show that different career paths of engineers in firms at least in part explain decreases in inventive output over time. This decrease would have otherwise been wrongly attributed to the relationship between output and age. Data for the analysis was derived from a survey of German inventors (N = 3,049) as well as from semi-structured interviews with inventors, R&D managers and human resource managers.

Acknowledgement

The author thanks Ferdinand Mahr and Maria Soltau for research assistance. Furthermore, the author would like to thank the conference audience at the 5th EURAM Conference in May 2005 as well as the conference audience at the 2nd ZEW Conference on Economics of Innovation and Patenting in September 2005 and at the AEA Conference on Innovations and Intellectual Property Values in June 2007 for helpful comments. Special thanks go to Dietmar Harhoff, Bruno van Pottelsberghe and Gaétan de Rassenfosse for valuable comments. The survey data used in the analysis originates from a coordinated survey carried out in Italy, France, Spain, the Netherlands, the United Kingdom and Germany. Financial support from the European Commission within the PatVal-Project is gratefully acknowledged.

1 Introduction

The end of the 19th century was characterized by outstanding and sustainable achievements in the German automobile industry, in particular, in engine construction. In 1876, Otto invented the "Otto Cycle Engine". In 1883, Daimler completed a prototype of the modern gas engine. Only two years later, Benz designed and built the first automobile powered by an "internal combustion engine". Finally, in 1897, Diesel invented the first "diesel fueled internal combustion engine", which was later called the "diesel engine". These four inventors had two things in common: (1) they were highly productive over their whole inventive career and (2) at the time they made the probably most important inventions of their lives, they were between 39 and 49 years old. This means that these inventions were made at later age, especially, when taking into account a much lower anticipated average life around 1900. This may implicate that great achievements require expert knowledge collected over decades and possibly also experience of life. Additionally, this could mean that the average inventive output needs not to decrease over time.

Studying Nobel Prize winners and famous inventors during the 20th century, Jones (2005) finds that young inventors are less productive compared to older ones. But there are also studies suggesting that a scientist's or engineer's output reaches a maximum at the age between 35 and 45 and declines afterwards (Vincent/Mirakhor 1972). Possible reasons for changes in the performance of researchers over time are (1) inventor related issues, e.g., motivation, experience or physical and mental performance or (2) external influences, e.g., incentive systems or career systems (Sauermann/Cohen 2007; Roberts/Biddle 1994; Stephan/Levin 1992).

Against the background of the aging of the economically active population accompanied by the current opinion of a decreasing productive efficiency with age, it will be interesting to analyze the age-output relationship of German inventors more closely. To do so, this study integrates both inventor related characteristics and external factors that may influence observable inventive output.

This paper moves beyond previous research by combining three data sources. First, it uses survey data on 3,049 German inventors, who hold at least one granted European patent. To trace the inventive output of each inventor over time, the EPOLINE database of the European Patent Office (EPO) was used. In particular, all patent applications with priority dates between 1977 and 1999 that listed one of the 3,049 inventors were extracted from the database. To validate the results of the following multivariate analysis, 24 interviews were conducted with R&D managers, inventors, IP managers, and human resource managers in firms active in different industries.

Citation counts are used as an output measure to overcome biases caused by strategic patenting behavior (Hall 2004). Since the number of citations a patent receives is a measure for its quality (Harhoff et al. 1999), citation counts seem to be rather independent of the increasing patenting activity. Additionally, including the number of claims per patent as a control variable allows controlling for an increasing number of citations per patent due to an increasing number of references appearing in the search report.[1]

To estimate the relationship between inventive output and age, a fixed effects panel regression will be conducted. To do so, the inventors' patent applications were sorted into groups according to the age of the inventor at the time of the application of the patent. In particular, nine five-year age groups were constructed which represent the time structure of the panel. Then the remaining variables were categorized according to this time structure (i.e., to the nine age groups). To accommodate different career paths of inventors over time, the sample is sub-divided into three groups: inventors who kept on inventing for their whole professional life, inventors who spent at least a major part of their professional life in inventive activity, and finally, inventors who stopped inventing after a short period of time.

Results reveal that the longer inventors remain in R&D, the higher their average inventive output. A possible interpretation may be that inventors who remain in R&D get more experienced and consequently increase their output. However, following the statements of the interviewees, it seems more reasonably to assume that the causality runs the other way around, inventors who generate more output stay in R&D, whereas less productive inventors leave R&D for another job, e.g., in sales. Additionally, results show that not taking different career paths of engineers into account leads to an underestimation of the output of older inventors. For instance, inventors who are promoted into management positions are no longer visible in terms of patents or citations, since they may no longer be part of R&D projects.

The remainder of this paper is divided into six sections. The following section provides an overview of the theoretical and empirical literature. The third section contains the description of the data used in the empirical part of this paper as well as the description of the dependent and the explanatory variables. Section 4 provides descriptive statistics. In section 5 a fixed effects panel regression estimation analyzes the age-performance relationship of inventors. Finally, section 6 discusses the results and provides implications for further research.

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[1] The patent examiner at the EPO conducts his search on prior art on the basis of the claims containing the scope of protection. An increasing number of claims per patent, hence, lead to an increase in the number of references in the search report. Since citations are calculated on the basis of the references, an increasing number of claims increases the number of citations.

2 Theoretical Background and Empirical Evidence

In the following, important results of two lines of research will be summarized. First, studies that analyze the relationship between age and output of researchers will be presented. Second, literature that deals with career paths of R&D personnel will be provided.

The relationship between age and output among technical personnel or scientists has been analyzed in a number of studies[2]. Early findings show an output maximum at the age of about 40 and a decline afterwards. This decline was explained by a decrease in motivation and risk-taking as well as by difficulties in keeping up with technological change (Dalton/Thompson 1971; Lehman 1966; Oberg, 1960). A recent study on European inventors conducted by Mariani and Romanelli (2006) confirms an inverted u-shaped relationship between the age of an inventor and the number of patents he produces. A second group of studies detected a curve with two modes, one before the age of 40, the second approximately at the age of 50 (Pelz/Andrews 1966; Vincent/Mirakhor 1972). These findings were criticized by Zuckerman and Merton (1972). Studying Nobel Prize winners, the authors showed that these scientists remained highly productive over time. A decline in productivity due to seniority was explained by differences between two groups: a small group of key scientists who increase or at least maintain their productivity level, and another, larger group showing a decrease in productivity over time. Stewart and Sparks (1966) analyzed the patent productivity of chemists and chemical engineers and also find no decline in productivity with age.

Jones (2005) uses data on Nobel Prize winners and 20th century great inventors. His analysis shows an upward trend in the age at which scientists and engineers begin their careers. A reason for this delayed start is an increase of the age at the time of the highest educational degree. Thus, scientists and engineers spend more time on education. This time shift is not compensated by a shift in the productivity of innovators beyond middle age. The combined effects lead to a decline of the overall innovative output of younger innovators. In particular, Jones observes a 30% decline in life-cycle output over the 20th century. Furthermore, the author finds that “the mean age of great achievement for both Nobel Prize winners and great technological inventors rose about 6 years over the course of the 20th century” (Jones 2005: 2).

Levin and Stephan (1991), who examined the research productivity of Ph.D. scientists in physics and earth science over their academic life cycle, come to different results. According to their data, the average research productivity decreases over time. The authors explain their finding by the fact that research activity may be "investment-motivated". This means that

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[2] See Goldberg/Shenhav (1984) and Börsch-Supan et al. (2006) for a summary of the relevant literature on the relationship between age and productivity.

scientists do research hoping to receive future financial rewards from their achievements. Given a finite time horizon, research productivity should decrease over time (Diamond 1984).

Finally, Allison and Steward (1974) use survey data on 1,947 U.S. scientists working in university departments and find a highly skewed distribution of productivity among these scientists. Furthermore, the authors observe an increasing output inequality with age. A possible explanation for this finding is the fact that a number of scientists stop publishing at a certain point of their career, e.g., because they leave university. This finding is especially interesting, since not taking a change in the publication behavior into account would result in biased productivity measures. One could assume that not only the number of publications of scientists but also the number of patents produced by inventors in firms are influenced by their career decisions. For instance, inventors changing to administrative roles become invisible in terms of patents. To get a better understanding of the relationship between career paths and visible patent output, important literature on career paths of R&D personnel will be summarized in the following paragraph.

First of all, Allen and Katz (1985) find that career systems of engineers and scientists in the U.S. are completely different compared to career systems of managers. In general, career prospects are less promising for technical professionals compared to management positions. Therefore, engineers and scientists are often attracted by higher wages to undertake administrative roles. Since tacit knowledge, which is stuck in the heads of researchers, plays a major role in R&D (Dosi 1988), key inventors leaving R&D to take up a management position could harm the competitive position of a firm. A possible solution proposed by the authors are so-called “dual ladder” career systems providing more career chances for engineers (Allen/Katz 1985). The advantages and disadvantages of a dual ladder system had already been discussed in previous research, e.g., by Shepard (1958) and Cantrall et al. (1977).

Based on semi-structured interviews conducted in five R&D labs in the U.S. and U.K., Bailyn (1991) distinguishes four different R&D careers: (1) the managerial route, (2) the technical route, (3) the from project to project route, and (4) the technical transfer route. Whereas the "managerial route", which is the most attractive due to the highest compensation, moves technical personnel away from R&D to administrative tasks, the "technical route" makes advancement for R&D personnel possible without leaving R&D. "From project to project route" means that technical employees evolve from project to project, e.g., by receiving larger overall responsibility for the budget. Finally, "technical route transfer" means that the R&D professionals move out of R&D into another division of the firm. Which route to choose depends on both the characteristics of the firm and the skills of the R&D professional. The motives and preferences of 2,500 scientists and engineers are analyzed by Allen and Katz (1992). The authors find that only 21% of the R&D professionals opt for a technical career path. The others rather prefer a managerial career. Additionally, the higher the educational level of the respondents, the more likely scientists and engineers choose the technical career path. A reason for this result may be that individuals who have a Ph.D. prefer the technical ladder, since the reward system is more similar to the academic reward system, i.e. recognition is more important than status related incentives. Roberts and Biddle (1994) suggest that about 50% of the R&D professionals involved in technical work move to a management position after about 35 years.

The age-output related literature summarized above clearly shows that the age of researchers does influence their performance. However, the shape of the performance distribution is considerably influenced by the ingenuity of the researchers under consideration. In particular, whereas productivity increasers over time if star inventors are considered, the productivity distribution for average R&D employees seems to be inverted u-shaped,. Within this paper the following hypothesis is proposed:

H.1: The relationship between the age of an inventor and his inventive output is inverted u-shaped.

Additionally, the literature provides evidence of a career path related dependency of observable inventive output. Generally, many different career paths are open to R&D personnel. Actually, scientists and engineers who keep on inventing for their whole professional life seem to be rather rare. However, inventors changing to a management position or to a non-R&D unit within the firm become invisible in terms of patents. Therefore, the following relationship is expected:

H.2: The shape of the output distribution of inventors strongly depends on the career path the inventors choose.

3 Data Source and Description of the Variables

3.1 Description of the Data

The data used in this chapter were collected in the course of a project sponsored by the European Commission. The project called PatVal aims at creating a database of patent characteristics based on a survey of European inventors named in European (EP) patents and from information drawn from the patent documents[3]. This paper relies only on the German dataset. 10,500 EP patents listing inventors living in Germany were chosen by stratified random sampling based on a list of all granted EP patents with priority dates between 1993 and 1997 (15,595 EP patents). A stratified random sample was used in order to oversample potentially important patents.[4] The information was obtained using a questionnaire. The first inventor listed on the patent document was chosen as the addressee of the survey. Overall, answers were received from 3,049 different inventors, resulting in a response rate of 32%.

The data from the questionnaire were merged with bibliographic and procedural information on the respective patents obtained from the online EPOLINE database. The database contains information on all published EP patent applications as well as all published PCT applications since the founding of the EPO in 1978. The dataset corresponds to the EPOLINE data as of March 1st, 2003 and covers over 1,260,000 patent files with application dates ranging from June 1st, 1978 to July 25th, 2002. For this study, inventor address data were available up to 1999.

To trace the output of each inventor over time, the EPOLINE database was used to search for all patent applications belonging to the 3,049 inventors with priority dates between 1977 and 1999. The search procedure resulted in a total of 35,971 EP patent applications. To ensure that the matching worked well, data from the PatVal questionnaire providing information about the mobility of the inventor was used.

To collect additional information about career systems of engineers and about the relationship between different career paths and the inventive output, additional explorative interviews were conducted. The sample consists of 24 interviews which were conducted between June and December 2006, either personally or via telephone. To obtain comprehensive information about the career system of engineers and about inventive output, inventors, R&D managers, IP managers, and human resource managers were interviewed. The interviewees have been working in different industries, i.e. in biotechnology, engine technology, energy supply, semiconductors, mobile telecommunications, automotive engineering, aerospace, and medical technology. Since a purposive sample was used, the responses cannot claim to be representative for the population of German firms. Nevertheless, the answers will be used to properly interpret the results of the multivariate analysis and to derive accurate implications for R&D management.

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[3] For further details on the PatVal project see Giuri, Mariani et al. (2007).

[4] The sample of 10,500 patents hence includes all patents an opposition was filed against by a third party (1,048) and patents which were not opposed but received at least one citation (5,333), and a random sample of 4,119 patents drawn from the remaining 9,212 patents.

3.2 Motivation for the Measure of Inventive Output

Former empirical studies on inventor productivity used patent counts to measure inventive output (e.g., Narin/Breitzman 1995). Ernst et al. (2000) were one of the first to use patent quality as an output measure. In particular, the authors used the grant rate (number of patents granted divided by the total number of applications per inventor), the share of valid patents (share of patents for which the renewal fees had still been paid), the citation ratio (number of citations received divided by the total number of patents), and the share of US patents in the inventors' patent portfolios.

The results of Ernst et al. (2000) and also the work of Hall (2004), which provides determinants of the "patent explosion" observable in the U.S. since 1984, prove that output measures are at risk of being biased due to:

- differences in the organization of the inventive process across firms and due to
- a strategic shift in the patenting behavior of firms over time.

Both problems as well as their handling in the following regression model will be discussed below.

Organizational Differences

R&D is organized differently in large firms compared to small and medium firms. For instance, Kim et al. (2004) showed that inventors in large firms contribute less in any single R&D project but are involved in more projects at the same time. Additionally, large firms have more resources at their disposal to operate larger projects, to recruit more R&D staff, or to apply for more EP patens. This could lead to an overestimation of the output of inventors employed with large firms. Consequently, one has to control for the size of the applicant or for the availability of resources. To control for the size of the applicant, one could use the number of employees. However, firm size does not vary considerable over time unless the inventor changed his employer. The data reveal that more than 60% of the inventors have not changed their employer at all and only 15% of the inventors changed their employer more than once. Since variables that vary little over time have only small power in a fixed effects approach, the number of employees seems to be a rather inappropriate control variable.

In contrast, the size of the inventor team should be more appropriate. In particular, team size varies considerably over time, i.e. it could be different for each patent. Additionally, team size is positively correlated with firm size and also controls for the resources that were assigned to the project that resulted in the specific patent. Figure 1 shows the variation of team size with firm size. Whereas an inventor team consists of an average of two inventors in small firms, in large firms an average of four inventors are jointly responsible for an invention.

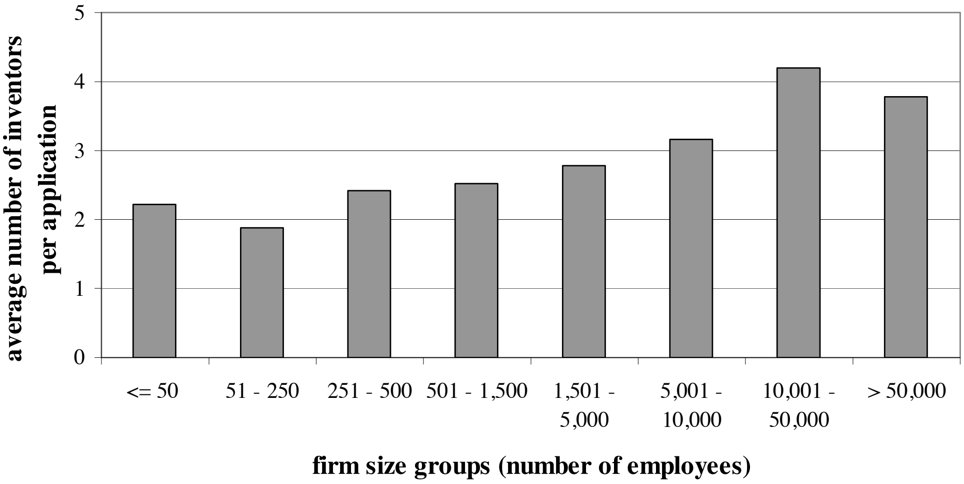

Figure 1: Average inventor team size by firm size (N = 28,542)

Furthermore, Figure 2 shows that the average size of inventor teams has remained almost stable over time.

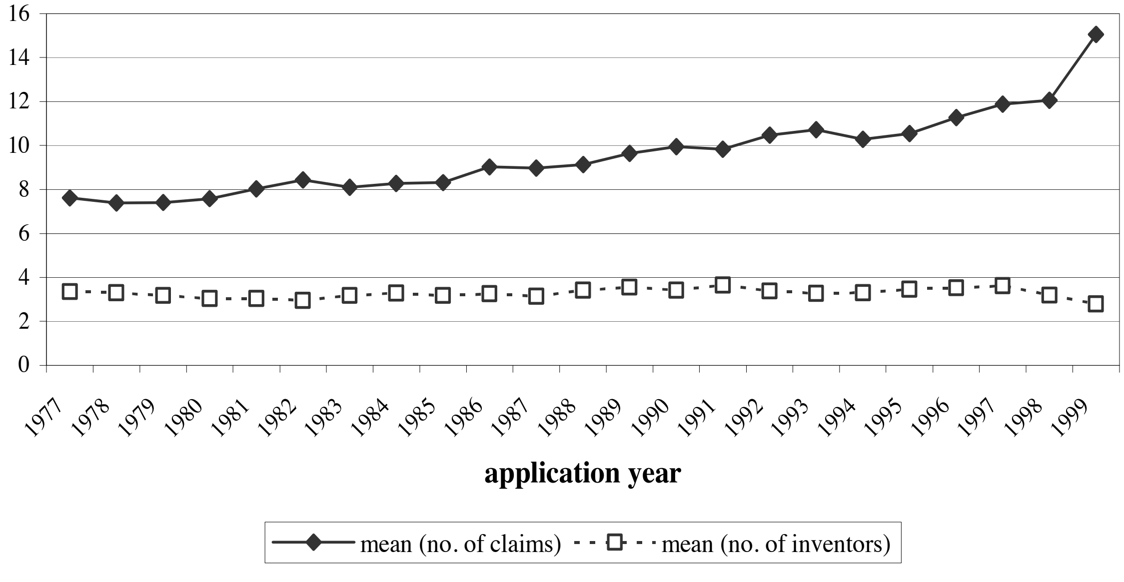

Figure 2: Yearly means of the number of claims specified in the patent applications and yearly means of inventor team size (N = 28,542)

Changing Patenting Activity

Over the last years, the annual number of patent applications increased both in the US (Hall 2004) and in Europe (Harhoff 2005, Harhoff 2006). One possible reason is that patenting has been extended to new technological areas such as genes, software, or business methods which were previously not patentable. Additionally, firms apply for more patents per unit of R&D expenditure due to strategic reasons. Hall (2004) uses U.S. patent data of about 1,400 U.S. manufacturing firms between 1980 and 1989 to explore the sources of patent growth in the U.S. since 1984. Results reveal that the increase of patent applications has taken place especially in the electrical, electronics, computing and scientific instruments industry. This "patent explosion" is assumed to be a result of a strategic shift in patenting behavior of U.S. firms in these industries (Hall 2004).

An increasing patenting activity over time leads to biased results when using uncorrected output measures, since younger inventors today (keeping all other variables constant) tend to patent more inventions than older inventors did in the past when they were the same age (Hall et al. 2005). To avoid these biases, an alternative output measure is employed. Following Ernst et al. (2000), who found that inventive quantity does not rule out inventive quality, the quality of the patent applications is used as a dependent variable. According to Harhoff et al. (1999) the number of citations a patent application received from subsequent patent applications within a certain period of time is an appropriate proxy for the quality of the application.

Not only the number of patent applications but also the number of citations has increased over time (Harhoff/Wagner 2005). However, this increase has to a large extent occurred as a result of the increasing number of claims per patent and not due to an increasing patent propensity of firms (see Figure 2). An application that seeks patent protection at the European Patent Office has to pass an examination process. During this examination process, a search report is prepared by the patent examiner. The search report contains patent and non-patent documents constituting the relevant prior art to be taken into account in determining whether the underlying invention is new and involves an inventive step. According to the Guidelines for Examination in the European Patent Office[5] the patent examiner should direct his search to the most important characteristics of the invention. Therefore, the search is conducted on the basis of the claims that describe the scope of protection for which patent protection is designated. An increasing number of claims per patent, hence, lead to an increase in the number of references included in the search report. Since references in the search report form

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[5] See http://www.european-patent-office.org/legal/gui_lines/pdf_2005/index.html, access on February 12, 2007.

the basis for calculating the number of citations a patent received by a subsequent patent, an increasing number of claims indirectly increases the number of citations per patent. Therefore, in the following multivariate analysis, the number of claims will be included as a control variable. However, possibly the fact that examiners have to choose the patent and non-patent literature to be referenced in the search report from a larger pool of available literature (caused by an increasing number of patents and scientific articles) leads to more references in the search reports and, consequently, to more citations per patent in later years. To control for this possible time trend, additional time dummies indicating the priority year of the patent applications will be factored into the panel regression.

3.3 Description of the Variables

(quality adjusted) inventive output – As an output measure (dependent variable) the number of citations will be used. This variable includes the number of citations a patent application received within 5 years following the publication of the search report added up for the total number of patent applications per inventor. Due to the skewness of the output distribution (Lotka[6] 1926, Price[7] 1965) the logarithm of the dependent variable is employed. To accommodate zero values, one was added to the total number of citations before calculating the logarithm. In accordance with Price (1976), who counts the publication of a paper as its first citation "success", the application of an EP patent is supposed to be its first patent citation.

age of the inventor - The variable contains the age of the inventors in 1999. The information was obtained from the questionnaire.

claims - This variable contains the number of claims per patent. The claims define the scope of an invention for which patent protection is requested. Within the multivariate analysis, this variable is used to control for an increase in the number of references in the search report caused by an increase in the number of claims per application over time.

inventor team size - This variable provides information about the size of the inventor team, i.e., it contains the number of inventors mentioned on the patent document. Team size will be included in the regression to control for the allocation of resources in different R&D projects and also for firm size.

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[6] Lotka formulated the "inverse square law of scientific productivity" (Lotka 126: 320). According to Lotka's Law, the number of researchers producing n scientific contributions is proportional to $1/n^2$.

[7] Price (1965) formulated the "square root law of elitism" (Ernst et al. 2000: 186) suggesting that a scientific community in a particular research field contains an elite group of scientists, almost identical to the square root of all community members. This elite group is responsible for about 50 percent of the entire scientific output within this research field.

status - This variable provides information on the status of the patent applications. Two variables were included accounting for the share of applications that were either refused by the examiner or withdrawn by the applicant, for instance, due to the results of the search report. Additionally, the share of patent applications that were finally granted was factored into the regression.

opposition - The variable contains the share of granted patents that were opposed by a third party within the opposition term of nine months after grant. The status variables as well as the opposition variable are included to control for the value of the patent applications.

technical area - Based on their International Patent Classification (IPC) codes, the patent applications were classified into 30 technical areas. This classification was proposed by Schmoch (OECD 1994).

priority years - The following priority year dummies will be used as additional control variables in the panel regression to account for a changing patenting and citation behavior over time: priority year 1977-1981 (reference group), priority year 1982-1987, priority year 1988-1993, priority year >1993.

4 Descriptive Statistics

The empirical analysis is based on the responses of 3015[8] inventors who are responsible for a total of 35,210 EP patent applications. Table 1 presents selected descriptive statistics of the variables described in the previous section. The total number of patent applications per inventor received an average of 14.94 citations, ranging from 0 to 709. Each patent application received on average 1.06 citations. Additionally, the inventors' patent applications contain on average 10.65 claims. The number of claims per patent ranges between 1 and 55.6.

Furthermore, Table 1 provides information on the legal status of the patents. On average 75% of the applications had been granted by the EPO. 7% of the inventors' granted patents were opposed by a third party. On average 11% of the applications had been withdrawn by the applicant and 2% had been refused by the EPO. Statistics of the EPO reveal that on average 29.7% of EP patent applications between 1980 and 1990 had been withdrawn and 5.2% had been refused by the EPO (Harhoff/Wagner 2005). A possible reason for the low rates of withdrawal and refusal within this data is the fact that the dataset includes only patents of

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[8] 3,015 of the 3,349 questionnaires were filled out completely with regard to the above described variables.

German inventors. The difference may especially arise due to a different behavior of German applicants in drafting patent applications. In particular, German applicants perform extensive search of prior art before filing a patent application. This should result in lower rates of withdrawal and refusal.

Variable	Mean	S. D.	Min.	Max.
number of citations (5 year window)	14.94	32.97	0	709
number of citations per patent (5 year window)	1.06	1.01	0	14
priority year				
1977 - 1981	0.03	0.08	0	0.84
1982 - 1987	0.08	0.15	0	0.83
1988 - 1993	0.31	0.30	0	1
> 1993	0.58	0.34	0	1
number of claims per patent	10.65	4.75	1	55.6
inventor team size	2.84	1.40	1	11
status of the patent appliations				
share of applications withdrawn	0.11	0.16	0	0.75
share of applications refused	0.02	0.05	0	0.5
share of applications granted	0.75	0.23	0.04	1
share of applications opposed	0.07	0.16	0	1
age of the inventor in 1999	50.18	9.95	28	83

Table 1: Descriptive Statistics (N = 3,015)

The responding inventors were between 28 and 83 years old in 1999 with a mean at 50.18 years. The size of the inventor team varies between 1 and 11 inventors and has its mean at 3 inventors per team.

Variable	no_cit (5yrs)	no_cit pp (5yrs)	no_ claims	age_ inv	share_ oppo	share_ withdr.	share_ refused	share_ granted	team_ size
no. of citations (5 yrs)	1.000								
no. of citations per patent (5yrs)	0.318*	1.000							
number of claims	0.170*	0.002	1.000						
age in 1999	-0.105*	0.036	-0.039*	1.000					
share_opposed	0.087*	-0.035	0.001	0.070*	1.000				
share_withdrawn	-0.008	0.150*	-0.038*	0.076*	-0.088*	1.000			
share_refused	0.028	0.050*	-0.003	0.057*	-0.021	0.072*	1.000		
share_granted	-0.077*	-0.182*	-0.083*	0.119*	0.145*	-0.621*	-0.239*	1.000	
inventor team size	0.226*	0.312*	0.028	-0.105*	-0.026	0.091*	0.014	-0.125*	1.000

* significant at 5% or lower

Table 2: Pearson correlation coefficient (N = 3,015)

Table 2 lists the Pearson correlation coefficients for interval scaled variables. The dependent variable “number of citations” is positively correlated with the number of claims, the number of patents opposed and the inventor team size. The number of citations is negatively correlated with the age of the inventors and the share of patents granted. The correlation coefficients of the explanatory variables are quite small. The strongest correlation (corr = 0.226) is observable between the variable “number of citations received” and inventor team size. Apparently, the qualitative output largely depends on firm size, i.e. on the availability of resources. This relationship will be further explored in the multivariate analysis.

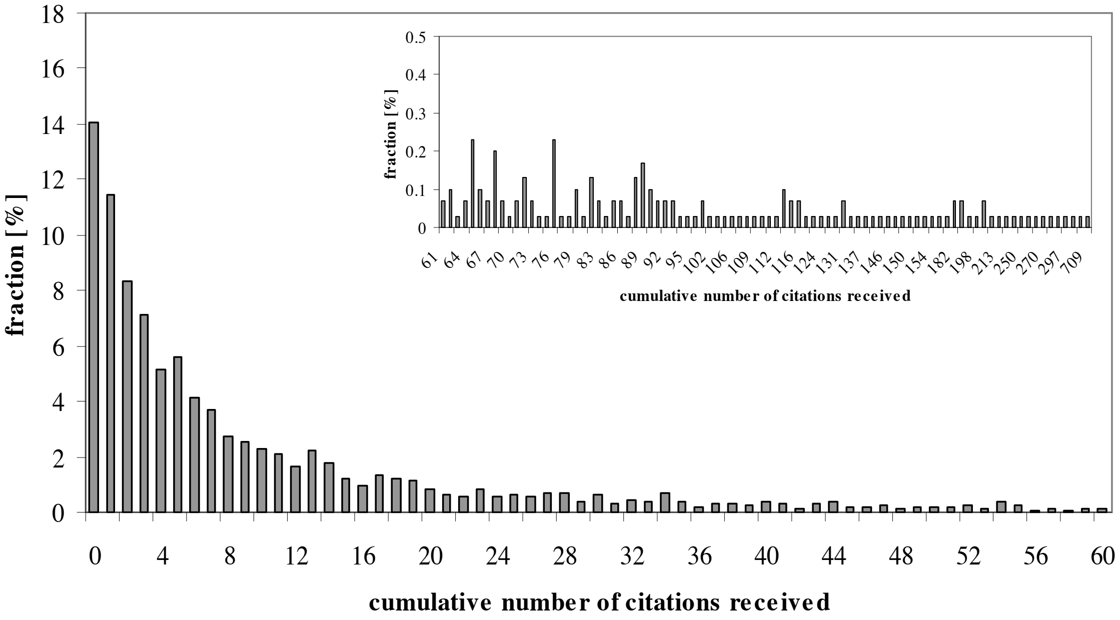

Figure 3: Distribution of the cumulative number of citations received (N = 3,015)

Figure 3 displays a histogram of the distribution of the citations the inventors received for their patent applications. The tail of the distribution (more than 60 forward citations) is displayed separately in the right hand upper corner. About 14% of the inventors generated patent applications that received no citations at all. 2% of the inventors are responsible for applications that received more than 100 cumulative citations.

5 Multivariate Specification and Results

To analyze the relationship between age and inventive output over time, in the following, a panel data analysis will be conducted. To do so, the inventors’ patent applications were sorted into groups according to the age of the inventor at the time of the application of the patent. In particular, nine five-year age groups were constructed: 25-29 years, 30-34 years, 35-39 years, 40-44 years, 45-49 years, 50-54 years, 55-59 years, 60-64 years, and >64 years.

The basic model (1) can be written as

$$y_{it} = \beta_1 x_{it} + c_i + u_{it} \qquad (1)$$

where *i* indexes the different individuals and *t* the different time periods. c_i denotes an unobserved individual effect, representing all factors affecting *y* that do not change over time, e.g., the educational degree of an inventor or his gender. u_{it} is called the idiosyncratic error term (Wooldridge 1999).

Two different methods exist that could be used for estimating the described unobserved effects panel data model: (1) the fixed effects estimator which uses the variation in explanatory variables over time to estimate regression coefficients. Inventor specific characteristics which are time invariant are automatically dropped from the equation procedure and regression analysis is employed to provide unbiased, consistent estimators. (2) The random effects estimator which makes assumptions about the unobserved individual effect c_i uses a GLS estimation. An advantage of the random effects model is that the coefficients of time invariant explanatory variables are estimated (Ruud 2000).

To decide, which method to use, a Hausman test was conducted. Since the test revealed that random effects estimators would be inconsistent[9], in the following a fixed effects approach will be employed.

Regression model (2) will be estimated:

$$\begin{aligned}\log(citation\ counts_{it} + 1) &= \beta_0 + \delta_{1m} * (d\_age)_{mt} + \delta_{2n} * (d\_priority)_{nit} + \beta_1 * (no\_claims)_{it} \\ &+ \beta_2 * (teamsize)_{it} + \beta_{3j} * (status)_{itj} + \beta_{4k} * (tech\_area)_{itk} + u_{it} \quad (t = 1,...,9) \qquad (2)\end{aligned}$$

where *i* denotes the different inventors and *t* indexes the time period. Age groups of the inventors *m* represent the nine time periods: 25-29 years, 30-34 years, 35-39 years, 40-44 years, 45-49 years, 50-54 years, 55-59 years, 60-64 years, and >64 years, which were factored into the regression as dummy variables. The time periods do not change across *i*, which is

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[9] The key consideration in choosing between a random effects and a fixed effects approach is whether c_i and x_{it} are uncorrelated which is an assumption of the random effects model. To test this assumption Hausman (1978) proposed a specification test based on the differences between the random effects and the fixed effects estimates. In particular, the null hypothesis tests if the coefficients estimated by the efficient random effects estimator are the same as the ones estimated by the consistent fixed effects estimator (Wooldridge 2001). Results of the Hausman test show that H_0 has to be rejected (Chi2 = 223.96, p = 0.000) which means the random effects estimators are not consistent.

why they have no *i* subscript. *n* denotes the priority year dummies: prio_1977-1981, prio_1982-1987, prio_1988-1993, and prio>1993, *j* indexes the status variables (application granted, withdrawn, or refused, patent opposed) and *k* indexes different technical areas. Due to the fact that inventor specific characteristics which are time invariant are automatically dropped from the equation procedure, the level of education of the inventors could not be used as an independent variable. However, the data reveal that the level of education of the underlying inventors is considerably high. In particular, 86% of the inventors in the sample have a university degree. Therefore, it can be assumed that the education variable would not have too much explanatory power in a regression model due to a lack of variation in the variable. This is illustrated by Hoisl (2007), who uses the same sample and shows that the level of education does not have a significant impact on output quantity.

To accommodate for different career paths of inventors over time, the sample was sub-divided into three groups. The first group includes inventors who were observable for at least five periods (≥ 20 years) within the panel (hereinafter referred to as *long-term inventors*). The second group comprises inventors observable for three to four periods (10 to < 20 years) (hereinafter referred to as *medium-term inventors*). Inventors who were only observable during two periods (< 10 years) were sorted into the last group (hereinafter referred to as *others*). Whereas the *long-term inventors* (5 or 6 periods) represent inventors who kept on inventing for their whole professional life, the *medium-term inventors* (3 to 4 periods) include inventors who spent at least a major part of their professional life on inventing. Finally, *others* (2 periods) comprise three types of inventors: first inventors who stopped inventing and left R&D for another job, e.g., in sales or marketing. Second, inventors who were still at the beginning of their career in 1999 (inventors who were about 40 years old in 1999 or younger) and who could due to truncation of the data only be observed for two periods. Third, these inventors may also be in the middle or at the end or their inventive life cycle and may for a short period in time have produced patented output.

Before presenting the results, it should be mentioned that the interviewees pointed out that technical specialists from the beginning of their career spend between 30 and 50% of their working time on administrative duties or paperwork. This applies also to full-time inventors. The respondents also explained that inventive activity of R&D personnel may also decrease before an official change to a management position, for instance, if engineers take over a project management position. Finally, if employees have a management position they do no longer produce any inventive output.

Table 3 and Table 4 display the results of the fixed effects panel estimation. Model 1 (Table 3) only includes dummy variables for the age of the inventors. Model 2 (Table 4) additionally controls for an increasing number of citations over time by including the number of claims as a control variable. Additionally, control variables for the priority years of the patent applications and further determinants of inventive output are factored into the regression. Model (a) is estimated for the full sample of inventors. Models (b) - (d) refer to the three sub-samples described before.

First of all, the outcomes of Model 1(a) will be discussed using results based on the full sample of inventors (Table 3, column 1). Results suggest that inventors aged between 25 and 29 receive 68% less citations compared to the reference group (45-49 years). Inventors aged between 30 and 34 still receive 18% less citations. The early literature in this field proposes a maximum of productivity at the age of about 35 to 45 and a decline afterwards (Dalton/Thompson 1971; Lehman 1966; Oberg 1960). Model 1(a) does not confirm the findings of earlier research. The number of citations rather reaches its maximum at the age of 55 to 59. As from this age the number of citations received decreases.

	Model 1			
	(a)	(b)	(c)	(d)
dependent variable	**log(no. of citations + 1)**			
sub-samples	full sample	5 to 6	3 to 4	2
reference group: age: 45 - 49 years				
age: 25 - 29 years	-0.680***	-1.508***	-0.607***	-0.090
	[0.100]	[0.332]	[0.116]	[0.185]
age: 30 - 34 years	-0.181***	-0.922***	-0.094	0.232*
	[0.064]	[0.158]	[0.076]	[0.135]
age: 35 - 39 years	-0.116**	-0.540***	0.028	0.133
	[0.054]	[0.108]	[0.063]	[0.117]
age: 40 - 44 years	-0.110**	-0.212**	-0.088	0.055
	[0.045]	[0.096]	[0.054]	[0.089]
age: 50 - 54 years	0.112**	-0.011	0.120**	0.151
	[0.046]	[0.098]	[0.054]	[0.094]
age: 55 - 59 years	0.058	-0.094	0.104*	0.061
	[0.054]	[0.113]	[0.062]	[0.107]
age: 60 - 64 years	-0.098	-0.483***	0.020	0.081
	[0.080]	[0.161]	[0.088]	[0.157]
age: > 64 years	-0.068	-0.950***	0.100	0.260
	[0.142]	[0.298]	[0.153]	[0.306]
Constant	1.359***	2.020***	1.345***	1.064***
	[0.034]	[0.070]	[0.039]	[0.077]
Observations	7237	929	3538	1990
Number of inventors	3015	184	1056	995
F-test (n1, n2)	8.58 (8,4214)	10.13 (8,737)	6.27 (8,2474)	1.55 (8,987)
R-squared	0.020	0.098	0.020	0.013

Robust standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Robust fixed effects panel estimation (Model 1) ($N_{full} = 7{,}237$, $N_{5\_6} = 929$, $N_{3\_4} = 3{,}538$, $N_2 = 1{,}990$)

Additional information is provided when dividing the sample into the three sub-samples according to the number of periods the inventors were observable in the panel dataset. Models 1(b) to 1(d) (Table 3, columns 2 to 4) provide the regression results for the three sub-samples. Figure 3 displays the differences in the productivity-age relationship between the three sub-samples. The three curves present the logarithm of the medium number of citations the inventors received for patents applied for at the age of, e.g., 25 to 29 or 30 to 34.

The upper curve represents *long-term inventors* who were observable for five or six periods. As proposed by the literature, the relationship between productivity and age is inverted u-shaped and has its maximum at an age of about 45 years. The medium curve represents *medium-term inventors* who were observable for three to four periods. These inventors still spent a considerable share of their professional career in R&D (10 to < 20 years) but are supposed to have stopped inventing at a certain point in time. Figure 3 shows that *medium-term inventors* are at the age of 25 to 35 even more productive than the *long-term inventors* (5 to 6 periods). After the age of about 35 output quality of the *medium-term inventors* is much lower than that of the long-term inventors. This could mean that those inventors, who are characterized by a very high level of productivity and are promoted. These inventors may then stop inventing or at least spend only part of their time on inventive activities leading to a lower observable productivity compared to the long-term inventors. As from the age of 30 to 34, the output of the medium-term inventors is rather constant, i.e. the performance curve is no longer inverted u-shaped.

The interviewees confirmed this finding. In particular, eight interviewees reported that they already started their job in R&D with having a management career in mind. Additional, they affirmed that a change to a management position typically takes place at the age of about 35 years. Three interviewees confirmed that their management orientation even prompted them to obtain a doctoral degree. Finally, ten respondents reported that are very happy with their technical specialization and that they do not plan to move into a management position in the near future.

Finally, the lower curve represents *others* who were only observable for two periods (about 10 years). *Others* receive, almost as from the beginning of their career, less citations compared to the other two groups. These inventors could first of all drop out of the sample since they are unsuccessful inventors and change to an administrative position or another position within the firm (or leave the firm completely). One of the interviewees reported that this third group does exist in firms. Inventors who are less successful in making inventions initially stay in R&D and will be assigned to routine jobs or industrious but uninspired work. In the long run, these inventors change to jobs or into a role that more strongly suits their capabilities, e.g., account management, sales or consultancy.

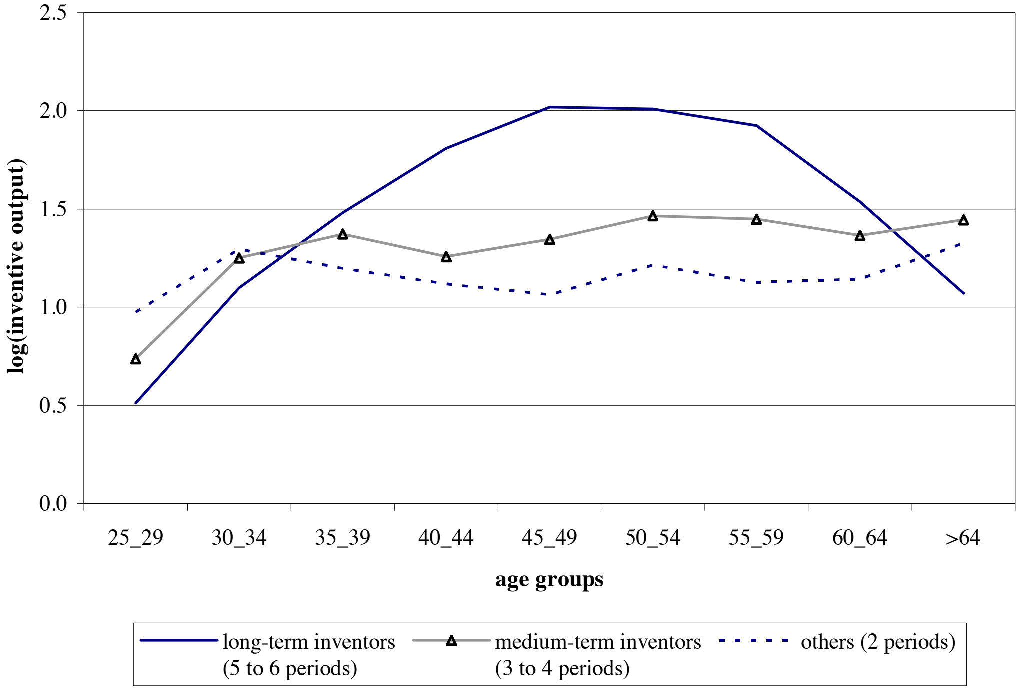

Figure 3: Productivity differences by age groups; subdivided into three groups by number of periods observed (N_{5_6} = 929, N_{3_4} = 3,538, N_2 = 1,990), graph of: $\log(no\_cit_{it} + 1) = \beta_0 + \delta_1 * d\_age25 - 29_t + ... + \delta_8 * d\_age > 64_t + u_{it}$ where the coefficient δ_1 is the percentage change in productivity between the reference group and the first age group. δ_2 to δ_8 have the same interpretation with respect to the remaining age groups. β_0 is the intercept for the reference group and $\beta_0 + \delta_1$ is the intercept for the first age group.

Second, inventors assigned to the third group (*others*) are also very young in 1999. Therefore, truncation of the data impedes observing these inventors any longer. Young inventors may be mistakenly sorted into sub-sample three (*others*). In the event these inventors are indeed on average more productive than the unsuccessful inventors, the first two or three age groups of the lower curve (including these young inventors) should suffer from an overestimation of productivity. Overall, it becomes clear that the patent applications of inventors remaining in R&D for a longer time receive more citations.[10]

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[10] Additionally, a robustness check was conducted. In particular, medium-term inventors and others were excluded who are characterized by a lack of patent applications for more than 2 periods (i.e., more than ten years) before the age of 45 and who were not observable in terms of patents before the age of 45. The reduced sample leads to the same results with respect to early years of inventive activity (age between 25 and 45). The exclusion of occasional inventors and of respondents who started inventive activity just before retirement led to similar results. However, the performance curve is characterized by a sharper decrease at later age. This robustness check provides evidence that the results are hardly influenced by the fact that certain inventors have not continuously produced inventive output.

	Model 2			
	(a)	(b)	(c)	(d)
dependent variable	**log(no. of citations + 1)**			
sub-samples	full sample	5 to 6	3 to 4	2
reference group: age: 45 - 49 years				
age: 25 - 29 years	0.038	0.048	0.143	0.118
	[0.174]	[0.585]	[0.215]	[0.282]
age: 30 - 34 years	0.395***	0.214	0.476***	0.423**
	[0.127]	[0.410]	[0.158]	[0.209]
age: 35 - 39 years	0.324***	0.261	0.419***	0.289*
	[0.091]	[0.268]	[0.112]	[0.159]
age: 40 - 44 years	0.147**	0.167	0.144**	0.159
	[0.058]	[0.155]	[0.070]	[0.105]
age: 50 - 54 years	-0.152**	-0.330*	-0.154**	-0.015
	[0.060]	[0.171]	[0.072]	[0.107]
age: 55 - 59 years	-0.400***	-0.678**	-0.372***	-0.298*
	[0.096]	[0.285]	[0.117]	[0.163]
age: 60 - 64 years	-0.693***	-1.254***	-0.574***	-0.473**
	[0.138]	[0.415]	[0.166]	[0.234]
age: > 64 years	-0.847***	-2.026***	-0.704***	-0.434
	[0.206]	[0.607]	[0.245]	[0.349]
reference group:(mean) priority year: 1977 - 1981				
(mean) priority year: 1982 - 1987	0.469***	0.719***	0.273***	0.581**
	[0.083]	[0.190]	[0.100]	[0.279]
(mean) priority year: 1988 - 1993	0.953***	1.154***	0.818***	0.906***
	[0.115]	[0.337]	[0.137]	[0.296]
(mean) priority year: > 1993	1.215***	1.750***	1.103***	1.134***
	[0.153]	[0.480]	[0.189]	[0.322]
(mean) no. of claims	0.009***	0.007	0.009**	0.011*
	[0.003]	[0.009]	[0.004]	[0.006]
(mean) no. of inventors	0.065***	0.024	0.069***	0.071***
	[0.014]	[0.036]	[0.017]	[0.023]
(mean) share withdrawn	0.329***	0.278	0.394***	0.22
	[0.084]	[0.233]	[0.103]	[0.140]
(mean) share refused	0.29	0.435	0.362*	0.033
	[0.177]	[0.467]	[0.205]	[0.335]
(mean) share grant	0.535***	0.774***	0.595***	0.356***
	[0.064]	[0.215]	[0.082]	[0.096]
(mean) share opposition	0.235***	0.304	0.228***	0.248*
	[0.075]	[0.225]	[0.087]	[0.138]
(mean) share technical areas	included	included	included	included
Wald test	n.s.	Chi2(5) =2.14 p=0.028	n.s.	n.s.
Constant	-0.298*	0.612**	-0.244	-0.602
	[0.154]	[0.290]	[0.180]	[0.375]
Observations	7237	929	3538	1990
Number of inventors	3015	184	1056	995
F-test (n1, n2)	17.83 (22,4200)	8.14 (22,723)	12.76 (22,2460)	4.08 (22,973)
R-squared	0.100	0.189	0.103	0.078

Robust standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4: Robust fixed effects panel estimation (Model 2) ($N_{full} = 7,237$, $N_{5\_6} = 929$, $N_{3\_4} = 3,538$, $N_2 = 1,990$)

The increase in inventive output observable for both medium-term inventors and others at the age of about 60 years may arise due to the fact that certain inventors started their inventive career at a later age that is these inventors were observable from the age of 45 to the age of 65. The increase may also be the result of a time trend. Therefore, the second model (Table 4) includes control variables for the mean share of priorities within the different age groups. The share of priorities between 1977 and 1981 forms the reference group. Results of Model 2 (Table 4) confirm this finding for the whole sample (Model (a)) as well as for the three sub-samples (Models (b)-(d)). In particular, the number of citations increases over time. The coefficients are highly significant at the 1% level. Model 2(a) provides results similar to those of Model 1(a). In particular, the relationship between age and inventive output is inverted u-shaped. However, the turning point of productivity is already reached at the age of 30 to 34 years. Afterwards, productivity again decreases but more rapidly compared to Model 1.

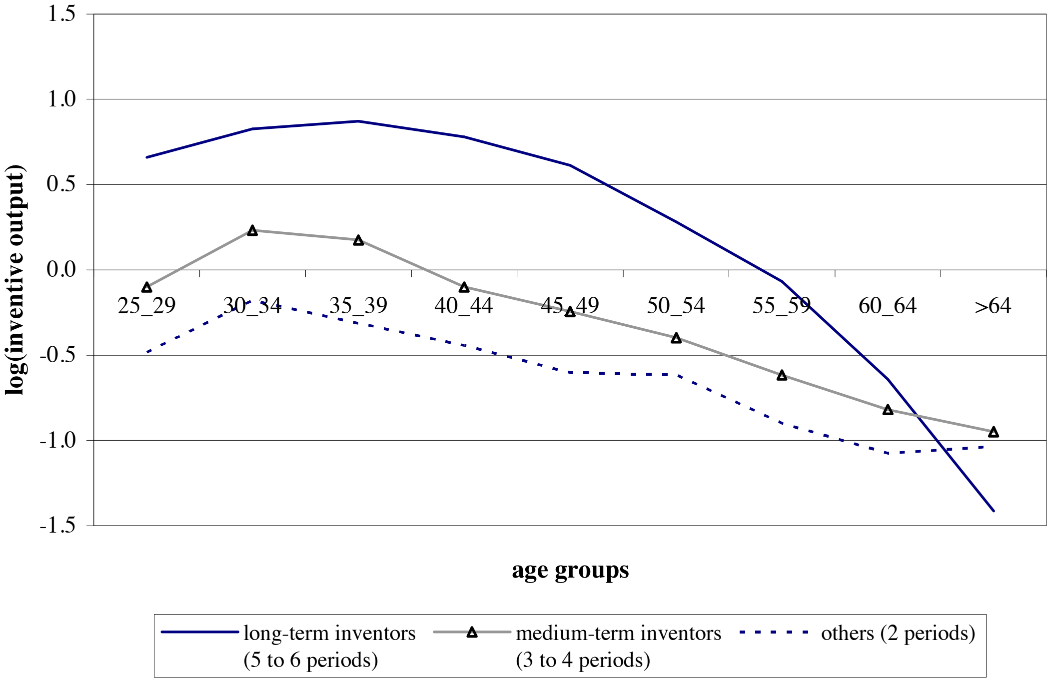

Figure 4: Productivity differences by age groups (additional control for the priority years of the patents); subdivided into three groups by number of periods observed ($N_{5\_6} = 929$, $N_{3\_4} = 3{,}538$, $N_2 = 1{,}990$).

Figure 4, in turn, displays the output-age relationship for the three sub-samples. It becomes apparent that *long-term inventors* (5 to 6 periods) are most productive and *others* (2 periods) again turn out to be least productive. However, the shape of the upper curve (*long-term inventors*) has changed slightly. In particular, *long-term inventors* no longer show a turning point at the age of 45 to 49 but at the age of 35 to 39. Afterwards, inventive output decreases monotonically. This change arises due to the correction of the time trend. In particularly, comparing Figure 3 and Figure 4 reveals that including control variables for the priority years and determinants of inventive output leads to a downward correction of the inventors' output at advanced age. Nevertheless, hypothesis H.1, an inverted u-shaped relationship between age and performance of the inventor, is confirmed for long-term inventors. Furthermore, the three sub-samples show that also hypothesis H.2 that the performance curve is highly dependent on the inventors' career paths is confirmed by the data, as well.

Finally, Table 4 shows that the control variables exhibit the expected signs. In particular, the number of claims affects the number of citations positively. The number of citations also increases with the size of the inventor team. This is not surprising, since inventor team size is a proxy for firm size. Inventors working with larger firms have more resources at their disposal to create inventive output. Surprisingly, claims and firm size only affect the output of *medium-term inventors* and *others* but do not affect the output of the *long-term inventors*. Industry dummies, on the contrary, do only exhibit a significant effect on inventive output with respect to the *long-term inventors*. A possible explanation for this finding may again be the different career paths of the inventors. On the one hand, inventors who decide to stay in R&D seem to produce output, regardless whether they work in large companies or in rather small firms. On the other hand, inventors who stop inventing at a certain point in time may profit from the organization of R&D in large firms, e.g., due to the fact that R&D managers are mentioned on patents because of seniority or their position within the firm.

6 Conclusion

The purpose of this paper was to analyze the age-performance relationship of inventors more closely, in particular, to trace inventive output over time. To do so, a panel regression model was estimated. Overall, results of the panel estimation provide clear evidence that the age of an inventor considerably influences his output. In particular, data show that the average inventive output decreases with the age of an inventor. However, results also suggest that one has to distinguish between *long-term inventors* and inventors who dropped out of R&D for certain reasons (*medium-term inventors*, *others*) to avoid biased results. Whereas *long-term inventors* remain visible in terms of patents over the whole period under consideration, *medium-term inventors* are no longer visible after they left R&D. Comparing the mean inventive output of both groups over time shows that not distinguishing between different career paths of inventors would lead to an underestimation of the performance of inventors who stopped inventing earlier. Furthermore, there is considerable evidence that failing to control for an increasing number of citations over time would also lead to biased results.

Finally, a limitation of this analysis should be mentioned: the problem of using patent data to measure inventive output. Griliches (1990) pointed out that “not all inventions are patentable, and not all inventions are patented”. This is one of the disadvantages of patent data used as output measures. Cohen et al. (2000) confirm that patent protection is accounted as a more effective appropriability mechanism for product innovations compared to process innovations. “Process innovations are less subject to public scrutiny and thus can be kept secret more readily” (Cohen et al. 2000). This constraint must be taken into account when interpreting the results.

Although this analysis improves on the current literature by including different data sources to depict the creative power of inventors as precise as possible, it does not raise the claim of providing a perfect picture of the inventive life cycle. In particular, since strong assumptions had to be made with respect to the interpretation of the three sub-samples. However, it is intended to provide a small step towards a better understanding of inventors’ ingenuity. Furthermore, this paper should sensitize further research to limitations that have to be taken into account when deriving implications for inventive output from patent data.

Overall, future research is needed to shed more light onto the inventors’ life cycle, for instance, onto reasons for leaving R&D. It is also necessary, to analyze career systems for R&D personnel more closely. In case, firms do not provide a dual ladder career system for management and R&D, a move into a management position is the only way for a productive inventor to get promoted. It will be interesting to analyze whether transferring productive inventors into management positions causes damage to the innovative potential of the firm or whether able inventors who agree to move to a management position do an even better job as a manager.

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Enforcing Intellectual Property Rights through Organisational Measures:

The Case of German Companies in China

Preliminary draft submitted to the 2nd Annual Conference of the EPIP Association

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Keywords: Intellectual property rights, organisational theory, resource based view

Abstract

Among practitioners and scholars it is a well known fact that the enforcement of intellectual property rights in newly industrialised countries is nearly not feasible. Neither are intellectual property rights sufficiently defined in such countries nor is the jurisdiction willing to assist foreign firms in enforcing these rights. At the same time companies from all industrialised countries establish subsidiaries in Asian NICs to evade rising costs in their home countries and to open up new markets. In order to run these subsidiaries they need to transfer technology and knowledge, which is not protected by intellectual property rights in the host country and therefore most likely subject to theft and imitation by local employees, competitors or even government officials. In the absence of a backing legal system companies must find different ways to protect their intellectual property rights.

Basing on a knowledge-based-view of the firm we explore the organisational measures taken by foreign firms in China to enforce their intellectual property rights. Our study consists of in-depth interviews with chief executives of Chinese subsidiaries of major German and Austrian companies from seven different technology-based industries (lighting, plastics, textile, pharmaceutical, specialty chemicals, automotive and medical engineering).

In our findings we identify three elements of organisational configuration, moderated by business strategy. Based on these results we discover three distinct patterns of organisational IPR protection mechanisms that can be applied to a wide variety of industries.

1 Dimensions of knowledge transfer to foreign subsidiaries

Among practitioners and scholars it is a well known fact that the enforcement of intellectual property rights in newly industrialised countries like India and China is nearly not feasible. Neither are intellectual property rights sufficiently defined in such countries nor is the jurisdiction willing to assist foreign firms in enforcing these rights (Boisot and Child 1999, Fernandez and Weinstein 2005, Zhao 2006). At the same time companies from all industrialised countries establish subsidiaries in Asian NICs to evade rising costs in their home countries and to open up new markets. In order to run these subsidiaries they need to transfer technology and knowledge, which is not protected by intellectual property rights in the host country and therefore most likely subject to theft and imitation by local employees, competitors or even government officials. In the absence of a backing legal system companies must find different ways to protect their intellectual property rights.

In order to start production in a NIC it is necessary to transfer production technology into the foreign subsidiary. This poses a problem for multinational companies (MNC). On the one hand they need to replicate their knowledge to gain growth, and on the other hand this replication increases the risk of imitation and product piracy (Kogut and Zander, 1992).

The knowledge relevant to technology transfer can be categorized into two dimensions. First it can be distinguished into tacit and codified knowledge. While the tacit dimension of knowledge is embedded in agents (e.g. experience) and organisational structures (e.g. cross-functional teams) which make it harder to imitate codified knowledge is embedded in objects such as production manuals, workflow documentation, technical drawings, ERP and other IT-Systems, machinery, tools or even simple emails. All these are relatively easy to steal (e.g. by forwarding email attachments) and imitate.

The second dimension describes the competitive relevance of the technology. Core technologies represent the combined knowledge of a company leading to competitive advantage (e.g. knowledge of price and cost calculation algorithms, R&D plans for new production tools); peripheral technologies are older or more irrelevant knowledge (e.g. knowledge of how to use MS Excel, out of date machinery) (Tsang, 1997; Schulz and Jobe, 2001; Cannice, Chen and Daniels, 2004).

One obvious advice to avoid unwanted technology spillovers would be: Do only transfer tacit and peripheral technology. Unfortunately this simple strategy will not work for most of the companies as there are different trade-offs in both dimensions. In the next chapter we will – on the basis of the existing literature – discuss organisational measures to protect IPRs by means of ownership, transfer of (codified and tacit) knowledge and the necessity to retain knowledge once it is transferred. In chapter three, after a short review of our sample and method, we will present our findings regarding a cross sectional comparison of the organisational elements identified in chapter two, distinguish the unique combinations of those elements for the business model of every single case and finally derive three strategic patterns, that can be observed and put to use in a wide variety of industries. The paper finishes with a few concluding remarks.

2 Organisational protection of IPRs

2.1 Control of knowledge by ways of ownership, organisational structure and IT-systems

2.1.1 Ownership structure

Foreign direct investments (FDI) into newly industrialised countries (NIC) are providing these countries with major opportunities of learning and knowledge transfer (Chen and Reger 2006). In their analysis of the interdependence of firm knowledge and firm structure Kogut and Zander (2003) find that a rising degree of tacit knowledge necessary for production increases the probability of a directly owned subsidiary, while firms producing less complex products or using easily codifiable knowledge are more likely to invest in joint ventures. This seems to be an efficient strategy for knowledge transfer as it reduces the costs of knowledge transfer in case of tacit knowledge and takes advantage of the comparative advantage of joint venture partners in NIC if the knowledge is more codified. In the latter case an equal distribution of property rights among the local and international partners guarantees easy interaction, communication and a free flow of knowledge within the joint venture (Pak and Park, 2004). Therefore in NIC with inadequate IPR protection and enforcement joint ownership with local partners will most likely lead to technology theft and breeding of new competitors (Bai, Maher, Nickolson and Wong, 2003). In order to protect knowledge from unwanted transfer we assume that the opposite strategy of the Kogut and Zander findings should be applied by foreign investors: The easier to codify the relevant knowledge, the more property rights should remain in the investor's hand. This approach is reflected by ABB CEO Fred Kindle's answer to a journalist about his concerns of technology theft in their Chinese subsidiaries: "…we believe we can control this. Today we are holding the majority of shares in all our joint ventures" (Wirtschaftswoche, 2006, p. 11).

2.1.2 Organisational structure and IT-systems

The organisational structure should be designed to separate different fields of strategic know how like R&D, production and sales. A functional division of labour leads to a division of knowledge, but divisional and process oriented structures are built to facilitate integration of knowledge. Local management staff should only have knowledge on one functional field (e.g. production *or* sales) to avoid one single manager copying the whole business model.

Nowadays the automated flow of information through different means of information systems is intertwined with the organisational structure. The use of centralised Databases, inter- and intranet, global ERP-systems and email are vital tools to the transfer of codified knowledge and even the codification of non-codified knowledge (see Nonaka and Takeuchi, 1995, 56pp.). Especially global databases and ERP-systems are creating competitive advantage by vastly reducing the cost of information (Xu, Wang, Luo and Shi, 2006). Of course the costs of information theft are reduced by the same amount. Beside the common practice of securing IT-based information through granting different levels of access to that information it should be considered not to codify NIC relevant know how within those systems or even not to use sophisticated information management tools.

2.2 Codified knowledge embedded in physical resources

As Liebeskind (1996) shows, one way to protect knowledge from abuse by third parties is by simply not disclosing it. As mentioned above, the ways to render unwanted spillovers more difficult are either by keeping transferred core technology as tacit as possible or by not transferring core technology at all.

In their study of nine US semiconductor and software companies and their technology transfer policy to subsidiaries in Singapore, Malaysia and China Cannice, Chen and Daniels (2004) were able to show the application of these protective mechanisms. Fifty percent of Chinese subsidiaries were not provided with any written documentation about production processes, workflows or other technical documentation. All relevant know how was kept tacit in the heads of the responsible managers and engineers. Nevertheless this strategy is not feasible for all industries. In some cases the mere complexity of production processes may make it necessary to document workflows and to make them known to the local production personnel (e.g. manufacturing of high precision tools), in other cases like the pharmaceutical industry it is a legal requirement to keep written documentation of drug formulas and production processes and disclose them to third parties. Moreover there may be legal, technical or market reasons to establish local R&D which will lead to the production of even more documented knowledge.

In 2001 Feinberg and Majumdar investigated the Indian pharmaceutical industry concerning spillovers from MNCs to local companies. Although it is an explicit political goal to achieve knowledge spillovers by attracting FDIs to NICs and the MNCs were forced to document and disclose their formulas and production process as well as to conduct local R&D to get their drugs approved for the Indian market, the authors were unable to find significant spillovers to the local competition. Instead they found spillovers within the respective MNC from the parenting company to the subsidiary. They conclude that the MNCs transferred older and peripheral technology and that their local R&D was restricted to “last mile” research just sufficient to get their drugs approved. These findings correspond to Zhao (2006) describing the complementary division of R&D efforts between the MNC’s home country (basic research) and application of this research in NIC based R&D departments, and in a broader sense the general division of complementary knowledge between different firms.

The applicability of these strategies of not transferring relevant codified knowledge depends on complexity and market demands. The less complex products and processes the easier it is to relinquish written documentation. At the same time the use of outdated, peripheral technology will only be possible if the local market needs can be satisfied with older products.

2.3 Tacit knowledge embedded in human resources

The common way to transfer knowledge embedded in individuals is by use of human resource policies like job specific training, visiting experts and consultants and the use of expatriates for middle and upper management positions (Almeida and Grant, 1998). The more positions are staffed with homeland personnel the less likely are unwanted spillovers and the less comparative cost advantage is gained from recruiting cheaper local staff (Boisot and Child, 1999).

Expatriation – the transfer of headquarter management staff to a foreign subsidiary for a certain time (1-5 years) – is a widespread technique to control the knowledge transfer to and within a subsidiary (Minbaeva and Michailova, 2004). *„Expatriates act as a link between headquarters (HQ) and foreign subsidiaries, and a great amount of information moves through their hands"* (Riusala and Suutari, 2004, p. 745). In his early work on expatriates Hays (1974) characterizes three tasks of the expatriate: 1. reproduce HQ-like organisational structures, 2. reproduce patterns of problem solving and 3. Tie these structures and patterns to the headquarters' structures. As it has been argued tacit knowledge is not only embedded in individuals but also in organisational structures. Therefore an expatriate is not only an expert putting his idiosyncratic knowledge to work in the subsidiary, but also an agent to ensure that the local staff work in patterns and structures more complementary to its own headquarter than to local competitors. The use of expatriates is a strategy advantageous in many ways. First, the use of expatriates guarantees the transfer of tacit knowledge without the necessity of further organisation specific training as the expatriates have accumulated their knowledge by organisational experience while working in the HQ. Second, it also guarantees the containment of competitive knowledge as the expatriates are bound by enforceable contracts in their homelands and due to wage differentials between homeland and foreign subsidiaries it is very unlikely that they will be headhunted by local competition. And third the reproduction of HQ structures by the use of expatriates creates organisational barriers that make it more difficult for the local staff to sell/commercialize this knowledge to local competitors (see also Edström and Galbraith, 1977).

Almeida and Grant (1998) describe it as nearly impossible to spill over knowledge that can only be acquired by long observation or training and/or if this knowledge requires high degrees of specialization and is only needed from time to time. MNCs can use this special kind of highly specific/low frequency attributes of strategic and technological knowledge to prevent unwanted spillovers by using internal consultants and experts. For example major reconfigurations of assembly lines, customizing of ERP systems or optimization of sales regions (or any other major change project) could be conducted by these experts, if necessary in cooperation with the expatriate staff, but without the help of local staff. In this way strategic knowledge would remain a "black box" to the local staff and the mobile consultants would take their highly specific knowledge back to the HQ after their work is done (Kogut and Zander 1992).

The techniques for transfer of tacit knowledge discussed so far both follow the axiom to centralize competitive knowledge in very few trusted heads. Observably this simple rule can not be applied to every situation without destroying the comparative advantage of a NIC subsidiary. There is a lot of codified and tacit knowledge that has to be put in the hands and heads of local managers and staff, especially in the areas of production, marketing and sales. Following Cannice et al. (2004) the best way to do that would be by group based training and by distributing the necessary knowledge in this group in a jigsaw puzzle style. The less idiosyncratic puzzle pieces of tacit knowledge are given to one local employee and the more pieces are needed to complete the puzzle (i.e. a production process) the less likely are unwanted spillovers. A local competitor would in the best case have to recruit the whole production floor staff which his highly unlikely to be done. To a certain extent this classic approach of "divide and rule" is even applicable to codified knowledge although it is much easier gather the whole information needed by an exchange of documents within the group. Nevertheless Cannice et al. (2004) find two third of their sample of high tech subsidiaries in China applying this kind of group based knowledge division.

This group based structure is likely to be found in the lower echelons of foreign subsidiaries, while the middle and upper management positions which have to be staffed with local managers for cultural, communication and cost reasons need to be supplied with competitive knowledge in order to make the right decisions and are therefore most likely to capitalize on this knowledge with local competitors (Grant, 1996; Liebeskind 1996).

2.4 Prevention of knowledge spillovers by retaining employees

The high average turnover of Chinese employees of 13% (worldwide: 6%) and the turnover rate of Chinese managers in MNCs of 30% per year is not owed to a special disloyalty of the Chinese, but due to the high demand and low supply of qualified workforce by MNCs. In this labour market situation Chinese managers are hired and trained by companies not able to pay premium wages and afterwards are recruited by firms willing to pay those wage premiums. To counteract this dynamics firms should use a dual strategy. 1. They should not invest in the general human capital of their local managers but train them highly specific skills needed for their actual job to decrease the probability of turnover. 2. Employees who have gained insight into competitive knowledge and/or have been specially trained should be offered incentives to stay with the company (Ramlall, 2004).

As it was shown by Chiu, Luk and Tang (2002) Chinese blue collar and white collar employees show a preference for current cash based compensation concerning short-term job motivation and long-term job retention. This includes base salary, performance boni, special payments in accordance with cultural events and corporate loans for houses and cars. Glass and Saggi (2002) argue that MNCs should provide well above average compensation packages to impede knowledge spillovers to local competitors through migrating workforce. The existence of such MNC wage premiums has not been investigated for China yet, but Aitken, Harrison and Lipsey (1996) were able to show these compensation effects empirically for Central America.

Nevertheless price competition in a job market with high demand and low supply is unlikely to be a good single mechanism to minimize labour turnover. Following Hertzberg's (*1959*, 1993) proposal of a two-factor-theory of work motivation short-term monetary incentives can be described as hygiene-factors whose absence create dissatisfaction leading to disproportionate labour turnover but will not create deeper commitment to the company if present. A firm successful in retaining employees must offer benefits that can be described as motivator-factors able to create satisfaction and the wish to stay with the current company.

All of these factors are dependent on the national and regional culture and – to make things more complicated – interact with the organisational culture of the firm. To assess these cultural contingencies we will use Hofstede's (2001) framework for assessing culture and of his five dimension we will only discuss the two most relevant to this investigation. Of more than 60 countries studied so far, China scored highest in *long-term orientation,* a factor describing the time horizon and the importance of the future relative to the present. The second relevant facet – *collectivism*, the willingness to act as a life long member of a life-long group or organisation – is very predominant in Asian cultures. Translated into organisational culture these aspects are represented by career (long-term orientation) and training and education (collectivism) as well as a management style respecting the local culture (collectivism) and the corporate reputation, which will facilitate the identification with the firm as relevant peer group. (Hofstede, 2001; Child, 1994; also Trompenaars and Hampden-Turner, 1997). We assume these non-monetary benefits to have a significant effect on labour turnover, although it must be taken into account, that those ancient Chinese cultural bounds in existing family and personal networks ("guanxi") will very likely overrule the commitment to the employer.

3 Case Studies of German Companies in China

3.1 Sample and Data Collection

Our study consists of in-depth interviews (60-90 minutes) with chief executives of Chinese subsidiaries of major German and Austrian companies from seven different technology-based industries (lighting, plastics, textile, pharmaceutical, specialty chemicals, automotive and medical engineering). Descriptive data on interview partners and companies are summarized in table 1.

---- Insert table 1 about here ----

Our sample reflects the method of representative sampling as a wide variety of technologies and markets, minimizing possible industry sector biases. To enhance the richness of information in the sample we tried to comprise critical cases in regard to the following three criteria: a) the competitive advantage of the participating firms is based mainly on production technology or products that are codified (e.g. in patents) and enforceable intellectual property rights in their home country, b) the technology and/or product is likely to be copied, because there are local competitors with sufficient know-how and c) none of the firms has encountered major problems with technology theft or imitation. All interviews were conducted using a broad guideline of the topics identified in chapter two and were accompanied by a questionnaire for cross-referencing the reliability of the interviewees statements. The interviews were voice-recorded and transcribed prior to the analysis. Both authors analysed the transcriptions alone and afterwards discussed their finding till they agreed on a mutual understanding of the facts.

3.2 Configurations of IPR related knowledge transfer

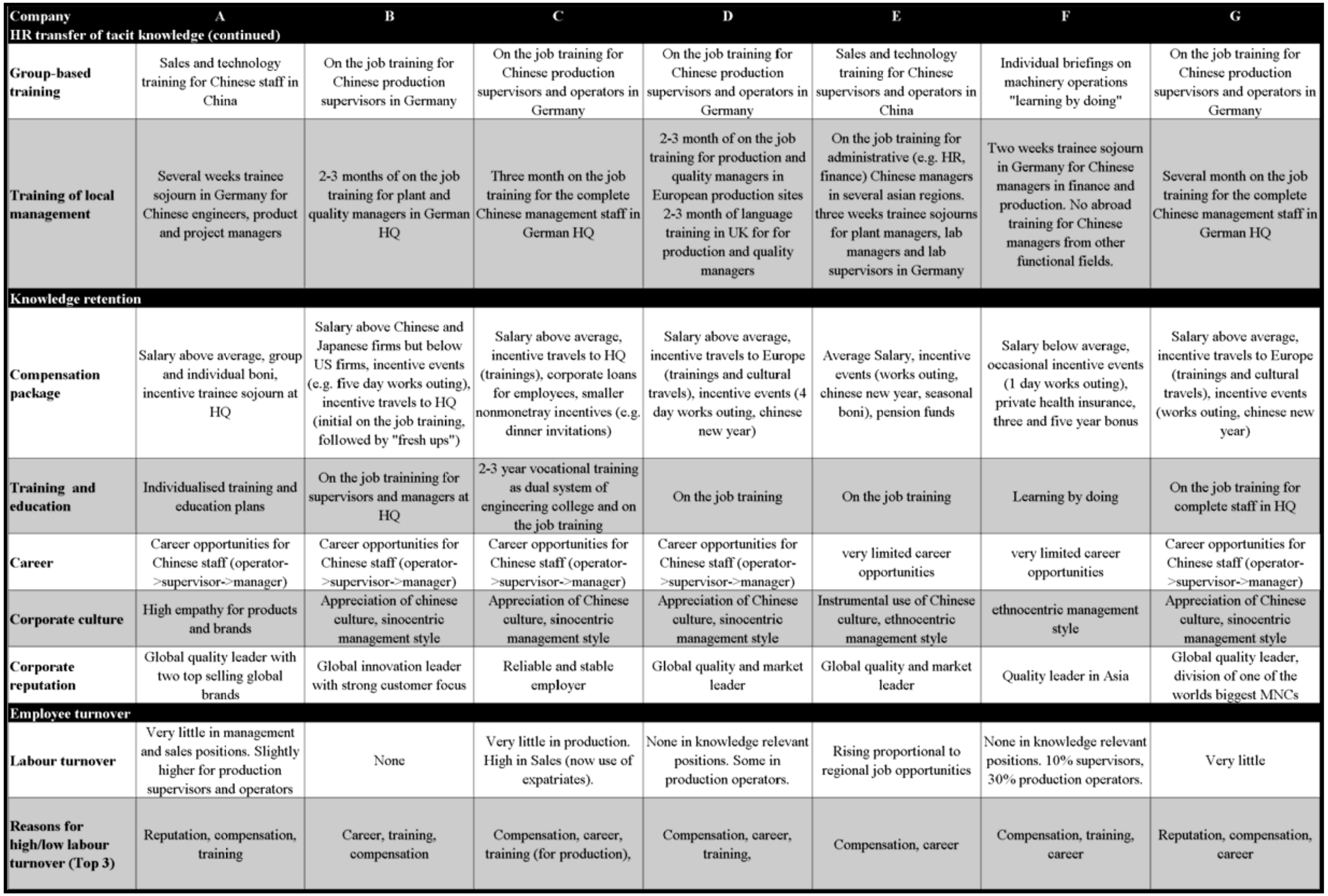
Prior to an in depth investigation into the unique strategies of the firms in our sample we are going to discuss some observations along the line of our literature review in chapter two and the synopsis of the interviews in table 2.

3.2.1 Company overview

First of all the *ownership structure* does not seem to have any influence on the IPR protection within our sample. Four of the companies started as joint-venture, two are still joint-ventures with Chinese financial investors with no interest in strategic or operational decisions. The remaining three firms were founded as wholly-owned subsidiaries with the explicit goal to stay in control over intellectual property. The *organizational design* and *information technology use* is very similar and – like ownership structure – does not seem to influence the IPR protection in a significant way. The *core competencies* stated by the interview partners are rather dissimilar, only two companies (F, G) totally match their core competencies, B and E match two competencies related to their production technology, while A and C are the only ones to mention market knowledge and at the same time are the only companies who state more than production technology as relevant *competitive know how in China*. While most of the companies have not experienced IPR infringement, D and E explicitly expect their products to be copied within the first three years of market entry and have embraced that fact in their business model. The existing variety in core competence bundles and relevant know-how validate the formal criteria for sample selection in representing a full range of possible approaches to the Chinese market and IPR protection.

Company overview	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Products	Industrial lighting fixtures	Plastic profiles	Felts for textile and technical use	Pharmaceutical products	Specialty chemicals	Manual transmission parts	X-ray emitters
Ownership structure	Joint-venture (majority of shares owned by MNC)	Wholly owned company (100% of shares owned by MNC)	Wholly owned company (100% of shares owned by MNC)	Joint-venture (majority of shares owned by MNC)	Wholly owned company (100% of shares owned by MNC)	Wholly owned company (100% of shares owned by MNC)	Wholly owned company (100% of shares owned by MNC)
Organizational Design	functional	functional	functional	functional	functional	functional	functional
Use of information technology	Worldwide intranet, local ERP	Local ERP	Local ERP	Customer complaints database	Worldwide ERP incl. procurement data, pricing, testing procedures, plans and results, production planning. But no information about blending procedures.	Local ERP	Worldwide ERP and intranet, e-learning platform
Core competencies	Market knowledge, reputation, service,	Process management, production technology, quality	Market knowledge, process management, quality	Employee skills, reputation, quality	Process management, production technology, quality	Production technology, quality, reputation	Production technology, quality, reputation
Competitive know-how relevant for Chinese subsidiary	Production technology, Sales and distribution, Marketing	Production technology	Production technology, Sales and distribution	Production technology	Production technology	Production technology	Production technology
Experience with IPR infringment	Copies of single products, irrelevant to business	None	Attempted piracy of brand name	Imitated products are expected to enter the market with a three year delay	Imitated products are expected to enter the market with a three year delay	None	None
Physical transfer of codified knowledge							
Type of technology transfered	Core technology incl. process documentation and technical drawings	Core technology incl. process documentation and technical drawings	Core technology incl. process documentation	Peripheral technology incl. process documentation	Core technology incl. process documentation	Core technology incl. process documentation	Core technology incl. process documentation
"black boxes" (Components of technology *<u>not</u> transfered)*	None (component strategy: every key technology is transferred when needed. Production technology is transparent and easy to imitate.)	Key tools for production process (every production tool is constructed as three different parts and each part is manufactured by a different company unknown to others. The tools are assembled at the production site.)	Key technology to production process (formulas for chemical treatment of felts)	None (production processes to complex to be imitated. Reverse engineering of products by chemical analysis not possible)	Key process for assembly of end-products (process instruction for blending chemical components)	Key product specifications (CAD drawings for transmission parts). Key tools for production process (every tool is manufactured in Germany and sent to China without further documentation. All worn out tools must be sent back to Germany)	None (production technology to complex to be imitated. High financial market entry barriers compared to a relatively small niché market.)
Local R&D	none	"last mile" (only for improvement of quality control)	development of new felts	"last mile" (adjustments to local market needs)	"last mile" (testing of products for local market)	none	"last mile" (adjustment of HQ-products to local production technology)
HR transfer of tacit knowledge							
Expatriates	all strategic positions	General manager, assistant general manager	General manager, sales manager, plant manager	Plant manager	General manager, marketing manager, sales manager	General manager (part time), plant manager (full time)	General manager (till 2007; new GM is Chinese), financial manager, supply chain manager
HQ-Experts and Consultants	Sales training for local staff, sales project managers, technical project managers	German service engineers for periodic maintenance	No use of homeland consultants	German service and chemical engineers design production processes and lab tests	Sales and technology training for Chinese supervisors and operators	Extensive use of German experts in the start-up phase 2004. Since then no use of HQ experts.	No extensive use of HQ consultants and experts

Table 2: Summary of finiings



Company	**A**	**B**	**C**	**D**	**E**	**F**	**G**
HR transfer of tacit knowledge (continued)							
Group-based training	Sales and technology training for Chinese staff in China	On the job training for Chinese production supervisors in Germany	On the job training for Chinese production supervisors and operators in Germany	On the job training for Chinese production supervisors and operators in Germany	Sales and technology training for Chinese supervisors and operators in China	Individual briefings on machinery operations "learning by doing"	On the job training for Chinese production supervisors and operators in Germany
Training of local management	Several weeks trainee sojourn in Germany for Chinese engineers, product and project managers	2-3 months of on the job training for plant and quality managers in German HQ	Three month on the job training for the complete Chinese management staff in German HQ	2-3 month of on the job training for production and quality managers in European production sites 2-3 month of language training in UK for for production and quality managers	On the job training for administrative (e.g. HR, finance) Chinese managers in several asian regions. three weeks trainee sojourns for plant managers, lab managers and lab supervisors in Germany	Two weeks trainee sojourn in Germany for Chinese managers in finance and production. No abroad training for Chinese managers from other functional fields.	Several month on the job training for the complete Chinese management staff in German HQ
Knowledge retention							
Compensation package	Salary above average, group and individual boni, incentive trainee sojourn at HQ	Salary above Chinese and Japanese firms but below US firms, incentive events (e.g. five day works outing), incentive travels to HQ (initial on the job training, followed by "fresh ups")	Salary above average, incentive travels to HQ (trainings), corporate loans for employees, smaller nonmonetray incentives (e.g. dinner invitations)	Salary above average, incentive travels to Europe (trainings and cultural travels), incentive events (4 day works outing, chinese new year)	Average Salary, incentive events (works outing, chinese new year, seasonal boni), pension funds	Salary below average, occasional incentive events (1 day works outing), private health insurance, three and five year bonus	Salary above average, incentive travels to Europe (trainings and cultural travels), incentive events (works outing, chinese new year)
Training and education	Individualised training and education plans	On the job trainning for supervisors and managers at HQ	2-3 year vocational training as dual system of engineering college and on the job training	On the job training	On the job training	Learning by doing	On the job training for complete staff in HQ
Career	Career opportunities for Chinese staff (operator->supervisor->manager)	Career opportunities for Chinese staff (operator->supervisor->manager)	Career opportunities for Chinese staff (operator->supervisor->manager)	Career opportunities for Chinese staff (operator->supervisor->manager)	very limited career opportunities	very limited career opportunities	Career opportunities for Chinese staff (operator->supervisor->manager)
Corporate culture	High empathy for products and brands	Appreciation of chinese culture, sinocentric management style	Appreciation of Chinese culture, sinocentric management style	Appreciation of Chinese culture, sinocentric management style	Instrumental use of Chinese culture, ethnocentric management style	ethnocentric management style	Appreciation of Chinese culture, sinocentric management style
Corporate reputation	Global quality leader with two top selling global brands	Global innovation leader with strong customer focus	Reliable and stable employer	Global quality and market leader	Global quality and market leader	Quality leader in Asia	Global quality leader, division of one of the worlds biggest MNCs
Employee turnover							
Labour turnover	Very little in management and sales positions. Slightly higher for production supervisors and operators	None	Very little in production. High in Sales (now use of expatriates).	None in knowledge relevant positions. Some in production operators.	Rising proportional to regional job opportunities	None in knowledge relevant positions. 10% supervisors, 30% production operators.	Very little
Reasons for high/low labour turnover (Top 3)	Reputation, compensation, training	Career, training, compensation	Compensation, career, training (for production),	Compensation, career, training,	Compensation, career	Compensation, training, career	Reputation, compensation, career

Table 2: Summary of finiings (continued)

3.2.2 Physical transfer of codified knowledge

All but one company (D) have transferred their *core technology* and relevant documentation to China because they would not be able to stand international competition with outdated technology and at the same time process and technical documentation is necessary because of legal requirements and/or the complexity of the technology. D is using peripheral technology and has built its Chinese business model around it. Companies B, C, E and F use key parts of their production as *"black boxes"* to protect themselves from technology theft. The others do not attempt to shield their technologies either because it is too transparent (A) or to complex to be imitated or reverse engineered (D and G). Only C conducts substantial *local R&D*. The common use of core technology in combination with only partial attempts to protect technology was rather unexpected, but shows the competitive edge production technology gives to these firms and at the same time the trade off between efficiency and IPR protection. An easily imitable technology is not worth to be protected; a very complex technology needs no protection.

3.2.3 HR transfer of tacit knowledge

The use of *expatriates* is more extensive in the group of A, C, E and F where the most strategic positions are staffed with homeland personnel, while at B, D and G most top management positions are held by Chinese managers. B and D use *HQ-Experts* to contain relevant knowledge, A and E to disperse knowledge among the local production staff; C, F and G do not use mobile consultants. B, C, D and G send parts (supervisors) or all (supervisors and operators) of their staff to their European HQs for *group based training*, A and E train their Chinese production and sales staff in China, F gives no specific training for their staff. All companies *train their Chinese management* at their HQ. While some (A, E and F) send them there for only a few weeks for a kind of "taster course", some others allow (B, C, D and G) several month of on the job training in Germany. The strategies pursued in tacit knowledge transfer seem largely to depend on the imitability and complexity of the production technology. E.g. A and E consider their technology to be easily imitated; therefore they try to transfer the least possible knowledge to the local staff (use of expatriates in most strategic positions, use of HQ-experts for group based trainings in China, only short HQ visits for Chinese managers). The far opposite can be observed in case G: the complexity and costliness of the technology in use prevents imitation and demands extremely well trained staff (use of Chinese managers in all strategic positions, no mobile consultants, group based training in Germany for complete Chinese staff, three month on the job training for Chinese managers). The tacit knowledge transfer strategies of B, C, D and F can be located between these two extremes.

3.2.4 Knowledge retention and employee turnover

The efforts to decrease employee turnover and thereby to impede knowledge transfer to local competitors can be differentiated along the dimensions of short and long term effects and of monetary versus non non-monetary incentives. All interviewees agree that the compensation package is the single most powerful short term motivator for Chinese employees. Companies A, C, D and G offer the most comprehensive *compensation* including above average salary, performance boni, incentives (travel, works outing, gifts) and special benefits (e.g. language courses, corporate loans, health insurance). B, E and F also comply with culturally expected incentives (e.g. Chinese New Year celebration) but can only offer average or below average salary. The configuration of e*ducation and training* has been discussed in the preceding section under the aspect of knowledge transfer and is the same under motivational aspects. Only C (two and three year vocational training programme) and F (no training for operating and supervisory staff at all) pursue special strategies which we expect to have impact on labour turnover. Most interviewed managers valuate training and career opportunities as two important long term monetary motivators. Both are considered to be investments in human capital to leverage the long term compensation profile. A, B, C, D and G offer normal *career* ladders to their Chinese staff, while E and F admit very limited opportunities for their Chinese employees.

Corporate reputation and corporate culture are fundamental long term non-monetary incentives. B, C, D and G do appreciate the Chinese culture and have applied a sinocentric management style; E and F use a more ethnocentric approach. A is not concerned about intercultural management at all and defines its corporate culture as a function of its *corporate reputation*. All companies but C and F do have a very strong reputation as a global leader in their branch.

The need to retain the knowledge transferred by decreasing the labour turnover originates from the characteristics of the relevant knowledge. The crucial areas are sales & market know how and knowledge about processes and technology. If the relevant know how is to complex to be imitated (e. g. D and G) it can hardly be copied and therefore creates little bargaining opportunities for employees with the companies' competitors. Moreover the necessity to train the employees in these solitary technologies creates human capital that can only be utilised in this specific context.

Firm specific human capital creates lock-in effects. Employees can not capitalise on their firm specific knowledge on the job market as the market value of their general human capital is below their current wages, at the same time the employer's necessary investment into education and training creates negotiating power for the employees. After receiving the specific training an employee could threaten to leave the firm, in which case the employer would lose his training investment and would again have to invest into the replacement. Therefore we expect that in firms with less imitable technology and high investments in (specific) human capital the efforts for knowledge retention should be high and turnover low. This can be observed in companies D and G.

For the same reasons complementary retention strategies can be found in firms with highly imitable technologies trying to protect their knowledge from spillovers by transferring lesser human capital to the local staff. These firms know that learning – especially in higher echelons of supervisors and managers – can not be avoided and try to retain this knowledge by offering premium (non-)monetary compensation. This strategy can be found in A and B, while E – sharing most of A's characteristics apart from the retention strategy – experiences rising turnover and knowledge spillovers to competitors. At the same time C (highly imitable/high transfer) does moderately invest in knowledge retention and F (middle imitable/ low transfer) accepts high labour turnover for cost efficiency reasons.

3.3 Firm specific strategies in IPR protection

Now, after having gained insight into recurring configurations of organisational measures protecting IPR we will now closely examine the firms IPR protection strategies in relation to their specific business model.

3.3.1 Company A: Spider in the Net

A’s business is project based. As a global leader in industrial lighting whose solutions are expressively requested by star architects, the special competence of this company lies at the interface of superior but easy to imitate production technology, strong corporate reputation & brands and in its outstanding capabilities in management of complex networks of architects, lighting planners, realty developers and institutional owners. The IPRs of A are mainly protected by its experience in this kind of *network management*. Buyers are not only interested in the products but mainly in the services these products are embedded in.

This business model is reflected in the core competencies (market knowledge, reputation, service) – this is the only company not mentioning product related competencies – and relevant competitive know how in China. The physical transfer of knowledge is very open; no “black boxes” are used. The transfer of tacit knowledge to the local employees is very restricted: on the one hand no highly specific skills are needed for production or middle management on the other hand market relevant know how (key accounts, project management, etc.) is confined to expatriates in strategic positions. The efforts to retain employees are rather comprehensive but lack the intercultural orientation of most other companies in the sample; it can be assumed that the strong corporate culture is able to partly replace the national culture.

3.3.2 Company B: Divide and Rule

The main IPR protection mechanism of this company is the *division of technology know how* (core competencies) into as many different heads as possible. All technology (machinery, tools) is classified into five classes ranging from peripheral/common knowledge to key technology/top secret. All construction work for the top three classes is done in Germany and the plans are sent to the expatriate general manager who keeps them under lock and key. All machinery and tools are composed of three different parts; the manufacturing of these parts is outsourced to three different toolmakers in China (who do not know of each other or the parts purpose). Moreover everyone but the currently working operators and supervisor must keep a minimum distance of 30 meters to the production tools and machinery. Although it was necessary to transfer codified core technology to China B has managed to keep the key technology as a black box to its employees. This is reflected in the transfer of tacit knowledge as well. Necessary maintenance – which would allow for a closer look into the black box – is done by German experts, only the Chinese supervisors have been trained in the HQ. Because of this tight sealing-off of key knowledge it is possible to use (cheaper) Chinese managers in most of the positions and in turn offer career opportunities for the local staff. Although the compensation is not totally above average the combination of career opportunities, sinocentric management and strong reputation inhibit labour turnover.

3.3.3 Company C: Faith in God

The situation of C is comparable to A: the production technology for felts is not in peril of being copied as it is common knowledge; therefore no attempt is made to protect it. There is one slight competitive advantage in chemical treatment of felts, which is protected by mixing the chemicals in Germany and not disclosing the ingredients (black box). The company is conducting genuine R&D in China. The main competitive advantage of the firm is sales and distribution know how, which is protected. Discrete customer databases are kept for different products and regions, sales staff is not allowed to enter the production site and production staff is not allowed to enter administrative buildings to prevent cross-functional spillovers

There is extensive tacit knowledge transfer to operators, supervisors and to the trusted local management that has been with the firm since the very beginning (2000) and is not expected to leave the firm. Unlike company A the market knowledge is not entangled in dense supplier-buyer networks but mostly about customers' needs and contacts. Once it is revealed to a local sales person she can easily capitalise on this knowledge in the job market. This has led to high employee turnover in the sales department in the past. Nowadays strategic positions in sales are held by expatriates to stop these spillovers. All in all the measures to retain knowledge are first-class except for the company's reputation.

3.3.4 Company D: The Tortoise and the Hare

D is the only firm in the sample using peripheral technology in the Chinese market and has indeed built its whole business model around this fact. As the Chinese market does not demand up to date products of this firm it utilises the technology gap: The first version of a product is introduced into the Chinese market when the third version is introduced into the European market. The first upgrade is introduced into the

Chinese market when imitations of the original product begin to gain market share (usually after 3 years). This product cycle protects innovative products from imitation, creates cost advantages through re-use of old European production lines in China and frustrates imitators; every time they launch an imitation into the market, the innovator launches an improved product at about the same price.

While the machinery needed to fabricate the products can be commonly bought and is quite affordable, the production processes cannot be reverse engineered from the final product and need specific skills and highly qualified pharmacists. For that reason no measures are taken to protect the codified technology from imitation, but the design of processes and lab tests are overseen by German experts. The complexity of the processes makes it essential to transfer a lot of tacit knowledge to the local staff and as a consequence large efforts are taken to retain this knowledge within the firm (e.g. language courses in UK).

3.3.5 Company E: Size matters!

As a global leader in specialty chemicals this firm relies on *economies of scale* in R&D, procurement, production, finance and marketing, realised by the extensive use of a global ERP-system. Very much like company D imitations of products are expected within three years, but are not feared. The company's customer selection (global chemical firms) makes local imitation extraneous to the business model. Most of the production is not destined to the European market. The singular ambition of this firm is to guarantee high quality products at competitive prices for their global customers

Of the codified knowledge only the blending (recipes and process) is used as a black box. The transfer of tacit knowledge is modest, the top management positions are held by expatriates; neither are high investments taken into the education of the local workforce, nor is the retention of knowledge emphasized by salary, intercultural management or career opportunities. This strategy is acknowledged through continuously rising labour turnover by the Chinese staff.

3.3.6 Company F: Code of Silence

As automotive supplier this global market leader in transmission parts relies on outstanding quality and cost efficiency of products. The quality is achieved by combination of superior production machinery (imitable) with tools for drop-forging that are constructed and manufactured in Germany. All tools are directly sent to the plant manager (expatriate) who supervises the installation of the tool and personally sends back all worn off tools to Germany, creating a black box at the heart of the technology. Furthermore virtually no tacit knowledge is transferred to the local staff as there is no on the job training provided for operators and supervisors and only very short on the job trainings for Chinese managers.

Company F does not need to retain employees because there is no relevant knowledge transferred to the Chinese employees in the first place. With below average sales, no training, no career opportunities and a proficient lack of intercultural management competencies labour turnovers of up to 30% are gladly accepted in exchange for cost efficiency.

3.3.7 Company G: The Stronghold

The final company in this review can be said to have the best product immanent IPR protection. The production of supreme quality x-ray emitters is based on a much elaborated technology that is to complex to be imitated without own genuine experience in developing the base technologies. The production facilities needed are extremely expensive *and* specific, so there are high financial entry *and* exit barriers to enter the market. Finally, the market itself is a very narrow niche market with only a few global suppliers and buyers connected in long term personal relationships. In other words if a local competitor would gather knowledge about the technology he would not be able to reproduce it, could not afford to do so and would not find buyers.

This sustainable competitive advantage is reflected in the firm's configuration: the codified knowledge is not protected by "black-boxing", all strategic positions including the general manager are held by Chinese and all echelons of the staff are thoroughly trained in the HQ. As argued above the intensive transfer of knowledge to the local staff calls for a comprehensive knowledge retention programme for efficiency reasons rather than for means of protecting IPRs.

3.4 Identifying IPR protection strategies

From the detailed investigations of the configurational elements across all companies (section 3.2) as well as the organizational configurations and business model of each company (section 3.3) three key factors for IPR protection can be inferred: *1.The* *imitability of production technology.* In the best case (G) the technology is too complex to be copied, the second best solution is an imitable, yet (partly) concealable technology (e.g. B) and the worst case would be a very transparent technology (e.g. A and C). In the later cases further protection of IPRs springs from core competencies or from controlling the flow of know how to the local personnel. *2. The knowledge transfer to the local staff.* As said above, the best way to protect knowledge is not share it (F), although with rising complexity of production technology the more knowledge must be shared with local staff to ensure a smooth-running production. A second reason to share knowledge with the locals is cost efficiency, many firms invested in China to benefit from the cost of labour in NICs, the more local managers (instead of expensive expatriates and consultants) employed, the lower the costs(e.g. B). If a company can not avoid sharing significant knowledge with its local personnel it must take action to keep the employees as long as possible. *3. The retention of knowledge within the firm.* The need to retain knowledge is a direct consequence of the unsatisfactory IPR situation in China and the transfer of knowledge. Again there are two reasons to minimize unwanted labour turnover. On the one hand the loss of well trained and productive personnel destroys the rents of specific human capital, on the other employees are expected to show opportunistic behaviour and to "sell" their knowledge to a competitor for higher wages.

These three factors are individually combined by the firms in our sample to fit their unique business model. In a simplified model – as visualised in figure 1 – three different strategic patterns to protect IPRs through organisational measures can be found. *Pattern 1 (A and B):* With highly imitable technology both companies try to keep knowledge transfer at bay. B does so by "black-boxing" their codified knowledge and A by minimizing the spillovers of tacit knowledge. Both are trying to retain their employees with an elaborated incentive structure. This balanced pattern merges an active protection of IPRs; technology based competitive advantages and cost efficiency. *Pattern 2 (E and F):* This strategy is similar to the first pattern concerning imitability and technology transfer but is based on exploiting low-cost workforce in China. Therefore no attempts are made to retain employees with these firms. Consequently both firms experience rising labour turnover. It can be assumed that this pattern does not provide sustainable competitive advantage, as rising labour costs in China are likely to diminish the existing cost margin. *Pattern 3 (D and G):*

This pattern represents high-tech firms whose complex production technology guards them from imitation and makes it at the same time necessary to transfer a lot of know how to the local staff. Like A and B these firms make high investments in employee retention, but primarily not because they fear knowledge spillovers to competitors, but not to loose their investments in the human capital of their highly specialised workforce. Both firms do not care very much for their IPR protection, this pattern might be as well found in countries with better IPR protection.

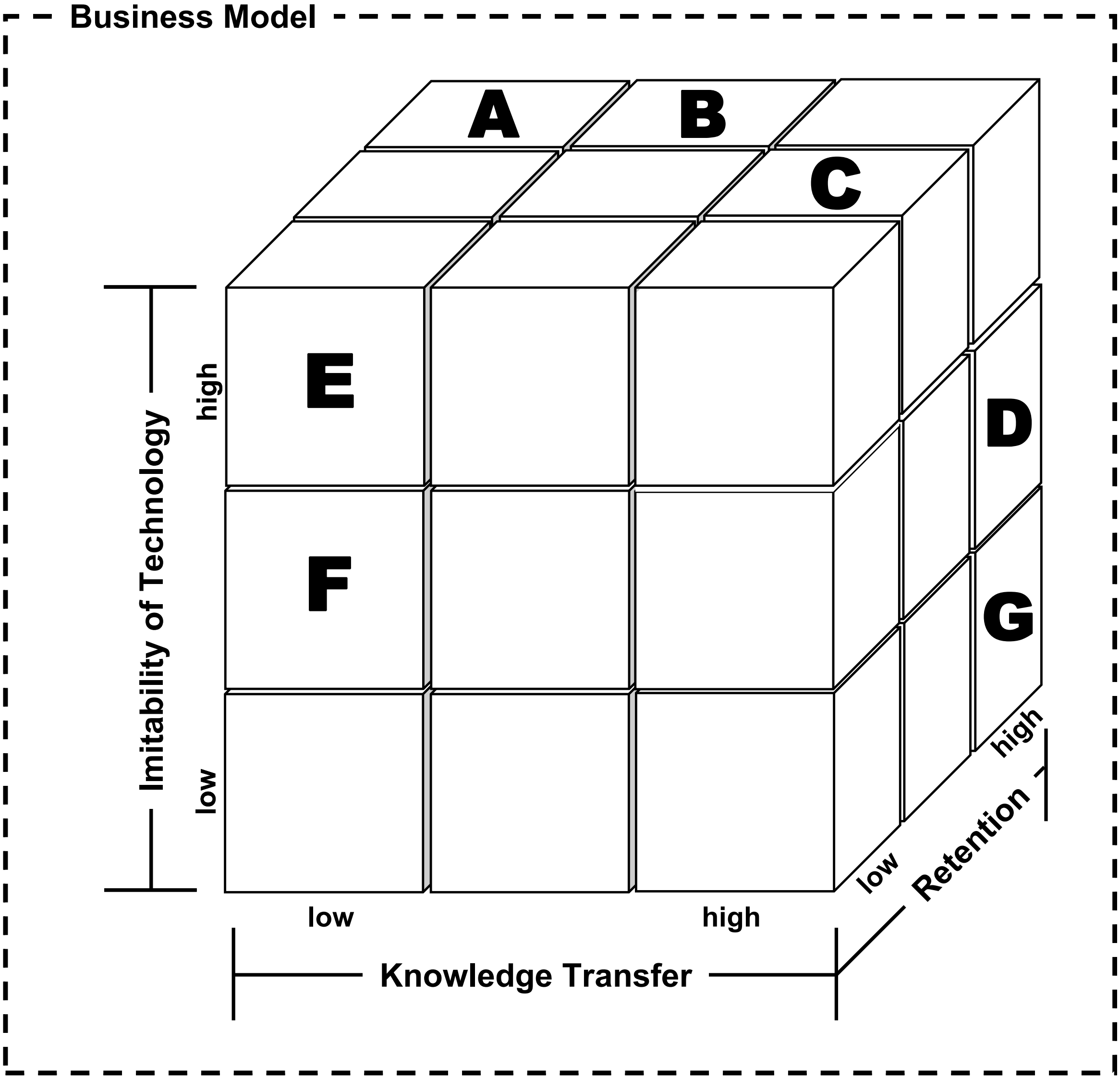


Figure 1: Strategic patterns

4 Concluding remarks

The existing strand of literature on the protection of intellectual property rights in newly industrialised countries is mainly engaged in the study of high-tech industries (mostly semiconductors), while the literature on knowledge transfer through foreign direct investments is mainly concerned with the advancement of spillovers instead of avoiding them. This study is one of the first to include not only high-tech, but also middle- and low-tech companies to investigate IPR protection in a wide variety of industries.

As we assumed the need to protect IPRs is higher in firms with less complex and easy imitable products and technologies. We were able to show consistent organisational elements used in IPR protection as well as the need to fit the companies' business model to their core competencies and resources. Finally we were able to derive broad strategic patterns in IPR protection, closely linked to the "tech-state" (high/ middle/ low) of the respective company. However this qualitative study can only grant first and preliminary insights. In further research it will be necessary to differentiate the identified elements and apply these insights to bigger samples using self reported or microeconometric data.

Considering the value of our findings to the practitioner planning to establish a subsidiary in a country with poor intellectual property rights protection our insights can be used in two ways. Either to fit the existing homeland business model to the needs of that country or, if that is not possible, to identify possible knowledge leaks and to counteract them by the elements described.

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How to improve patenting at universities in Europe

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*** Draft Article - Work in Progress ***
Please do not quote without contacting the authors

Abstract:

The article starts with an assumption that patents have a role to play in the knowledge transfer process as facilitators of the exchange between university and industry. Based on this, the article addresses the issue of university patenting in Europe, especially in the framework of efficiency of public research and development funding. Following, a concrete measure to improve patenting in European universities proposed by the European Patent Organisation and targeted especially to countries with lower innovativeness is illuminated. The proposal concentrates on the implementation of comprehensive patent service centres, which provide specialist link between university and industry.

Key words: university patenting, patents, innovation, knowledge transfer, patent-related services, technology transfer.

*Disclaimer
All three co-authors work at the European Patent Office. The opinions expressed here are purely our own, and neither the European Patent Office nor any other party necessarily agrees with them.

1. Introduction

> ***"Everyone can publish a scientific document. However, the challenge for a researcher is to have an impact on society: to create jobs and wealth"***
>
> Antonio Camara[i], CEO of YDreams

University patenting is analyzed within the broader context of technology and knowledge transfer and the general European Union policy framework of knowledge-based society. Knowledge transfer is understood to consist of "the range of activities which aim to capture and transmit knowledge (either explicit, such as in patents or tacit such as know-how), skills and competence from those who generate them to those who will transform them into economic outcomes. It includes both commercial and non-commercial activities such as research collaborations, consultancy, licensing, spin-off creation, researcher mobility and publication. Knowledge transfer is a wider concept than "technology transfer": it includes other transfer channels, such as mobility of staff or publications" (European Commission, 2007b).

A subset of knowledge transfer is the phenomenon of university - industry technology transfer, of which an important part is the university patenting. In particular, patents are a key tool for protecting innovation in a number of science-based technologies. "Academic scientists contribute to these technologies both indirectly, by widening the science base, and directly, by producing inventions susceptible of industrial application, and therefore protected by patents" (Lissoni et al. CESPRI pg. 2).

The goal of this paper is to present an initiative of the European Patent Office to improve university patenting in Europe. This is done in several steps. First, a link is drawn between university patenting, technology transfer, and research and development funding. Next, differences in capacity to innovate between the new EU-12 Member States and the EU-15 are discussed. Following, conditions under which patenting at universities can be improved are considered. In order to facilitate a systematic analysis, a model of university patenting proposed by ProTon is used. The model tries to answer the following:
1) Who are the actors involved?
2) What are the necessary conditions for university patenting?
3) What competences are required?

On the basis of the model, the article highlights one possible approach, chosen by the EPO, whereby the national patent offices play an important role in stimulating university patenting. The EPO pilot project on Knowledge Transfer Offices foresees the establishment of comprehensive patent centres at universities with expertise input from the national patent offices, especially in those Member States of the European Patent Convention, where patenting in general, and university patenting in particular, is low. The article postulates that better patent-related services offered to the universities will increase the patenting rate. This will be due to the fact that the pilot knowledge transfer offices will employ high-quality, customer-oriented specialists, who will provide services to link the researcher and the industry needs.

It is important to acknowledge that there is an ongoing debate on the extent of the contribution of patenting to the improvement of the innovative capacities of an economy. Moreover, some researchers find evidence that university patenting may be hindering or at least slowing industrial innovation (Fabrizio). On the other hand, there are recent studies, which show how university patenting and technology transfer positively influence the quality of work in academia (Breschi et al. showing that academic inventors publish more and better quality papers than their colleagues with no patents, and increase their productivity after patenting). It is possible to conclude that the issue of the importance of patents in the innovation policy will remain a point of discussion for some time. In this paper, patents are seen as catalysts of the university-industry technology transfer. This, however, does not imply that the authors are proponents of blind push for more university patents. Rather, the general recognition that patenting as a phenomenon should be welcome at universities is accompanied by the assumption that only high quality university patents, flanked by appropriate transfer mechanisms can indeed be beneficial for the university and society at large.

Furthermore, there is a clear political guidance from the European Council to be active in the context of technology transfer from universities to industry. This is by now identified as a key issue for the strengthening of innovation, and of the European economy in general, as stated in the Presidency conclusions of the European Council meeting of 8-9 March 2007 in Brussels (European Council). Furthermore, the communication from the Commission to the Council "Improving knowledge transfer between research institutions and industry across Europe: embracing open innovation" dated 4 April 2007 gives clear recommendations and includes several points, such as:

- promotion of trans-national dimension of knowledge transfer;
- establishment of "Voluntary guidelines for universities and other research institutions to improve their links with industry across Europe";
- dependence of success of knowledge transfer offices on skills and competencies of their staff;
- increase of staff mobility between the public and private sector;
- promotion of an entrepreneurial mindset based on a professional management and understanding of intellectual property issues.

Also WIPO acknowledges that university patenting has increased in importance and provides policy considerations as to the next steps in development of a" framework aimed at fostering a greater interaction between public research and industry in order to increase the social and private returns from public support to R&D" (WIPO).

2. Academic patents

"Universities and other higher education institutions are key elements in the science system in all EU countries. They perform research and train researchers and other skilled personnel. The role of universities and scientific research in the innovation system has broadened in recent years. For example, according to the OECD, there is a 'growing demand for economic relevance' of research, and 'universities are under pressure to contribute more directly to the innovation systems of their national economies' (OECD, 1998). In particular, universities are becoming more dependent on output and performance criteria and academic research is increasingly mission-oriented as well as contract based (European Commission 2003c; OECD, 1998). At the same time, universities have established closer links with business through cooperative research, networks and exchange of information" (European Commission 2004, pg. 48).

Despite this broader role of universities in innovation, university patents worldwide represent only 5% of all inventions. While the top US university patent assignee - University of California - had almost 600 patented inventions in 2005 and in Asia, the University Quinghua, China, had 900, in Europe, the best university patent assignee - the CNRS (Centre National de la Recherche Scientifique) took the lead with just over 130 inventions (Trotter and Yeatman).

At this point it must be acknowledged that the literature on university–industry relationships is mainly empirical and based on case studies, patent and bibliometric analyses, or large surveys. In most current research on university patents in Europe Lissoni et al (2007) point to the fact that there might have been an underestimation of patenting based on research in universities due to appropriation problems. Nevertheless, the closing of the gap between Europe and the United States is supposed to occur due to the inclusion in the statistical analysis of those patents, which were obtained by companies from activities performed by university researchers. However, the article argues that this correction of the statistical information does not contradict a recent observation included in the EU communication that "compared to North America, the average university in Europe generates far fewer inventions and patents. This is largely due to a less systematic and professional management of knowledge and intellectual property by European universities."(European Commission, Implementing the Lisbon Agenda).

While it may be true that overall patents produced on the basis of publicly-funded research are similar in number in the US and Europe, it is also acknowledged that in Europe these patents are, to a certain degree, applied for, retained and exploited by companies. Universities seem to support research but appear unable to profit from it.

If that highlighted observation is then analysed in terms of efficiency of publicly funded research and development, and it is assumed that patented inventions are outcomes of academic research, it is possible to conclude that whether or not patents were counted correctly, the issue of universities owning the patents remains problematic.

Additionally, it must be observed that to date analysis of the academic patenting in Europe has almost exclusively concentrated on the "old" EU-15 countries. This is also the case of the Lissoni et al (2007) study. Such situation provides a skewed view of Europe. If by Europe, at least the European Union is meant then the analysis has, up to date, only focused on the Western part of that geography. In the following, the two issues raised here: economic efficiency and specificity of Central and Eastern European university patenting are discussed.

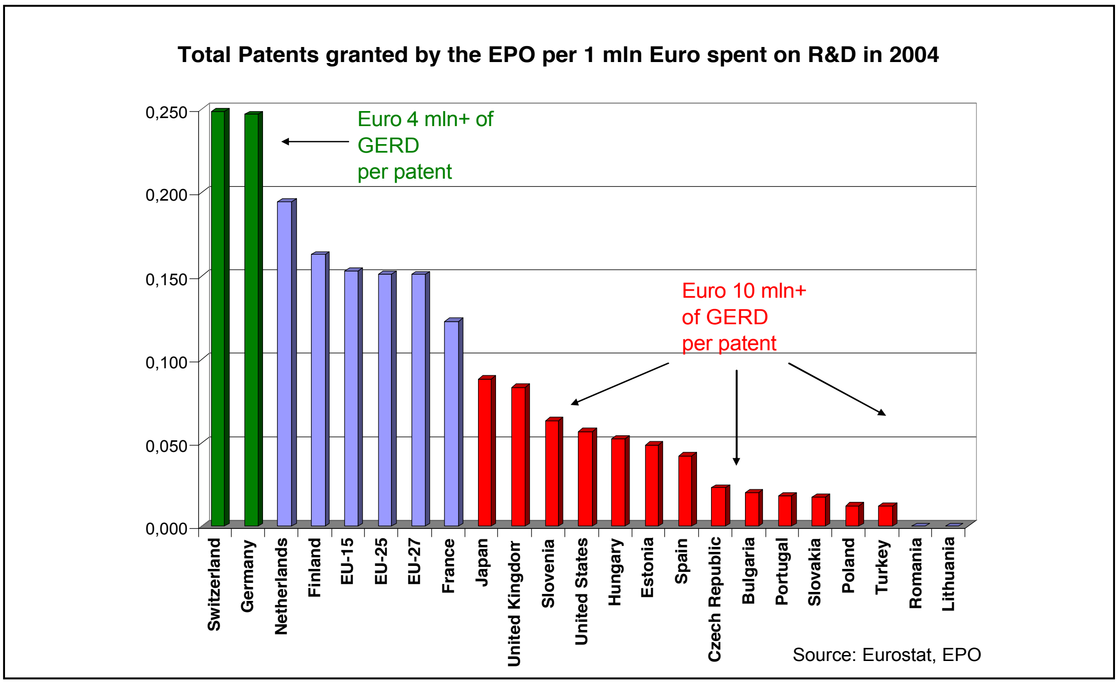
2.1. Economic efficiency of R&D investment

The broader policy of technology transfer from university to industry, based on transfer of explicit knowledge in form of patents and implicit know-how is linked to the idea of recouping public money invested in the research and development process through licensing income, positions offered to qualified graduates and more business funding of R&D.

Public activity in the area of R&D can be discussed from two angles. First, it is possible to describe the actions of the public sector, i.e. to measure the degree of public intervention. This includes a discussion of direct R&D expenditures by the public sector (for example expenditures for higher education or civilian and non-civilian R&D) as well as government instruments aimed at raising the economy-wide degree of R&D activity (for example tax subsidies, tax credits and matching grants). Secondly, it is equally important to assess the impact (or effects) of public R&D. These impacts concern both the additional R&D activity induced in the private sector and the impact of public R&D efforts on outcomes such as patents, new products and labour productivity (European Commission, 2004, pg. 47).

In this paper, efficiency of funds directed towards R&D is defined by number of patent applications per 1 million euros spent on research at a given institution and/or number of patents granted per 1 million euros.

On average, in EU-27, 6.7 million Euros have to be spent on R&D, in order to obtain 1 patent filed at the EPO. In some countries, like Germany, each 4mln Euros, on average, invested in R&D result in an EPO patent, however there are also countries like Hungary, Spain, Portugal, and Poland, where 1EPO patent requires more than 10 million GERD investment.


Total Patents granted by the EPO per 1 mln Euro spent on R&D in 2004

Source: Eurostat, EPO

Graph 1. Total Patents granted by the EPO per 1 million Euro spent on R&D in 2004.

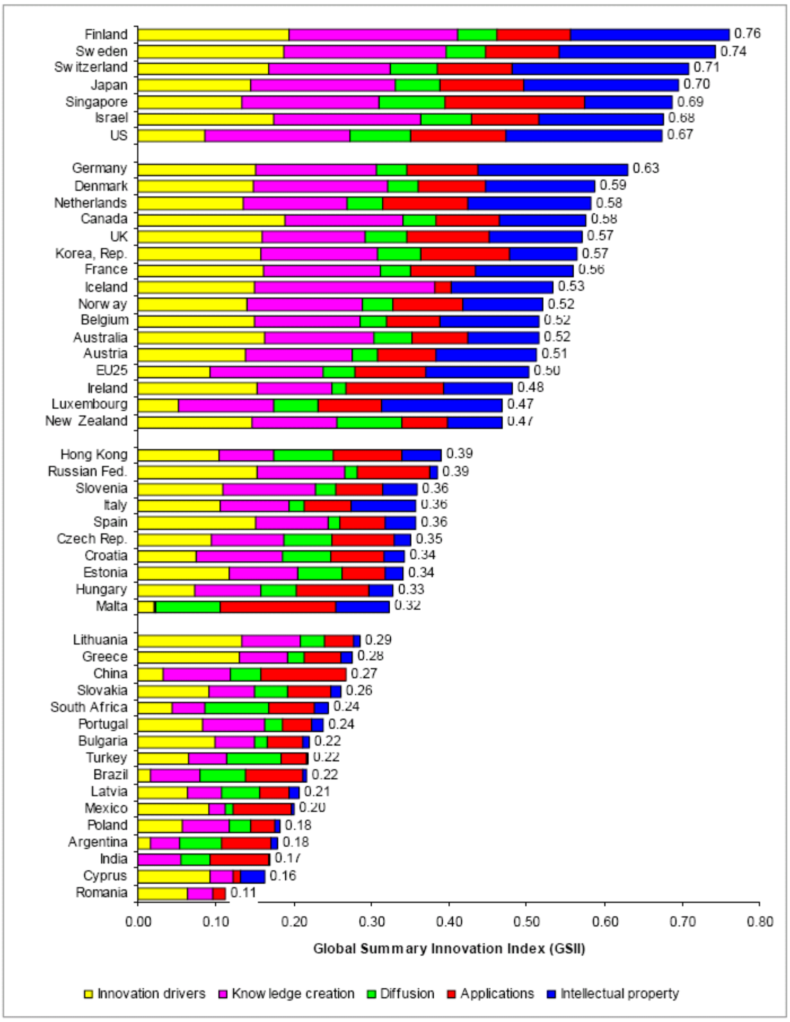
It is difficult to define what level of patenting is an efficient way of using public funding. However, graph 1 clearly shows that of those European Union countries, where 1 EPO patent requires more then 10 million Euros investment, 8 are the new European Union Member States.

3. Specificities of Central and Eastern European university patenting.

As mentioned in the section on academic research, Central and Eastern European Members of the European Union are very rarely an object of study within the context of technology transfer.

From the available sources, the European Innovation Scoreboard provides an overview comparison of EU-27 countries in the global summary innovation index, illustrated in the graph below.

FIGURE 8: GLOBAL INNOVATION PERFORMANCE



Graph 2. Global Innovation Performance. Source: European Innovation Scoreboard.

On the general, comparative level, it can be observed that all new EU-12 Member States score below the EU-25 average, while 8 of the old EU-15 Member States score above it. Moreover, 3 of the 5 countries with lowest scores are the new EU-12

Member States. One of them is Poland - a country with 17 universities and 18 universities of technology (Polish Information and Foreign Investment Agency).

In addition to the comparative data provided above, all governments of the Central and Eastern countries with membership in the European Union admit that they need to improve their performance in the innovation area, in order to reduce the gap with the EU-15. Furthermore, a brief survey of technology transfer offices in Poland provides an impression that although several of these institutions have been established in Poland in the second half of the 1990s and thus have about a decade of experience, patents are not in their focus. Aims of the Technology Transfer Offices are represented by the example of the Wrocław Centre for Technology Transfer (WCTT), established in 1995, which counts among it successes training, consultation, project assistance, and organisation of business idea competitions. It must be noted that WCCT also mentions arranging 20 international technology transfer agreements. However, it is not specified what type of transfer it was.

Moreover, the article by Morkvenas (2006) points to the issues, which are generally a source of concern in the region. He states: "Lithuania has a lot of problems with the transfer and diffusion of new technologies. It is proved by the statistic of European innovation. Universities are not normally known for their entrepreneurial attitude and flair. They are recognized, however, as major knowledge and research centres. One of the main problems of the Lithuanian technological sector is the interaction between universities and businesses, which is a casual and uncontrolled process." (Morkvenas, 2006).

4. Model

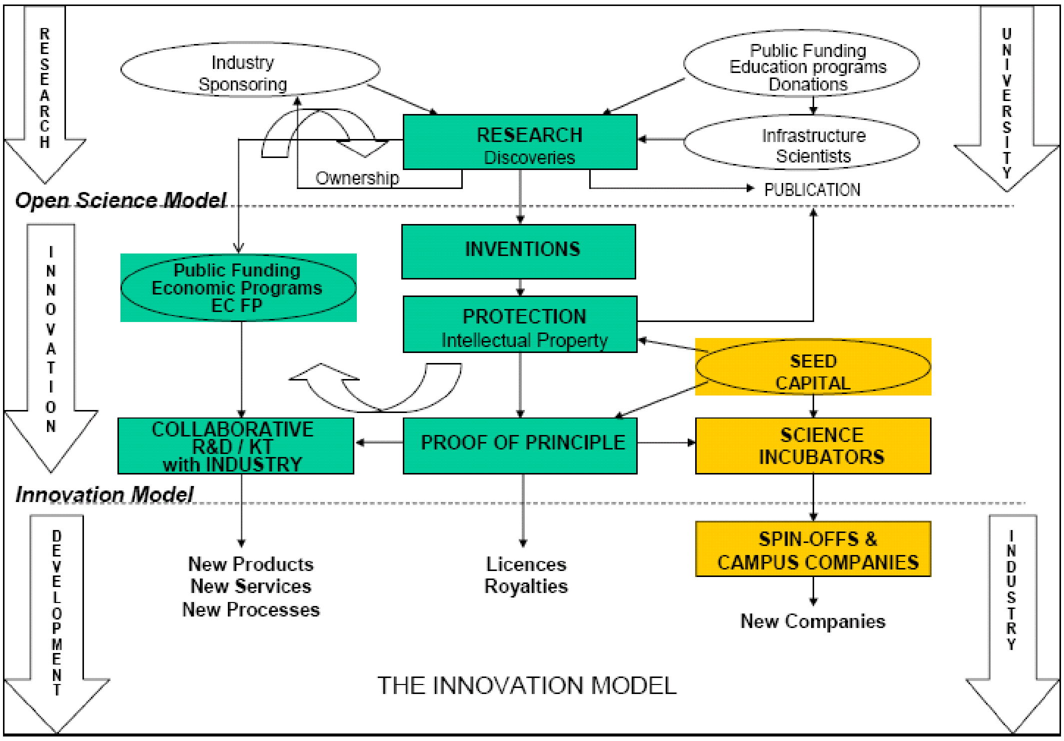
The model, developed by Proton[ii] is a framework for establishing linkages between the different factors contributing to the university patenting.

4.1. Actors

There are two types of actors: institutional and individual. In the process of university patenting, universities and policy-making bodies are the most significant institutional actors, while researchers employed by the universities and companies negotiating patent licenses and transfers are the individual actors.

4.2. Conditions

The conditions forming part of the model are those aspects that govern the relationships between the main actors. Thus, legal framework defines who can own IP in a given state. Cultural set up defines the propensity to patent and acceptance of patenting by universities. Finally financial framework influences the capacity to research and ability to patent. As acknowledged by the EU, "efficient knowledge transfer in European research institutions is hindered by a range of factors, including: cultural differences between the business and science communities; lack of incentives; legal barriers; and fragmented markets for knowledge and technology"(European Commission, 2007a).



Graph 3. The Innovation Model. Source: Proton (Haywood).

4.2.1. Law

"Encouraging universities to commercialize research results by granting them title to IP can be useful but it is not sufficient to get researchers to become inventors. The key is that institutions and individual researchers have incentives to disclose, protect and exploit their inventions. Incentives can be "sticks" such as legal or administrative requirements for researchers to disclose inventions. Such regulations are often lacking in many countries, even in those where institutions can claim patents." (WIPO)

A number of aspects in the research regulatory framework in Europe make university patenting uncertain. Firstly, approaches as to IP ownership differ throughout Europe. This especially negatively influences possibilities of European-wide research initiatives. It also contributes to the ambiguity on the licensing scene. Secondly, for some areas, there exist EU guidelines. However, these have only advisory character, which only further contributes to the unstructured approach. Finally, there are areas of research, such as stem cell research, which have not been included in laws and advisory documents.

4.2.2. Culture

In this part, we posit that some EU Member States have a well established innovation culture, while in others it is still very limited. Moreover, the framework and methodology for comparing innovation culture is missing.

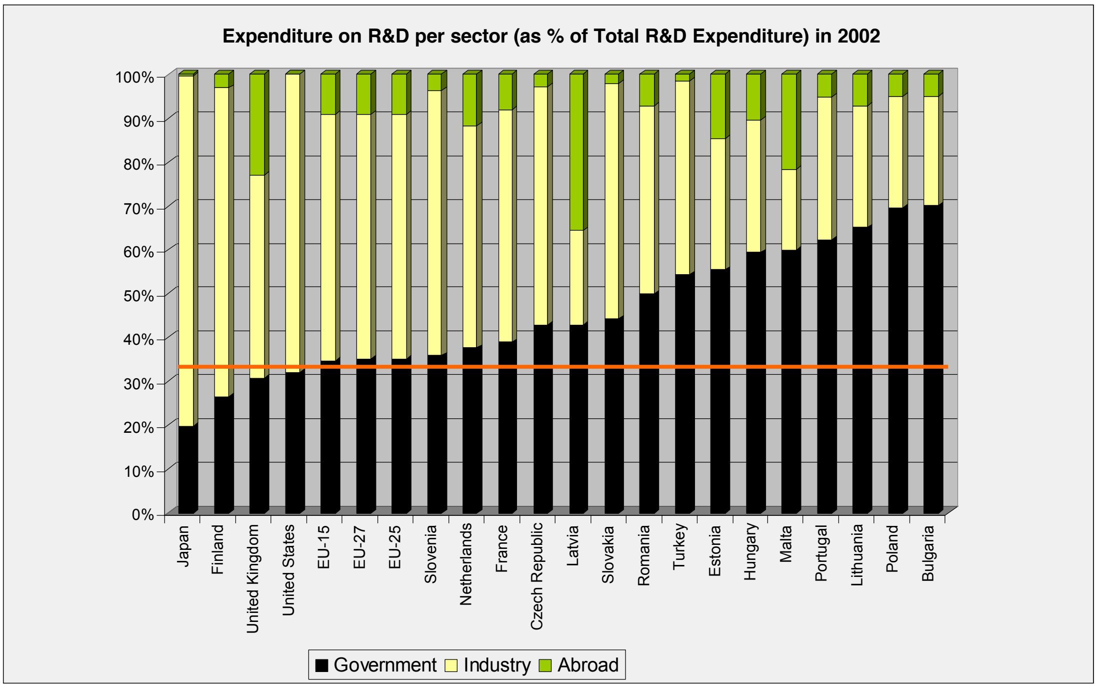
It can be argued that ability to innovate depends largely on two factors:

(1) The people, organizations and institutions in society and
(2) System of values and incentives and the ways they guide our behaviour, collectively and individually. It is, therefore, an issue dependent on

soft and horizontally spread factors such as profiles of the researchers and university professors, perceptions of the public, values of the society - all of which combine into the concept of culture. Especially the attitude of university professors and researchers, who value research for the honour of contributing to the greater human knowledge, can play an important role in the innovation process.

4.2.3. Financing R&D

The Member States of the European Union have agreed to strive towards the 3% GERD by 2010. With 1.88% GERD spent in 2002, the EU-27 is far behind Japan and the US. Few countries will fulfil their pledged rates. Moreover, providing money is not the only core issue. Grants and financial aid need to be coupled with incentives or requirements to patent and become less and less dependent on the granting institution. One of the striking features of the European R&D financing is the predominance of public funds, in particular in Central and Eastern Europe. In the long-term, the goal is to reverse the proportions of public and private contributions to the financing of research. Nevertheless, in the short-term, the high proportion of public money leads to a concern about how the society benefits from it. Increasing the university patenting will help promote innovation and raise efficiency of publicly used funds.



Graph 4. Expenditure on R&D per sector.

5. How can change happen? - the EPO pilot

5.1. The European Patent Organisation in a nutshell

Established by the Convention on the Grant of European Patents (EPC) signed in Munich 1973, the EPO is the outcome of the European countries' collective political determination to establish a uniform patent system in Europe. The EPO is the centralised patent grant system administered by the European Patent Office on behalf of all contracting states. The European Patent Organisation comprises the legislative body, the administrative council and the executive body, the European Patent Office. The European Patent Convention provides a single patent grant procedure, but not yet a single patent on the point of view of enforcement. After grant, the European patent becomes equivalent to a number ("bundle") of national patents. The Administrative council consists of delegates from the 32 member states and performs the following functions:

- adopt the budget
- approve the President's actions
- implements and amend the budget
- Regulations and Rules relating to Fees

5.2. EPO Pilot

In view of the discussed issues, and on the initiative of some member states of the European Patent Organisation, the European Patent Office proposed to the Administrative Council an initiative to improve knowledge transfer from universities to industry by making optimised use of intellectual property expertise available in the National Patent Offices.

This is also in response to the observation of the European Commission that "many European research institutions have set up knowledge transfer offices in recent years, aiming to improve collaboration and exploitation of research results and their uptake by business. Their success is largely dependent on the skills and competencies of their staff as well as the strategic role assigned to them and their managerial autonomy. The personnel working on knowledge transfer must possess a wide range of skills in order to carry out their tasks effectively. However, relatively inexperienced staff is often appointed to such positions." (European Commission, 2007a). It should be noted that the EPO does not offer the pilot in order to compete with national or supranational initiatives in knowledge transfer but rather to complement those capacities and target a very specific group of services, namely those linked to the patenting process and licensing of patents.

In the official document, CA/110/07, adopted by the Administrative Council of the European Patent Organisation on June 08, 2007, the pilot constitutes a significant part of the Cooperation Programme on "The Role of Patent Offices in Knowledge Transfer and Patent Promotion in Universities". In that document, the Administrative Council has acknowledged that "a more efficient and faster transfer of knowledge and technology from universities to industry is being recognised as an essential element to improving Europe's competitiveness and economic performance. The contribution of the patent system and the patent offices can, in some countries, facilitate significant improvements." Among other objectives, the representatives have agreed to "test the proposed concept in a pilot project with a number of selected European universities."

The initiative of the EPO aims to provide a solution within the European political dimension and EPO's particular area of expertise. To the former, the pilot is designed as a single project for several partners, some of which have experience in knowledge transfer, such as Portugal and some which need support in launching such initiative. Moreover, the goals of the EPO's pilot are in line with EU goal to increase innovativeness. As regards expertise, the EPO is in the unique position to facilitate the exchange of experiences and expertise of the National Patent Offices staff and develop new ways of dealing with the patenting process and the information generated from it.

This proposal focuses on how to create local one-stop-shops at universities for all patent related matters, and how such Comprehensive Patent Service Centres can be linked with the innovation support centres to form a regional network. At the most fundamental level, the pilot project aims to shape or restructure the profiles and services of the existing technology transfer offices at universities to move from the position of information provider (patent libraries) to a profile of a pro-active actor in the technology transfer process, who offers a palette of expert services. Moreover, in countries where few or no technology transfer offices exist, introduction of the functional link between university researchers and industry is aimed at.

Foreseen activities include training of staff, building up a common services scenario and defining minimum standards for the services, qualifications of staff and documentation at the Comprehensive Patent Service Centres. Moreover, extensive collaboration on including intellectual property topics into the general curriculum and defining standard minimum requirements for IP courses. Exchange within the pilot participants, following the European Council emphasis on "the significance of exchanging best practices in the context of multilateral surveillance and calls for increased cooperation (European Council)" is also aimed at gathering information and providing analysis of the technology transfer from universities to industry, as well as university patenting, especially in the Central and Eastern Europe.

6. Conclusion

The differences in innovation performance between EU-15 and new EU-12 countries have been cursorily pointed out. Additionally, the paper points to the limited academic consideration of university patenting in Central and Eastern Europe. It is pointed out that one of the aims of the proposed EPO initiative is to stimulate the analysis of the technology transfer and university patenting landscape in the region.

The EPO initiative as such aims to improve the weak link between university patenting and industry. This link is normally provided by technology/knowledge transfer offices. In the EPO project, Comprehensive Patent Service Centres will provide professional services and will proactively seek patent opportunities in order to foster the exchange between the inventor and the business. This, in turn, is hope to bring a new highlight for the university, more income other than public funding, and improved relations with industry sector.

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[i] Comment during a workshop on Knowledge Transfer organized for National Patent Offices in Lisbon in March 2007.

[ii] The model has been included in several documents. One of the earliest sources is the presentation given by Martin Haywood, Chair of ProTon Europe Steering Committee in April 2004. This document is referenced. Another source is a presentation given by Gilles Capart, chairman of ProTon Europe, at WIPO in 2005 and European Commission in 2006.

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Not invented here:

Knowledge transfer and technology licensing from a German public research organization

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This version: September 2007
This printout: September 10, 2007

Preliminary – do not cite or quote without authors' permission

Abstract:
Using a new dataset encompassing more than 2,000 inventions made by Max Planck Society researchers from 1980 to 2004, we study the effects of information asymmetry and imperfect knowledge transfer on the licensing and successful commercialization of technologies from public research, distinguishing among types of licensees as well as invention and inventor characteristics. Technologies licensed to foreign firms and spin-offs are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. Our findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

Keywords: Licensing, public science, uncodified knowledge, collaborative invention, spin-offs.
JEL classifications: L26, O32, O34.

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[*] Corresponding author. We are grateful to Max Planck Innovation GmbH for granting us access to their data. For helpful comments and discussions, we thank Joerg Erselius, Astrid Giegold, Bernhard Hertel, Evelyn Kaiser, Lionel Nesta, and Dieter Treichel. Wolfgang Ziegler and Sebastian Schmidt at the Patent Information Office of the University of Jena helped us assemble the patent database. Wolfhard Schumann provided valuable research assistance. The usual caveat applies.

Introduction

Throughout the developed economies, public attention and policy measures are increasingly focusing on the transfer of knowledge and technologies from public research to the private sector. Following the Bayh-Dole Act in the U.S. and similar legislative changes in other countries, technology transfer has been recognized as a primary objective of universities and other public research organizations (Mowery et al, 2001; Phan and Siegel, 2006). Notwithstanding the importance of alternative transfer channels (Bozeman, 2000; Zellner, 2003), commercialization of scientific results based on patents, licensing, and spin-off entrepreneurship has found particularly intensive scrutiny. Yet in spite of the increased emphasis on the protection of universities' intellectual property rights (IPRs) and IPR-based commercialization, we still know little about the underlying processes of knowledge transfer and innovation.

Academic inventions are typically far from being readily marketable. Existing research suggests that the commercialization of results from public science is complicated by uncertainty stemming from the early-stage character of most university inventions (Jensen and Thursby, 2001), information asymmetries between inventor and potential licensee (Shane, 2002), and the uncodified nature of important elements of the knowledge base underlying the traded technology (Lowe, 2002; Agrawal, 2006).

Reflecting this non-trivial nature of technology transfer, conclusive evidence on the effectiveness of alternative kinds of commercialization is lacking. For example, the relative commercialization performance of university spin-offs vis-à-vis external licensees is a contested issue (Shane, 2002; Lowe and Ziedonis, 2006). Other issues, including the effectiveness of international licensing, as well the relationships between alternative channels of technology transfer such as collaborative research and technology licensing, are largely unexplored. Furthermore, most empirical studies are based on U.S. data, and it cannot be taken for granted that their results generalize to other countries and institutional settings.

In the present paper, we exploit a newly assembled dataset with detailed information on the licensing activities of the Max Planck Society, Germany's largest non-university public research organization dedicated to basic science. Unlike German universities, the Max Planck Society has consistently been subject to a Bayh-Dole-like IPR regime since the 1970s. This enables us to draw on a rich set of inventions and licensing activities, which encompasses more than 2,000 inventions and about 700 license agreements closed since 1980. In addition to licensing agreements, the data also contain information on royalty payments, indicating whether or not the technology was successfully commercialized in the marketplace.

We use this dataset to analyze a set of specific issues. First, we study how licensing and commercialization are affected by licensee characteristics. Specifically, we look at licensing across national boundaries as well as spin-off versus external licensees. While less relevant in the U.S. context, licensing to foreign firms is a pertinent issue in the smaller and more open European economies, which has received little prior attention in the research on technology transfer. The effectiveness of inventor spin-offs as commercializers of technologies from public research is an unresolved issue in the existing literature to which we add new evidence. Second, we investigate the effects on technology characteristics on the effectiveness of license-based technology transfer. In this context, we study whether inventions based on collaborative research with private firms differ from "pure" university inventions in their licensing and commercialization patterns. We also analyze whether technologies (co-) invented by senior scientists differ in their licensing and commercialization odds.

Our analysis indicates that information asymmetries and problems in transferring uncodified knowledge indeed are critical determinants shaping the success of license-based technology transfer from public research. Inventions licensed to foreign firms are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. The findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

The paper is structured as follows. The next section discusses the role of information asymmetry and the transfer of uncodified knowledge in the licensing and commercialization of academic inventions. In section 3, hypotheses are derived as to how these factors influence licensing and commercialization outcomes for different types of licensees and inventions. Section 4 provides background information on the technology transfer activities of the Max Planck Society, while section 5 describes the data and methodology of the empirical analysis. Results are presented in section 6 and discussed in section 7.

2. Technology transfer through licensing of academic inventions

Inventions by scientists in public research often provide the foundations of commercially viable innovations. Academic inventions may arise as joint products of research activities (think of instrumentation or lab equipment first used for the researcher's own use), or the same results can both be published in a scientific journal and applied commercially (such "patent-paper pairs" are widespread in the life sciences; cf. Murray and Stern, 2005). In a Bayh-Dole-like institutional setting, academic inventions have to be disclosed to the scientist's employer and become its property. If they are to be used for commercial purposes, the prospective innovator has to obtain a license. Most universities and public research organizations have established technology transfer offices (TTOs) that organize the protection of their IPRs and actively market their inventions.

In addition to their strong links to current science, a common characteristic of academic inventions is their early stage nature. In most cases, they have not been developed beyond the proof-of-concept or prototype stage (Jensen and Thursby, 2001). Accordingly, licensees need to engage in substantial further development efforts to obtain a marketable product. Successful commercialization often hinges on the continued involvement of the academic inventor (Agrawal, 2006). The combination of being science-based and early-stage gives rise to at least three kinds of difficulties for the licensing and commercialization process: uncertainty, information asymmetry, and the need to transfer uncodified knowledge.

Like all inventions, university technologies cannot always be turned into successful products in the marketplace. Potential innovators obtaining licenses for technologies from public science face substantial uncertainty as to whether (i) they will be able to develop a functioning product, (ii) they will do so faster than potential competitors, and (iii) the product will be sufficiently successful with customers to justify the costs of licensing and development.

Problems of asymmetric information further complicate innovation activities based on technology transfer from public science. As opposed to technologies developed in-house, potential licensees lack in-depth knowledge of the prior research and development efforts that underlies the academic invention. This limits their ability to evaluate its commercialization prospects. On the other hand, licensees typically have better knowledge of the markets for the prospective products than the inventor or the TTO representing her. To some degree, these problems of asymmetric information can be reflected in the design of licensing agreements and the payment schemes they provide for (Jensen and Thursby, 2001; Lowe, 2006). However, there is no guarantee that a licensing agreement is closed at all. Typically, only a few potential licensees are interested in a particular technology, and licensing is based on small-numbers bargaining.

Asymmetric information arises as a problem in negotiating licensing agreements because both parties have incentives to withhold information, because this may increase their share in future innovation rents. However, even if both parties faithfully try to share their knowledge (for example, after a licensing agreement providing for sales-based royalties is closed so that inventors have an interest in successful commercialization), substantial obstacles in communicating this knowledge typically have to be overcome. They derive from the nature of the knowledge to be communicated, which tends to be complex and imperfectly codified. Agrawal (2006) argues that academic inventions often draw on multiple fields of knowledge. Potential licensees are unlikely to have substantial prior knowledge in all these fields. Accordingly, their absorptive capacities (Cohen and Levinthal, 1990) may be insufficient to fully understand information related to the invention, even if the inventor and or the TTO disclose all their knowledge. In addition, relevant elements of that knowledge may be uncodified (even if they would in principle be codifiable; in which case they can be characterized as "latent," Agrawal, 2006; cf. also Lowe, 2002). For example, knowledge that the inventor gained from failed and therefore unreported experiments may frequently be latent and inaccessible for an external licensee.

While some degree of uncertainty about innovative success is irreducible, information asymmetries and communication problems are not equally pronounced for all licensing and commercialization processes. In the next section, we derive hypotheses on how differences in the types of licensees and kinds of technologies affect the severity of these problems. These hypotheses are then tested empirically.

3. Hypotheses

Both information asymmetries and problems of knowledge transfer depend on the cognitive "distance" between licensor (the academic inventor represented by her employer's TTO) and licensee. This distance is plausibly related to observable characteristics of the licensee and the technology, which consequently are expected to affect the likelihood of closing a licensing agreement and successfully commercializing the invention.

Likelihood of successful licensing

We consider differences in the types of licensees along two dimensions: domestic versus foreign licensees, and inventor spin-offs versus external licensees. As regards the first dichotomy, information asymmetries are expected to be more pronounced in licensing negotiations across national boundaries. Information is harder to obtain for foreign licensees, particularly if they do not come from countries speaking the same language, and the design and monitoring of contracts is more difficult internationally. IPR protection for the target technology may not have been obtained in the county of the potential foreign licensee, exposing it to an enhanced risk of imitation by competitors. The likelihood of agreements with foreign licensees may be further reduced by biases in the TTO's marketing efforts. Possibly, such biases are even due to strategic considerations or political pressure motivated by the goal of maximizing the national payoffs from public science.

These arguments suggest that licensing negotiations with foreign firms are less likely to be successful than negotiations with domestic firms. We cannot test this hypothesis directly since we only have information on the pool of inventions and on licensing agreements that were actually closed. However, we can investigate the relative frequency of licensing agreements with foreign firms, and also their timing as compared to agreements with domestic firms. The following relationship is predicted:

Hypothesis 1: At any given time, the hazard of closing a licensing agreement with a foreign firm is lower than that of closing an agreement with a domestic firm.

The likelihood of successful licensing may also depend on the organizational nature of potential licensees. Following the earlier work on U.S. universities, we study differences between inventor spin-offs and external licensees (established firms and startups without inventor involvement). In the case of spin-offs, information asymmetries should largely be mitigated since inventors licensing back their own inventions know these technologies rather well. This should increase the chances and the speed of arriving at a license agreement:

Hypothesis 2: At any given time, the hazard of closing a licensing agreement with an inventor spin-off is higher than that of closing an agreement with an external licensee.

However, licensing to inventor spin-offs is sometimes characterized as some kind of "last resort" utilized only when attempts to find an external licensee have failed (e.g., Shane, 2002). If this temporal order is widespread, it might compensate the positive relationship predicted by Hypothesis 2.

In addition to the effects of licensee characteristics, we also expect that licensing is affected by the time that a potential licensee learns about a nascent university technology. Particularly relevant in this context appear collaborative inventions based on industry-sponsored research or joint research projects between public and industry partners. Industry involvement at an early stage of technology development is likely to mitigate information asymmetries and problems of knowledge transfer. In a research project sponsored by a commercial firm, the firm will bring some related prior knowledge (motivating its interest in the project), and it will try to monitor the ongoing research efforts. Joint research projects with industry partners likewise presuppose some relevant prior knowledge of the industry partner, and some communication of knowledge between both partners. Both forms of collaborative research therefore come with an increased capacity of industry partners to evaluate the potential of inventions made in the project. If their assessment of the technology is low, they may withdraw from the cooperation even before an invention is arrived at, which would increase the average quality of inventions from sponsored and joint research. In addition, knowing the inventor from the collaborative research project helps to build mutual trust, enhancing the willingness to close a licensing deal in the absence of fully symmetric information. Reputation effects and the prospect of future cooperation further reduce the attractiveness of opportunistic behavior. These considerations lead us to the following hypothesis:

Hypothesis 3: Academic inventions from sponsored research or collaborations with industry partners are more likely to be licensed than other inventions.

Lowe (2002) has suggested an effect that might countervail the prediction of Hypothesis 3. He argues that in the process of collaborative research, industry partners may acquire sufficient knowledge of the invention to render subsequent licensing unnecessary. This argument presupposes that the firm is able to design its innovation around the public partner's intellectual property rights, or that the public partner is unable to enforce them.

Finally, we can also conjecture about an effect of inventor seniority on the likelihood of closing a licensing agreement. The superior reputation and more extensive personal network of senior researchers should enhance the credibility of technologies (co-) invented by them, thus increasing the willingness of potential licensees to enter into a contractual agreement. If negotiations are mediated by a technology transfer office (as is the case in our empirical sample), it is likely that senior scientists have more influence on their employer institution than more junior ones. This may further increase the likelihood of a successful licensing agreement. We accordingly conjecture:

Hypothesis 4: Technologies (co-)invented by senior scientists are more likely to be licensed than those by more junior researchers.

Commercialization of licensed technologies

Not only the likelihood of closing an agreement, but also the likelihood of successfully bringing the technology to the market can be expected to differ according to licensee, technology, and inventor characteristics. Post-agreement inventor involvement in the development efforts has been demonstrated to increase the likelihood of successful commercialization (Agrawal, 2006). If a royalty-based contract has been closed, bringing the product to the market is the interest of both licensor and licensee (Jensen and Thursby, 2001). Accordingly, academic inventors harm themselves if they do not cooperate in post-licensing development efforts. They may nonetheless exert less effort than would be called for because of competing demands on their time, particularly when primarily motivated by the reward mechanisms of public science (Stephan, 1996). Equally important for successful commercialization appears their ability to communicate their knowledge to the licensee.

In the case of foreign licensees, geographic distance and language barriers complicate the transfer of uncodified knowledge. Post-agreement inventor involvement is more costly and possibly less effective if national boundaries have to be crossed. This consideration leads us to predict the following:

Hypothesis 5: Inventions licensed to foreign firms are less likely to be commercialized successfully than inventions licensed to domestic firms.

Spin-offs represent an extreme form of inventor involvement. Transfer of uncodified knowledge to the spin-off firm is mostly realized by personal migration of the inventor and/or associates from her laboratory to the new firm. Even though senior scientists frequently do not enter the active management of spin-offs (co-) founded by them (cf. Buenstorf, 2006), inventor-founders nonetheless have strong incentives for engaging in the spin-off's development activities, and they typically assume at least consulting positions in the new venture. Staff members of the spin-off may moreover be able to informally contact their prior co-workers in the inventor laboratory when in need of additional knowledge.

Commercialization activities by spin-offs are expected to benefit from the facilitated transfer of uncodified knowledge. In addition, given a smaller product portfolio, spin-off survival is typically more dependent on specific technologies than survival of established firms. Spin-offs consequently face stronger incentives for successful commercialization (Lowe and Ziedonis, 2006), and are unlikely to license a technology for purely strategic reasons (i.e., to prevent others from using it). Based on these considerations, we predict the following:

Hypothesis 6: Inventions licensed to inventor spin-offs are more likely to be commercialized successfully than inventions licensed to external licensees.

Effective knowledge transfer clearly is not sufficient to ensure successful commercialization. Existing evidence on the commercialization performance of spin-offs is inconclusive. Counter to Hypothesis 6, Shane (2002) stipulates that spin-offs are inferior in commercialization because they lack the required complementary assets (Teece, 1986). He suggests that licensing to spin-offs is primarily observed when patents are ineffective. In contrast, for their sample of licensed inventions from the University of California system, Lowe and Ziedonis (2006) find neither lower commercialization odds nor lower licensing income for spin-off licensees.

In the case of collaborative research projects, knowledge transfer between inventor and licensee is facilitated by absorptive capacities and shared understandings developed in the prior research process. Pre-existing familiarity with the technology also provides the licensee with a speed advantage, enhancing the odds of successful commercialization (Markman et al., 2005). In addition, licensees that were involved in collaborative research leading to the licensed technology have superior information about this technology. Their ability to evaluate its merits should thus be enhanced, which increases the likelihood that licensed inventions can also be commercialized (the selection effect already suggested above). We accordingly expect the following positive effect:

Hypothesis 7: Inventions from sponsored research or collaborations with industry partners are more likely to result in commercially viable products and processes than others.

Agrawal (2006) studies the same issue in the U.S. context, using a sample of 124 licensed inventions from MIT's mechanical engineering and electrical engineering / computer science departments. He finds positive effects for sponsored research both on the likelihood of successful commercialization and on the level of revenues generated thereby. Neither effect is statistically significant, however.

Finally, the successful commercialization of a university invention may also depend on the seniority of the inventor(s). The more senior an inventor is, the higher are her opportunity costs of post-agreement involvement. *Ceteris paribus*, senior scientists are therefore expected to spend less time on their inventions, which will lower their chances to be successfully commercialized. This will be particularly true for inventions licensed to external licensees. We expect senior scientists to be more willing to spend time with their spin-off firms, the success of which is more relevant both to their income and their reputation. This leads us to the last hypotheses:

Hypothesis 8a: Technologies (co-) invented by senior scientists are less likely to be commercialized than inventions by more junior scientists.
Hypothesis 8b: If senior scientists engage in spin-off activities, the commercialization odds of their inventions increase over those of technologies they license to external licensees.

4. Technology transfer at the Max Planck Society

Public research in Germany is characterized by a distinctive division of labor between universities and non-university public research organizations. The Max Planck Society, whose roots go back to the early 20th century, is the country's largest non-university public research organization dedicated to basic research. It receives more than 80 per cent of its budget from public, institutional funding (Max Planck Society, 2005). 78 individual Max Planck Institutes are dispersed all over the country (in addition, three institutes are located abroad). They currently employ some 4,000 researchers.

The Max Planck Society's mission is to complement the university system by taking up large-scale, interdisciplinary, or particularly innovative activities that are out of reach for individual universities. Its research activities encompass the whole spectrum of the sciences and the humanities. Institutes are organized into three sections: the biomedical section, the chemistry, physics and technology section, as well as the humanities and social sciences section.

The Max Planck Society's internal organization is unique. Its strategy – known as the Harnack Principle – is to put its highest-level researchers, the Max Planck directors, in a particularly autonomous and powerful position. Directors are recruited from the most successful researchers of both German and foreign universities. Their mission is research-oriented, with substantial long-term, institutional funding. Currently, there are roughly 260 active directors in the Max Planck Society.

Academic inventions and technology transfer activities from the Max Planck Society have historically been treated differently from those of German university researchers. In general, employees of German firms are subject to the *Arbeitnehmererfindungsgesetz*, which mandates that employees must disclose inventions to their employer, and assigns the property rights in these inventions to the employer. University researchers used to be exempt from this law. They retained the intellectual property rights (IPRs) in their inventions. This so-called *Hochschullehrerprivileg* or "professors' privilege" was abolished in 2002. Since then, German universities have been the legal owners of the inventions made by their researchers. Consequently they are now responsible for patent applications and the licensing of inventions. In particular they have to bear all costs of the patenting process. The inventing researcher is entitled to 30 per cent of the gross licensing revenues from her invention.

The new IPR regime for inventions by German university researchers essentially replicates the rules that Max Planck researchers have always been subject to. They are required to disclose all their inventions to the Max Planck Society, which can then claim ownership of the technology. In this case, the Society organizes the patent protection for the invention (if possible and deemed adequate), as well as the subsequent negotiation and administration of licenses. The inventing researcher receives 30 per cent of all revenues from licenses and patent sales, and the Max Planck Institute employing the researcher gets an additional third of all income.

To organize the patent application and the marketing of Max Planck technologies, the Society in 1970 established a legally independent technology transfer subsidiary that recently was renamed Max Planck Innovation GmbH (before, its name was Garching Innovation after one of the Society's research campuses). After some early and largely unsuccessful attempts of constructing and selling prototypes based on Max Planck inventions, Max Planck Innovation has for the past three decades focused on patenting and licensing activities.

Disclosure of inventions is actively solicited at the individual institutes. Patents are applied for if the invention is patentable and considered sufficiently promising, even if no licensee for the technology has been identified.[1] Technologies are marketed to both domestic and foreign firms. Systematic support and counseling of spin-off activities was taken up in the 1990s, and spin-off numbers have strongly increased since then. Total returns from the licensing activities amount to some € 180 million, with the bulk of income resulting from a small number of highly successful blockbuster technologies. Annual license revenues contribute 1 to 2 per cent to the Max Planck Society's overall budget (Max Planck Society, 2005).

5. Dataset and econometric approach

Sources

This study is primarily based on two sets of data made available by Max Planck Innovation. The first dataset contains all inventions disclosed by Max Planck researchers from the early 1970s to 2004.[2] In total, it encompasses 2,726 inventions. 1,754 resulted in at least one patent application

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[1] In this regard, Max Planck Innovation's patenting policy thus appears to be closer to that of the MIT than that of the UC system (cf. Shane, 2002; Lowe and Ziedonis, 2006)

[2] Researchers employed on a scholarship basis, mostly PhD students and international postdocs, are not subject to the German law on employee inventions. To the extent that these individuals made inventions without other Max Planck researchers being involved, they do not show up in the data.

(Table 1). The database includes the title of the invention, names and institute affiliations of the inventors, day of disclosure and (if eligible) patent application, as well as various information regarding further use of the invention.

We linked these data with a second dataset assembled from Max Planck Innovation's licensing agreements. 793 inventions (583 patented inventions) have been licensed, and because some non-exclusive contracts have multiple licensees, there are in total 1,014 licensing agreements. For each contract, information is available on the licensee name and address, dates of closure and (possibly) termination of the contract, arrangements on licensing fees and royalties, as well as actual dates and amounts of payments. The Max Planck inventions are similar to other datasets on commercialized inventions in that payments (in particular, royalties) are extremely skewed. One single Max Planck invention accounts for more than 75 % of the overall returns.

Patent data is used to control for heterogeneity in the quality of (patented) inventions. Our primary proxy for patent quality is the number of members in the patent family. It indicates the geographical breadth of the IPR protection sought by the patent application and is a widely accepted measure of patent quality (Harhoff et al., 2003). We also experimented with the number of IPC classes and granted patents in the family as quality indicators, but they were less predictive.

To obtain this information, we constructed a unique patent database using *Depatisnet*, the publicly available patent search site of the German Patent Office. First, some 8,000 patent applications by the Max Planck Society were identified. These were grouped according to their priority patents, which were then matched to the patents listed in the invention database.

About one third of the patented inventions could not be found in this way because they were not assigned to the Max Planck Society. For these inventions, the patent listed in the inventions dataset was searched in *Depatisnet*, and the corresponding patent family was retrieved. This procedure yielded about 2,800 additional patents.[3]

We restrict our empirical analysis to the 2,261 inventions disclosed in or after 1980. Earlier inventions are excluded for three reasons. First, the earliest entries in the inventions dataset are not consistently inventions by Max Planck researchers, since at the time Garching

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[3] In about 70 cases, no patent information was found even though the inventions database identified them as patented. We suspect that most of these cases reflect cancelled applications. On the other hand, for another 70 inventions patents were found that closely matched the disclosed inventions in terms of title and inventor names, but the respective patents do not show up in the inventions database. We do not use this information in the subsequent analysis.

Innovation was offering its services to a variety of other public research organizations and even commercial firms, whose inventions show up in our data. Second, the quality of the earliest data was below that related to later inventions. Third, systematic support of spin-off activities out of the Max Planck Society only began around 1990, and spin-off activities were of little import in the earliest years of the data.

Variables

Two dependent variables are used in the subsequent models. First, we study whether or not an invention was licensed. Licensing can readily be inferred from the existence of a licensing agreement. 699 (31 per cent) of all inventions disclosed after 1980 have been included in a licensing agreement. This number is comparable to U.S. institutions studied before. For example, Lowe and Ziedonis (2006) study 734 licensing agreements closed by the UC system between 1981 and 1999. Second, we are interested in the factors conditioning successful commercialization. While this information is not directly contained in the data, we derive it from the existence of positive royalty payments. Of course, this restricts the sample for studying commercialization to those inventions where licensing agreements provided for royalty payments (not only fixed fees). In the post-1980 sample, there are 644 cases of this kind, of which 307 (48 per cent) have resulted in positive royalties.

As central explanatory variables, the analysis uses four indicator variables identifying, respectively, foreign licensees, spin-off licensees, collaborative inventions, and senior inventors. To study effects of international licensing, licensees were classified into domestic versus foreign according to the postal address given in the data. Accordingly, German branches and subsidiaries of foreign companies are classified as German licensees. This is in line with our primary interest in potential difficulties arising from information asymmetries and the transfer of uncodified knowledge, which we would expect to depend more on the licensee’s physical location than to whether or not it is foreign-owned. International license agreements are commonplace in the Max Planck Society. Of the 896 license agreements for inventions disclosed since 1980, 273 are with foreign licensees. Spin-offs among the licensees were identified on the basis of Max Planck Innovation’s spin-off database. There are 211 cases of licenses to spin-offs in the sample.

Collaborative inventions are identified on the basis of patent applications. We define as collaborative all inventions that were not exclusively assigned to the Max Planck Society (i.e., they are either assigned to the Max Planck Society and a private-sector firms, or they are exclusively assigned to a private-sector firm). Their total number is 349. Finally, senior scientist involvement is proxied by technologies (co-) invented by one or (in rare cases) several Max Planck directors, which is justified by the distinctive position directors have in the Max Planck hierarchy. We identified the directors using published sources (Henning and Ullmann, 1998; Max Planck Society, 2000) and information provided by the Max Planck Society's human resource department.

A set of control variables is used. Existence and quality of patents related to an invention is proxied by patent (application) family size. We also control for discipline-specific factors with a dummy variable denoting inventions from the biomedical section of the Max Planck Society. This dummy is zero for inventions out of the chemistry, physics and technology section.[4] Time effects are captured by distinguishing two cohorts of inventions (those disclosed up to and after 1990, respectively).

Methods

To study the incidence of licensing events, two sets of competing risks models are used, which are both based on semi-parametric Cox regressions (Lunn and McNeil, 1995). We alternatively interpret licensing to foreign versus German firms (models 1-3), or licensing to spin-offs versus external licenses (models 4-6), as competing risks. Cox regressions are attractive because as hazard rate models, their coefficient estimates are based on both the occurrence of the event and the time elapsed before it occurs, thus making full use of the available information. Right censoring imposed by the end of the observation period is also taken into account in the Cox regressions. Cox models are preferred over fully parametric hazard models because no assumptions need be made about the time-dependence of the hazard, which would be hard to justify in the present context. The proportionality assumption underlying the Cox regression is in line with the actual shapes of the survivor functions (cf. the Kaplan-Meier graphs in Figures 1 and 2). Since we have daily data, interval censoring and ties are no relevant issues, and continuous-time Cox regressions can be applied. An invention enters the risk pool at the day of

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[4] There are a handful of inventions that cannot be assigned to one of these sections, mostly because they were disclosed by staff of the Max Planck Society's general administration. The dummy variable is zero for these inventions. No inventions were disclosed out of the humanities section. We also experimented with individual dummy variables denoting the top seven institutes in the number of commercialized inventions (five of which are from the biomedical section). This had little effect on the results.

disclosure or initial patent application, whichever comes first.[5] It leaves the risk pool at the day that the initial licensing agreement is concluded.

The likelihood of successful commercialization is studied in two steps. First, we estimate a set of logit models where commercialization is the dependent variable, using the set of licensing agreements as our sample.[6] As noted above, commercialization is defined as the existence of positive royalty payments. Obviously, this restricts the sample to those licensing agreements that contain provisions for royalty payments. A shortcoming of this approach is that it does not account for selection effects: Technologies licensed to different kinds of licensees may differ in their characteristics, and these differences may affect their subsequent commercialization odds. To illustrate, it might be possible that a researchers retains her best inventions for spin-off activities, while inferior technologies are licensed to external licensees.

As can be seen from Table 2 for the case of spin-off versus external licensing, there are indeed substantial differences in the values of the explanatory variables for the different subsets of technologies, suggesting that selection into the different kinds of licensing contracts (domestic versus foreign, spin-off versus external) may not have been random. To test whether differences in the commercialization likelihood of different types of licensees are due to differences in observables, we interpret specific kinds of licensing agreements as treatments, and estimate how being treated affected the commercialization likelihood using propensity score matching (Rosenbloom and Rubin, 1983; Heckman et al., 1998; cf. also Sianesi, 2001; Wooldridge, 2002, ch. 18). Specifically, two propensity score matching estimators are employed: in the first one, the treatment consists in being licensed to a foreign licensee. In the second one, licensing to a spin-off is the treatment.

The intuition underlying propensity score matching is as follows. In non-experimental data, for each observation only one outcome (here: commercialization success) is observed. If Y_{i0} denotes observation *i*'s outcome without treatment, Y_{i1} denotes observation *i*'s outcome with treatment, and $T \in \{0, 1\}$ denotes treatment, we would like to know the treatment effect $Y_{i1} - Y_{i0}$,

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[5] Particularly for patented inventions that were not assigned to the Max Planck Society, we found a number of instances where the disclosure date is later than the date of patent application. This is explicable by the fact that the industrial partner may have processed the patent application independent of the disclosure process initiated by the Max Planck inventor. The time gap between the dates was mostly small. In a small number of cases, licensing agreements were (technically) concluded before either disclosure or application dates, mostly because options for licenses on nascent technologies were negotiated, or new inventions were included into existing licensing agreements. These cases are excluded from the analysis of licensing hazards.

[6] We also experimented with the corresponding probit models, which yielded very similar results.

but can only observe one of the two outcomes. If selection into treatment is nonrandom, the effect of treatment on the outcome cannot be separated from the selection effect in the data.

Propensity score matching uses the available information on individual observations to generate a counterfactual control group from the untreated observations, such that differences in observable characteristics are minimized between the treated observations and the members of the control group. The basic approach is to calculate the probability of receiving treatment for each observation based on its observable characteristics, using probit or logit models. This conditional probability is the propensity score, which is then used for matching the treated observations to similar non-treated ones. Under the assumption that selection into treatment only depends on observables, the average effect of treatment can then be estimated at the population level. Specifically, both the *average treatment effect* (ATE), $E(Y_{i1} - Y_{i0})$, and the *average treatment effect on the treated* (ATT), $E(Y_{i1} - Y_{i0} \mid T = 1)$, can be estimated.

Various propensity score-based matching methods have been proposed. When large samples of non-treated observations are available, each treated observation can be matched to an "identical twin," i.e. a non-treated observation that is very similar in its propensity score, and the outcomes of both observations are then compared. Alternatively, each treated observation can be matched to a weighted average of untreated observations, where the weights are determined by how similar the propensity scores of the untreated observations are to that of the treated one. We adopt the latter approach below. We report results obtained by estimating propensity scores with logit models, using a Gaussian kernel for matching, where the weights of the untreated observations follow a normal distribution around the propensity score of the respective treated one. The estimations were performed using the *psmatch2* routine for Stata 9.0 (Leuven and Sianesi, 2003).

6. Results

Hazard of licensing

Hypothesis 1 posits that licensing agreements are less likely to be closed with foreign licensees than with domestic firms. This is supported by Figure 1 and by the results of Models 1-3 (Table 3), which find a large and significantly negative coefficient estimate for the variable indicating foreign licensees. The models also find that in the biomedical section of the Max Planck Society, inventions are significantly less likely to be licensed to foreign firms than in the chemical-physics-technology section. In contrast, the effects of neither the size of the patent family nor of the time period of the invention are systematically different for foreign versus domestic inventions.

Models 4-6 (Table 4) find that, overall, the likelihood of licensing to spin-offs is significantly lower than that of licensing to external licensees, which contradicts Hypothesis 2. A possible interpretation of this finding is that spin-off licensing is indeed turned to only when prior attempts to find external licensees have been unsuccessful (Shane, 2002). Again, there are systematic differences in how the control variables in the estimation affect the alternative types of licensees. Inventions from the biomedical sections are not only more likely to be licensed in general, but even more so in the case of spin-off licensees (Model 4). There has moreover been some substitution of spin-off licensing for agreements with external licensees, as the former became more likely after 1990, while the latter became less common (Models 4-6). Finally, the coefficient estimates for patent family size do not suggest that licensing to spin-offs is less affected by patent protection than licensing to external firms, which would be expected if spin-offs were primarily turned to in situations of ineffective property rights protection (Shane, 2002).

As regards collaborative inventions, the evidence from the competing risks models is mixed. Models 2 and 3 indicate that collaborative inventions are less likely to be licensed, but this effect is restricted to domestic licensing. Likewise, Models 5 and 6 (Table 4) find a significantly negative effect of industry cooperation on spin-off licensing, but not on licensing by external firms. Thus, we find that collaborative inventions are disadvantaged in specific licensing situations (domestic, spin-offs), but not in others (foreign, external licensees). Apart from a marginally significant positive coefficient estimate in Model 6, however, no evidence is obtained in support of Hypothesis 3, which predicted a higher licensing likelihood for collaborative inventions.[7] These findings suggest that reduced information asymmetry through prior joint research does not systematically increase the chances of the respective technology to be licensed. They may be explicable by Lowe's (2002) argument suggesting that knowledge transfers during the collaborative project may render licensing unnecessary. Possibly, selection enabled by better information is also counteracting the effect of reduced difficulty in negotiating, and only the most promising technologies from collaborative research are actually licensed.

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[7] These findings are corroborated by estimating separate coefficient estimates for the competing risks in stratified models (Lunn and McNeil, 1995, Method B).

In both Model 3 and Model 6 a large and significantly positive effect of director-inventors on the licensing hazard is obtained, indicating that senior scientists are more successful in licensing their inventions, as predicted by Hypothesis 4. Model 6 moreover suggests that the director effect is even stronger in the case of spin-off licensing. In contrast, while the coefficient estimate for director-inventors is positive in the case of foreign licensees, it is not significantly different from zero.

Likelihood of commercialization

As predicted by Hypothesis 5, logit models estimating the likelihood of successful commercialization suggest that foreign licensees are significantly less likely to commercialize a licensed technology (Models 7-11 in Table 5).[8] They thus lend support to the conjecture that international knowledge transfer causes problems hindering the successful development of university technologies. This finding is corroborated by the results of the propensity score matching, which are reported as Model 12 in Table 6.[9] In the original dataset, the commercialization likelihood of technologies licensed to foreign firm is -.133 lower than that of technologies licensed within Germany. Comparing the technologies licensed to foreigners with similar technologies licensed at home reduces this difference to -.105, which is significant at the .05 level. If the whole population of licensed technologies is considered, the average effect of treatment is -.113. We thus conclude that the observable disadvantage of technologies licensed abroad is not primarily due to selection.

Logit models also find that spin-offs are less likely to commercialize inventions than external licensees (Models 9-11). Apparently, enhanced inventor involvement in spin-off licensees is not sufficient to ensure the success of these firms. However, propensity score matching indicates that the poorer commercialization record of spin-offs reflects substantial effects of selection. When selection into spin-off licensing is controlled for (Model 13 in Table 6), the average treatment effect on the treated (ATT) is reduced from -.174 to -.049, which is not significantly different from zero. In contrast, the average treatment effect on all population members is -.112 and significant at the .05 level.

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[8] All logit models were alternatively estimated as probit models, which yielded qualitatively identical results.

[9] To obtain propensity scores, a logit model for the likelihood of being licensed to a foreign licensee was estimated first, using as explanatory variables the patent family size, dummies denoting collaborative inventions, director-inventors, post-1990 invention and inventions from the biomedical section, as well as seven additional dummy variables denoting the institutes that had the largest number of commercialized inventions. Kernel-based matching of treated and untreated observations was then adopted (cf. also section 5).

In line with Hypothesis 7, we find that collaborative inventions have significantly higher chances of being commercialized (Models 8-11). This indicates that knowledge transfer is indeed facilitated by prior joint research activities. It is moreover consistent with the possibility that licensed collaborative inventions are a pre-selected sample from all collaborative inventions.

If Max Planck directors are among the inventors of a technology, its subsequent commercialization odds are reduced, which is consistent with the opportunity cost argument underlying Hypothesis 8a (Model 10). Adding the director-inventor variable to the model reduces the coefficient estimate of the spin-off dummy by less than 20 per cent, suggesting that spin-off licensees may be inferior in commercialization even when controlling for the involvement of senior scientists.

To probe this further, in Model 11 we replace the overlapping dummy variables denoting spin-off licensees and director-inventors by three separate, non-overlapping dummies denoting, respectively, director-inventions licensed to spin-offs, other inventions licensed to spin-offs, and director-inventions licensed to external licensees. The results indicate that these three groups of inventions are all similarly disadvantaged in their commercialization likelihood (relative to non-director inventions licensed to external licensees, and after controlling for the other explanatory variables). Thus, if inventions by directors are licensed to spin-offs, the negative effects found for both variables do not seem to be cumulative. While these findings are not consistent with Hypothesis 8b, a weaker version of the Hypothesis would be supported: in the case of director inventions, licensing to a spin-off does not reduce the commercialization likelihood further. Possibly, this result is due to two counteracting influences: higher incentives for inventor collaboration, but less business experience by the spin-off. Relatively speaking, spin-offs are then more suited to commercialize inventions by senior scientists than those made by more junior ones.

Even though they are not in the focus of the study, the control variables finally deserve some attention. Patent family size, our proxy of invention quality, has no effect on commercialization. Inventions from the biomedical section, which were licensed more often, seem to have lower odds of commercialization (Models 7 and 8), but this effect loses its significance after controlling for spin-off licensees and director-inventors, both of which are more widespread in the life sciences. Finally, all commercialization models find a sizeable and highly significant negative effect of later inventions. This is to be expected since later inventions had less time to be commercialized, particularly since the logit model cannot control for right censoring. It cannot be ruled out, however, that at least some of the difference in commercialization odds between older and younger inventions may reflect a decreasing trend in the commercial values of Max Plank inventions.

7. Discussion

Our findings on foreign licensees and collaborative inventions are largely in line with the theoretical considerations of sections 2 and 3. They suggest that license-based technology transfer from public research is complicated by information asymmetry and problems of ensuring post-agreement inventor involvement, which is essential due to the partially uncodified character of knowledge in early-stage technologies.

Licensing agreements with foreign licensees were found to be less frequent and less successful in commercialization than agreements with domestic firms. In contrast, our findings paint a largely positive picture regarding the licensing of cooperative inventions. While they are less likely to be licensed to spin-offs and to (undifferentiated) domestic licensees, no negative effects could be discerned regarding the licensing of collaborative inventions to domestic incumbents or foreign firms. In addition, they consistently had higher chances of commercialization than "pure" university inventions. In evaluating these findings, it has to be considered that industry cooperation may itself lead to the transfer of knowledge to the private sector (irrespective of subsequent licensing), thus the present results can be considered as lower bound estimates of effective knowledge transfer through collaborative research. A caveat also has to be made in this context: our identification strategy based on patent applications underestimates the extent of industry cooperation, as we cannot identify collaborative inventions unless they result in patent applications.

In contrast, the results on spin-off licensees are less compatible with the conjectured role of information asymmetry and uncodified knowledge, as spin-offs had lower licensing hazards than external licensees, and were not more likely to commercialize licensed technologies. While this pattern might be consistent with interpreting spin-offs as a kind of last resort licensees, we found spin-off licensing to be unaffected by the extent of patent protection. This is not in line with Shane's (2002) suggestion that spin-offs are turned to when knowledge transfer problems frustrate the negotiation of contracts with established firms.

Propensity score matching suggests that selection effects underlie the inferior commercialization performance of spin-offs. The trend toward spin-off licensing instead of external licensing discernible in the data may nonetheless be problematic. This is because our results indicate a conflicting relationship between industry cooperation on the one hand and domestic licensing, particularly to spin-offs, on the other. Possibly, cooperative research, a successful form of technology transfer, is adversely affected by the increasing spin-off activities. In our view, such interdependencies between the different forms of technology transfer warrant closer scrutiny in the future.

Finally, when singling out the most senior scientists of the Max Planck Society, we found their inventions more likely to be licensed, yet less likely to be commercialized. Again, this pattern is easy to reconcile with the theoretical considerations. Network and reputation effects enhance the chances of finding a licensee, while senior scientists face the highest opportunity costs of engaging in post-agreement involvement.[10]

The findings on director-inventors may also provide a new perspective on the spin-off process. Director-inventions are particularly likely to be licensed to spin-offs, and their commercialization likelihood is not further reduced by spin-off licensing. This suggests a specific role for spin-offs in the commercialization of the knowledge of "star scientists," (Zucker and Darby, 1996) who have little incentive to engage in more traditional forms of licensing.

A general limitation of this study was that commercialization success was not measured in monetary terms. A preliminary analysis of the payments flows based on licensing of Max Planck Society inventions indicates that alternative criteria of commercialization success, in our case the hazard of commercialization versus the flow of licensing revenues, do not necessarily move together. We will explore this more thoroughly in future work. There are of course further limitations. Among them is that the present analysis only covered a single organization, which moreover follows a dedicated mission to focus on basic research. This clearly restricts the possibility to generalize the results. Also on the agenda is a closer look at developments over time. Given that the Max Planck Society was a pioneer of IPR-based technology transfer even by international standards, we plan to study in more detail the evolution of these activities.

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[10] In the long run, this pattern should of course not be stable.

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Table 1: Inventions disclosed by Max Planck researchers, 1970-2005

	Full sample	*1980-2005 Inventions*
Inventions (patented)	2,726 *1,754*	2,261 *1,454*
Licensed inventions (patented)	793 *583*	699 *507*
Collaborative (patented only)	389	349
First licensed to foreign firm	206	178

Table 2: Descriptive statistics

	All inventions			*Licensing contracts providing for royalties*		
				All	*External licensees*	*Spin-off licensees*
	(mean)	*(min)*	*(max)*	*(mean)*	*(mean)*	*(mean)*
Collaborative invention	.151	0	1	.127	.139	.103
Director-inventor	.133	0	1	.408	.323	.595
Biomedical section	.600	0	1	.763	.732	.831
Patent family size	2.550	0	45	4.731	4.432	5.395
Post 1990 invention	.748	0	1	.669	.584	.856
Commercialization				.463	.517	.344
Spin-off licensee				.311	--	--
Foreign licensee				.301	.363	.164

Table 3: Licensing hazards 1: domestic versus foreign (competing risks Cox models)

	Model 1	*Model 2*	*Model 3*
Foreign licensee	-1.783*** (.274)	-1.724*** (.277)	-1.705*** (.269)
Collaborative invention		-.708** (.304)	-.608** (.279)
Collaborative*foreign		.793** (.333)	.732** (.310)
Director-inventor			1.398*** (.208)
Director*foreign			.298 (243)
Biomedical section	1.168*** (.211)	1.100*** (.210)	.924*** (.215)
Biomedical*foreign	-.619*** (.234)	-.542** (.234)	-.606** (.246)
Patent family size	.066*** (.007)	.079*** (.009)	.055*** (.010)
Patent family*foreign	-.012 (.155)	-.026** (.011)	-.033** (.013)
Post 1990 invention	-.019 (.183)	.048 (.187)	-.155 (.190)
Post 1990*foreign	-.138 (.206)	-.212 (.210)	-.216 (.216)
Observations (events)	2245 (630)	2245 (630)	2245 (630)
Log-likelihood (p > chi^2)	-4926.874 (.0000)	-4923.125 (.0000)	-4789.436 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 4: Licensing hazards 2: spin-off versus external (competing risks Cox models)

	Model 4	*Model 5*	*Model 6*
Spin-off licensee	-2.499*** (.315)	-2.438*** (.319)	-2.353*** (.302)
Collaborative invention		.189 (.134)	.225* (.131)
Collaborative*spin-off		-.999*** (.352)	-.856*** (.288)
Director-inventor			1.407*** (.119)
Director*spin-off			.684*** (.214)
Biomedical section	.574*** (.107)	.598*** (.108)	.431*** (.110)
Biomedical*spin-off	.456** (.220)	.361 (.223)	.136 (.228)
Patent family size	.057*** (.005)	.053*** (.005)	.031*** (.007)
Patent family*spin-off	.007 (.008)	.028*** (.011)	.009 (.011)
Post 1990 invention	-.446*** (.102)	-.462*** (.102)	-.629*** (.102)
Post 1990*spin-off	1.573*** (.261)	1.664*** (.268)	1.499*** (.266)
Observations (events)	2245 (612)	2245 (612)	2245 (612)
Log-likelihood ($p > chi^2$)	-4790.771 (.0000)	-4784.471 (.0000)	-4649.138 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 5: Likelihood of commercialization (logit models)

	Model 7	*Model 8*	*Model 9*	*Model 10*	*Model 11*
Foreign licensee	-.547*** (.192)	-.532*** (.193)	-.658*** (.199)	-.596*** (.202)	-.588*** (.202)
Collaborative invention		.586** (.260)	.518** (.264)	.518* (.266)	.541** (.267)
Spin-off licensee			-.538*** (.198)	-.438** (.204)	
Director-inventor				-.414** (.186)	
Director*spin-off licensee					-.711*** (.252)
Director * external licensee					-.649*** (.227)
Non-director * spin-off licensee					-.780*** (.277)
Biomedical section	-.425** (.205)	-.389* (.206)	-.340 (.208)	-.284 (.211)	-.268 (.211)
Patent family size	-.007 (.014)	-.014 (.014)	-.011 (.014)	-.005 (.015)	-.006 (.015)
Post 1990 invention	-1.143*** (.183)	-1.110*** (.210)	-1.080*** (.191)	-1.051*** (.192)	-1.087*** (.195)
Constant	1.136*** (.210)	1.098*** (.210)	1.173*** (.213)	1.204*** (.214)	1.285*** (.220)
Observations	628	628	628	628	628
Log-likelihood (p > chi^2)	-402.364 (.0000)	-399.798 (.0000)	-396.071 (.0000)	-393.605 (.0000)	-391.881 (.0000)
Pseudo-R^2	0.072	0.078	0.087	0.092	0.096

Standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 6: Likelihood of commercialization (propensity score matching)

	Model 12 (foreign vs. domestic)			*Model 13 (spin-off vs. external)*		
	Unmatched	*ATT*	*ATE*	*Unmatched*	*ATT*	*ATE*
Treated	.370	.370		.344	.344	
Untreated	.503	.476		.517	.392	
Difference	-.133	-.105	-.113	-.174	-.049	-.112
S.E. (bootstrapped)		.046	.047		.048	.048
95% Confidence interval		-.197	-.206		-.016	-.207
		-.014	-.021		.047	-.145

Note: Kernel matching (Gaussian kernel; bandwidth = .06); standard errors obtained through bootstrapping (n = 100)

Figure 1: Licensing hazards: domestic (0) versus foreign (1) licensees

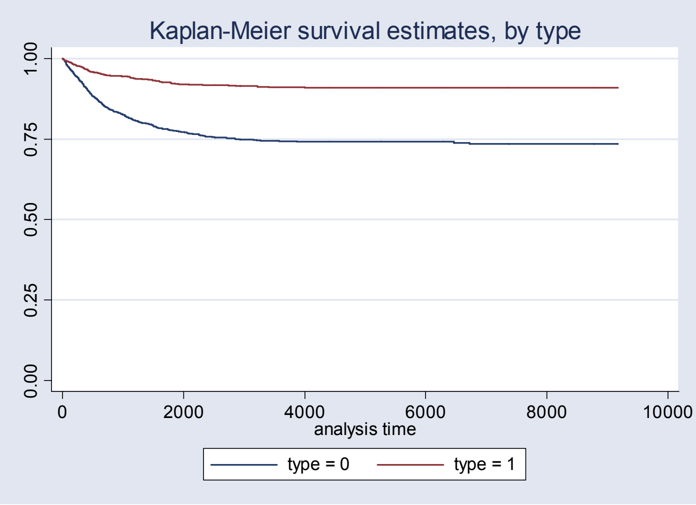
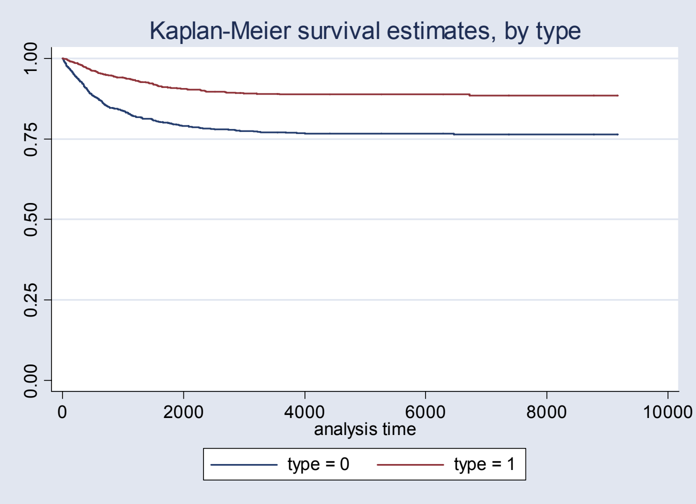


Figure 2: Licensing hazards: external (0) versus spin-off (1) licensees



APPROPRIATING VALUE FROM "LEISURE TIME" INVENTION

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Paper presented to the EPIP Conference
Lund, Sweden
September 2007

ABSTRACT

This paper investigates how "leisure time" invention contributes to firm innovation. We seek to answer three main questions: (1) How can leisure time invention create value? (2) What motivates leisure time invention? (3) How can firms utilize leisure time invention? First, we examine the degree to which leisure time invention is a market or non-market activity, and propose a simple model connecting the knowledge generated in leisure time invention with the knowledge generated by the firm. Second, drawing on the distinction between direct and indirect utility goods, we contend that there is a higher proportion of direct utility involved in the performance of leisure time invention than is the case for paid inventive activities. Such inventors may also try to achieve material rewards for their efforts – but often, they do not. Third, because leisure time invention is highly motivated by direct utility, attempts to realize its commercial value can pose special challenges. We analyze what contractual arrangements can be implemented to govern the relationship between a firm and an employee who has made an invention of potential interest to the firm in her leisure time. We conclude by discussing some of the implications of the analysis.

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APPROPRIATING VALUE FROM “LEISURE TIME” INVENTION

1. Introduction

In the film *October Sky*, a Hollywood version of a true story, four high school students in a West Virginia coal mining town, inspired by the 1957 Russian launching of Sputnik, experiment with their own home made rockets. Made aware of a university fellowship prize offered at a national high school fair in Chicago, they develop an entry to the fair and win the prize. This leads to university fellowships for all four, their escape from a future in the coal mines. While the details of their prize submission are not revealed – Hollywood not being inclined to explain technicalities in films involving scientific achievement – this story raises an important point. Sputnik inspired a rash of rocket building activities among the U.S. teen population, including one of the authors of this paper. None of this inventive activity, as far as the authors are aware, was entered into the U.S. national accounts. Yet in many instances it has inspired career choices, and provided the impetus upon which many scientists were recruited into the U.S. National Aeronautics and Space Administration.

This paper seeks to investigate, in an exploratory manner, how individuals working in their leisure time can contribute to the development of new products, processes, and services – a phenomenon we will call “leisure time” invention. While much has been written about the economic value of unpaid work – a category which includes subsistence production, housework, work in the informal sector of the economy such as industrial piece work, and volunteer work (Beneria, 1999) – none of these scholars include inventive activity in their analyses. Yet there is a great deal of anecdotal information about *de facto* leisure time invention. Examples include a schoolgirl designing a weblog, a father building a remote-controlled toy boat for his child, or a computer nerd helping to develop the Linux operating system.

We were intrigued to look into what motivates people to devote their free time to inventing new products of this type – products that probably will never earn them any money, but that they still find rewarding to invent, and products that could well contribute in ways not yet well understood to innovating firms – and, by implication, to the economy as a whole. We believe that leisure time inventive activity does have important economic value, even if it cannot directly be measured in terms of paid work (present or anticipated).

There has been considerable interest in the literature in the various manifestations of leisure time invention. Scholars have investigated the dynamics of open source software (e.g. Lerner and Tirole, 2005, Weber, 2004), user innovation (e.g. von Hippel, 2005, Harhoff *et al.*, 2003, Franke and Shah, 2003), customer creativity (Berthon *et al,* 1999), "crowd-sourcing" (Howe, 2006, Lakhani *et al.,* 2007), and prize contests like the X-prize (National Academy of Sciences, 2000, Davis and Davis, 2006). But these studies investigate leisure time invention from the demand side. Our interest here lies mainly in the supply side, including the jointness between the leisure time invention and firm inventive activities. Other forms of leisure-time invention have received little or no academic attention. For example, many individuals invent games which they share with friends and family. But because these games are not sold on the market, they remain invisible to the public at large.

Our essay is structured around three main questions. In Section 2, we ask: How can leisure time invention create value? We examine the degree to which leisure time invention is a market or non-market activity, and propose a simple model connecting the knowledge generated in leisure time invention with the knowledge generated by the firm.. In Section 3, we ask: What motivates leisure time invention? Drawing on the distinction between direct and indirect utility goods (Hawrylshyn, 1979), we contend that there is a higher proportion of direct utility involved in the performance of leisure time invention than is the case for paid inventive activities. In other words, people enjoy tinkering, and directly consume the benefits from it. Leisure time inventors may also try to achieve material rewards for their efforts – but often, they do not. Because leisure time invention is highly motivated by direct utility, attempts by firms to realize its commercial value can pose special challenges. Section 4 analyzes what contractual arrangements can be implemented to govern the relationship between a firm and an employee who has made an invention of potential interest to the firm in her leisure time. We conclude by discussing some of the implications of the analysis.

2. How can leisure time invention create value?

Leisure time invention may be defined as inventive activity that takes place outside of the formal labor market, efforts for which the inventor gets neither a wage nor a salary. We begin, in Section 2.1, by presenting the concept informally, and illustrating it by the story of the Wright brothers. In Section 2.2, we formalize the definition by introducing a simple model, variations of which cover the main aspects of leisure time invention. We start by considering the case of an inventor who works both at her place of employment ("market-based") and in her leisure time at home. In this case, her leisure time activity represents a continuation of her inventive efforts at work, but she is not paid for it. We then refine the model to include four further cases:

- Where the inventor is working on something else in her leisure time in which the firm is not (necessarily) interested
- Where two employees in a single firm pursue two types of inventions in their leisure time and utilize each other's knowledge in their pursuit
- Where a firm broadcasts a particular need over the Internet and non-employees compete to fill it, and
- Where employees from different firms pool their knowledge sets in their leisure time to achieve successful invention.

2.1. Invention as a "market" and "non-market" activity

In this paper, we argue that inventive effort can be divided between that effort for which the inventor is paid by an employer (market invention), and that effort which the inventor, individually or as part of a larger group of like-minded agents, makes in her (their) leisure time. Leisure time invention, like a hobby, may be motivated by purely personal enjoyment, and is thus a "non-market" activity. Hawrylshyn (1977) discusses the general problems of measuring non-market activities, without specifically mentioning invention. If we substitute the term "inventive activity" for his term "economic activity," we can paraphrase Hawrylshyn's analysis of non-market activities (1977: 79-80) as follows:

- *Proposition One:* Inventive activity comprises only a part of economic activity, but that part is significant enough to merit the attention of scholars.
- *Proposition Two*: Market activities comprise only a part of economic activity. The economic value of many activities fall outside the market, here most notably household work, but also unpaid inventive work done in leisure time.
- *Proposition Three:* Market related inventive activity therefore makes up only a portion of a total societal inventive economic activity.

But the notion of leisure time invention is complex. The leisure time inventor's intent might instead be to sell or license the rights to her invention to another party. In this case, the inventor is still utilizing her leisure time but on a "market" basis.[3] As we will note, a major challenge for society is to "incentivise" the field of leisure time invention so that these inventions can contribute to the commercialization of new products or services.

Invention refers to the conceptualization and further development of a novel idea. Innovation refers to the commercialization of the invention in the form of a new product, process or service. In this paper, we focus on the invention process. Inventive activity is seen as the practical implementation of a new idea derived from new combinations of knowledge based on "prior art" and "know-how." By "prior" is meant preceding. "Art" is defined in terms of learning. "Know-how" refers to procedural knowledge: the knowledge of how to perform some task.

The story of the invention of the first airplane provides a striking illustration of the practical implementation of new ideas based on combinations of knowledge involving prior art, and the use of procedural knowledge or know-how. The airplane was developed in the early twentieth century by two brothers, Wilbur and Orville Wright. They were untutored in formal

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[3] To take a parallel, a professor might buy a house, use her leisure time to modernize the house, and then 'flip' it on the market. The motivation here is market-based, while her activity is leisure time.

engineering skills. Their income came from a very successful printing/bicycle enterprise in Youngstown, Ohio, which alone financed their leisure time activities.[4] An airplane is clearly quite different from a bicycle, but its invention in fact built on many of the brothers' work-related skills. This story demonstrates how inventors can be motivated by both direct and indirect utility, providing a good example of the synergies characteristic of our joint firm and leisure time invention model. (Much of the following can be found in Heinsohn, 2007, but see also U.S. Centennial of Flight Commission, 2004; and Smithsonian Institution, National Air and Space Museum, 2004).

The Wright brothers' invention was to a large degree based on knowledge acquired from others. Otto Lilienthal, a German engineer, had discovered that to give a wing lift, its leading edge had to be curved upward (cambered wing). His experiences with hang gliding, published in magazine articles, inspired the Wright brothers. Octave Chanute, an American engineer, solved the problem of wing structural soundness. He found that by having double decked wings with a Pratt truss (connected by vertical struts for compression, and diagonal wires for tension), sizable wings could be constructed that would not fall apart under pressure. Both the gasoline engine and the propeller had already been invented as well, but would have to be modified to provide air power.

Know-how acquired through experimentation and observation was, in many ways, even more important. For example, the brothers' use of the Lilienthal designs (prior art) for optimum wing camber led to some gliding disasters. These were rectified after the brothers had tested more than 200 model wings in their primitive wind tunnel (the first of its kind in the world). This enabled them to design wings better able to solve the problems of lift and drag.

A major problem concerned executing controlled turns in the air. The airplane had to both turn and at the same time maintain lift under the wings. The two brothers noted how vultures accomplished this manoeuvre by banking in their turns, twisting one wing upward and the other downward. This knowledge, gained through observation of birds in flight, was creatively combined with their knowledge about bicycles and wire strength (light weight bicycles use many wires under tension connecting points on the wheel to tangential points on

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[4] In addition to inventing the airplane, the brothers also took out patents on bicycle design. They were particularly successful in designing and marketing various forms of ultra-light bicycles.

the wheel hub), yielding new forms of know-how which aided them in designing structurally sound biplane wings. It proved critical in their development of the wing warp, and their ability to bank turns in the air. They had found that wings might be warped by applying tension to the diagonal wires of the Pratt truss.

The Wright brothers' early experiments in quantifying wing lift and drag were based first on small test wings mounted on the handlebars of a bicycle, which would be ridden at a particular speed. To this end, they built their wind tunnel, which used a gasoline-powered engine driven fan. This experience, in turn, gave them the know-how as to better construct both gasoline engine and propeller. They then built an aluminum 74 kilogram 12 horse power engine, and the first propeller designed for "screwing through air."[5]

Most of all, the brothers used their bicycle know-how in designing the control system. **Flyer One** carried over the symbiotic relationship between rider and bicycle to that between pilot and airplane. To this end, they designed a hip cradle. The pilot would fly lying down, his hips in the cradle, which was attached to those wing trusses critical to wing warp. Moving hips laterally would apply pressure to the trusses causing the wings to warp and the plane to turn, much as a bicyclist leans to the left or the right to make turns. This leaning also controlled the rudder. Hand levers controlled the elevators. Other pieces of equipment came right out of the bicycle shop. The twin propellers were powered by bicycle chains. The landing gear utilized a bicycle hub to guide **Flyer One's** skids along the take-off track.

Could the Wright brothers have invented the airplane in their leisure time without the skills, perceptions, and know-how developed in their successful bicycle business? Clearly, their invention would have been impossible without the knowledge acquired from experts like Chanute and Lilienthal. But more importantly, the brothers solved the fundamental problems of control in heavier-than-air flight. They might never have succeeded without combining existing outside knowledge based on prior art with knowledge based on experimentation

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[5] The engine could have been built by others than the Wright brothers and their mechanic, Charlie Taylor. The reason they designed and built the engine was that they felt they only needed the one model and ordering a single model from another firm would have been costly. The propeller design with its twist towards the tips of the propellers was significant in enabling sufficient thrust to carry the plane into the air. All propellers since the Wright brother's first propellers incorporate the same essential design.

derived from designing, manufacturing, and repairing bicycles. Together, these yielded the knowledge behind their successful invention.

2.2. A simple model

2.2.1. The basic model: Leisure time invention as a continuation of paid work

We start by considering a simplified case of an inventor who works both at her place of employment and in her leisure time at home, where her leisure time activity is a joint product of her inventive efforts at work, but for which she is not paid. We assume that an inventor divides her work on a specific invention into work at her place of employment (market-based), and work at home (leisure time invention, not market-based).

Let time at work inventing be T_w, and T_h represent leisure time at home inventing. Let us consider one firm with I employees. Knowledge is assumed to be quantifiable and discrete, comprising a set of knowledge types. Let us denote each knowledge type as K_n, where $n = 1,...,N$. Each employee possesses some types of knowledge. Denote each employee i's possession of K_n by e_{in}, where $e_{in} = 1$ if the employee possesses that knowledge type, and $e_{in} = 0$ otherwise. If at least one employee possesses a knowledge type, then the firm also possesses that knowledge type. Denote the firm's possession of one type of knowledge, K_n as f_n, where $f_n = max(e_{1n}, \ldots, e_{In})$. So, $f_n = 1$ if the firm has that knowledge type, and $f_n = 0$ otherwise. Let h represent some combination of the minimum number of knowledge types necessary for an invention, for example $h = min(K_1, K_2, K_7)$, if knowledge types K_1, K_2 and K_7 are required for the invention. Then if $h=1$ the invention is made; if $h=0$, the invention is not made.

2.2.2. First variation: Leisure time invention in which the firm is not (necessarily) interested

Here, the firm can only develop a small proportion of the very many available subsets of knowledge types. Therefore the firm has to prioritize. Management sorts out the different types of knowledge, separating those it finds valuable from those without value, either due to economic feasibility, or to what it defines as the firm's core competences, or both.

Define the set of all knowledge types as K. Assume subsets of knowledge types K_X, K_Y, and K_Z, where $K_X, K_Y, K_Z \subset K$, and where K_Y, K_Z are the knowledge types available, but for one reason or another are not utilized by the firm, which is concentrating on knowledge type K_X. Let one or more of the firm's employees spend their leisure time developing knowledge types K_Y, and K_Z. We are now considering the impact of leisure time invention in terms of three related types of knowledge: type X, pursued by salaried employees within the firm, and types Y and Z, which are the focus of one or more employees in their leisure time at home.

Assume that management has erred and the minimum knowledge types needed for the firm's invention is $h_X = min(K_{X1}, K_{X2}, K_{Y1})$. The firm effort would then fail. Assume that an employee who has developed knowledge type K_{Y1} in her leisure time, sees the proper solution, and convinces management of its worth. The firm effort would then succeed. Here, it was the leisure time inventive activity which (perhaps unconsciously) led to firm success. Alternatively, assuming that the individual inventor is working on invention $h_Y = min(K_{Y1}, K_{Y2}, K_{X1})$, she can benefit from the knowledge acquired from other colleagues at her workplace. Job skills thus render home-grown invention successful.

2.2.3. Second variation: Leisure time invention where two employees in a single firm pursue two types of inventions and utilize each other's knowledge types

Let two employees working in their leisure time develop knowledge types K_Y, K_z. We are now looking, again, at the impact of leisure time invention in terms of three related types of inventions, type X at work for the firm, and types Y, and Z, the focus of one or more employees at home in their leisure time – but in this case, the employees communicate their knowledge types to one another. Successful leisure time inventive effort for the two could be expressed as follows

$$h_Y = min(K_{X1}, K_{X2}, K_{Y1}, K_{Y2}, K_{Z1}) = 1 \qquad (1)$$

$$h_Z = min(K_{X1}, K_{Y2}, K_{Y3}, K_{Z2}, K_{Z4},) = 1 \qquad (2)$$

Invention skills and expertise acquired both at work and at home have been successfully combined in the hobby activities of the two leisure time inventors.

And, as an important note, leisure time invention does not need to be successful in order to have an impact. For example, a leisure time inventor pursuing h_Y in *(2)* above, may never acquire the other knowledge types to be successful, but if she acquires K_{Y1}, she can make a useful contribution to collective efforts to solve h_X in the firm variation in section 2.2.2 and to solving her collaborating friends efforts, as shown in expression *(1)* (above).

2.2.4. Third variation: Leisure time invention where a firm broadcasts a particular need and non-employees compete to fill it

While this variation resembles the previous one, it differs in that the required knowledge types for successful invention are outside the firm set of knowledge types, in our basic model (Section 2.2.1). Say management realizes that their employees do not possess the expertise to master knowledge type K_ω and, recognizing this need, are confronted with a choice. They can either invest resources in acquiring this expertise, or they can search for firms or individuals from whom they can purchase it. (This is the source of the current “crowd sourcing” wave, where leisure time inventors or hobbyists play a surprisingly large role, and rewards are offered for successful solutions). These working on their own time have come up with a surprising array of solutions to scientific problems which have stumped multinational giants such a Proctor and Gamble and Boeing.

2.2.5. Fourth variation: Collective leisure time invention

This is a self organising variation of the leisure time invention puzzle. Predominant here are the self organised computer programmers who have invested leisure time in developing programmes such Linux and other open computer languages. Also included in this category are groups of inventors who use their leisure time in order to win one or another well advertised prize contests. Contests which come to mind here include the Ansari-X prize for space flight, the Grainger prize for removing arsenic from drinking water, and the DARPA prize for unmanned vehicle navigation, to which we will return below.

3. What motivates leisure time invention?

The motivations for leisure time invention have many similarities with the motivations for open source software (which also often fall within our definition of leisure time invention). Economists discount altruism as a motive here. They also largely discount classic economic explanations. Referring to the Linux phenomenon, Raymond states flatly: "The 'utility function' Linux hackers is [sic] maximizing is not classically economic, but is the intangible of their own ego satisfaction and reputation among other hackers" (quoted in Lerner and Tirole, 2002: 198).

In contrast, Lerner and Tirole (2002: 212-213) have their own explanation of the open software phenomenon:

> A programmer participates in a project, whether commercial or open source only if he derives a net benefit (broadly defined) from engaging in the activity. The net benefit is equal to the immediate payoff (current benefit minus current cost) plus the delayed payoff (delayed benefit minus delayed cost)… The delayed reward covers two distinct, although hard-to-distinguish, incentives. The *career concern incentive* refers to future job offers, shares in commercial open source-based companies or future access to the venture capital market. The *ego gratification incentive* stems from a desire for peer recognition. Probably most programmers respond to both incentives.

Lerner and Tirole then explore various facets of the open source software movement: Leadership, the "alumni effect," customization and bug-fixing benefits, control of the developer's economic environment are all assigned a role in the scheme of things. In conclusion, they state that the answer to their question is to be found in the “literatures on ‘career concerns’ and on competitive strategies (*Ibid*.: 231).”

While we largely agree with Lerner and Tirole’s analysis of leisure time invention, we believe it does not fully capture the motivations of these individuals. We question whether it can sufficiently explain our own discussions with leisure time inventors who uniformly downplay the role of immediate and long range net benefits associated with their efforts. Instead, these inventors focus on the challenges involved in finding a solution to a problem or on the sheer joy of tinkering. Nor do Lerner and Tirole explain why leisure time inventors often accept little or no economic compensation, when others seek to utilize their inventions. Either leisure time inventors are not really aware of their fundamental economic motivations, or there is some other determining element here. In contrast to Lerner and Tirole’s analysis (which relies solely on measuring indirect utility), we turn to the leisure time literature’s emphasis on both direct and indirect utility maximization. We see leisure time inventor motivation as being a complex combination of these two classic economic concepts.

3.1. The significance of leisure time invention for the inventor-agent

By regarding leisure time invention as a portion of an individual’s leisure time, in line with the three propositions in section 2.1, we regard the individual inventor-agent as maximizing her utility. She trades time spent in developing an invention with other leisure time activities, such as watching television, playing tennis, or dining at exclusive restaurants. Here, Hawrylshyn’s (1977) distinction between direct utility goods and indirect utility goods is useful. The leisure time inventor maximizes her utility directly by consuming goods like watching television. At the same time, she maximizes her utility by producing goods. These can include the production of basic commodities (like watching the children, preparing food), of commodities that enable her enjoyment of the consumption of basic commodities (putting the children to bed so as to see a television program in peace and quiet), or that ease her work load in producing basic commodity goods (building a summer cabin to enjoy her vacations). These are all indirect utility goods. Producing these goods enables the individual to enjoy direct utility goods (like the television program, or the summer vacation).

Leisure time invention involves non-paid utility maximization in both senses, and in both non-market and market contexts. Suppose our leisure time inventor derives pleasure from tinkering with her invention concept (direct utility) and plans to use the invention as a gift to her husband (indirect utility). This inventor is engaging in non-market leisure time activities. Suppose, alternatively, that she both enjoys tinkering (direct utility) and intends to patent and license her invention to enjoy a future income stream from her leisure time activity (indirect utility). She is then engaging in invention in her leisure time, but her efforts involve a combination of non-market (direct utility) and market (indirect utility) efforts.

What is critical about these distinctions is that they underline the ambivalence surrounding leisure time invention. Key here is the direct utility which the leisure time inventor derives from her efforts, successful or unsuccessful. *Ceteris paribus*, if the entire inventive effort is prompted by a form of direct utility, the "reward" for invention is the satisfactory solution of a problem *per se*. Such an inventor will be more likely to share her results with others, and less likely to enter into a dollar-for-dollar patenting and licensing effort. The higher the indirect utility involved, the less the reward for solving the problem *per se*, and the more meaningful the *ex post* return on the inventive effort. While there are many intervening variables here, one can draw a parallel with university scientists who enjoy doing research, but are often not interested in patenting and licensing the resulting inventions. Rather, these scientists are more susceptible to corporate blandishments which enhance their direct utility (bigger and better laboratories, research grants, more research assistance).

3.2 The significance of leisure time non-market invention for the firm

Two varieties of leisure time invention are significant for the firm: that undertaken by the firm's employees, and that undertaken by third parties (whether by the firm's customers or other societal stakeholders) that is relevant to the firm's innovation activities. Unlike the individual home tinkerer, the firm has an interest in converting this leisure time non-market invention to market-oriented economic use.

For example, if the Wright brothers had been employees of another bicycle firm (i.e. a firm not owned by them), would their employer have allowed the multifarious activities involved in designing and flying **Flyer One,** even if these activities did not directly impinge on their productivity in the bicycle shop? This can be analyzed using the model presented in Section 2.2. The jointness of knowledge sets illustrated by inventions X, Y, and Z, and their relationship to invention at the firm level, leads to the following critical management predicament:

Firstly, it is not a given that inventions X, Y and Z are based on joint knowledge sets. Secondly, even if they were, it is not a given that inventions Y or Z have a commercial application. And, thirdly, even if Y and Z had commercial applications, these would not necessarily fit into the firm's core competences. In each case, invention by the firm's employees in their leisure time should perhaps be confined to developing those types of knowledge relevant to invention X. Management would encourage only leisure time activities directly relevant to invention X, that could increase the expertise necessary to develop subsets of knowledge, K_{Y1}, K_{Z1}. In this manner, the firm's assessment of the commercial value of other invention activities would prevail over its possible interest in developing any of these, even if they became available.

Alternatively, management might decide that the acquisition of less relevant knowledge types, such as K_{Y2}, K_{Z4}, could lead to more productive invention within the firm. This would lead them to encourage leisure time inventive activity in the home, in the anticipation that related types of knowledge thereby developed would work to the firm's longer run, overall competitive advantage.

As regards leisure time invention relevant to the firm undertaken by that firm's customers or other societal stakeholders, management faces a variation of the same set of problems. On the one hand, managers would like to remain open to its potential commercial applicability; but on the other, they would not wish to waste resources in what might be a fruitless exercise.

3.3. Leisure time invention and the self organising group

Self organising inventing groups can take two major forms. The first are leisure time inventors who have worked together on a specific technology for a long time, and found that sharing knowledge is more profitable than not sharing. An example is open source software. The second category refers to groups of individuals organized to win a prize.

In Lerner and Tirole's (2002) analysis of the institutional arrangements behind the open software phenomenon, they note that the early development of computer operating systems was dominated by institutions which were either essentially academic, or firms with a "great deal of autonomy (*Ibid*: 200)." Sharing of computer code was then quite common, with no attempt to define property rights to the languages involved. In 1983, the Free Software Foundation was established to promote varieties of software without cost to the users. An end to this means was the development of the General Public License (GPL). Diffusion of this open access system accelerated with developments in the Internet and the introduction of the Linux language. Interestingly enough, Lerner and Tirole (2002: 220) note that the "fun" and "crowd" effects had a stimulating influence on developments:

> Open source projects have trouble attracting people initially unless they leave fun challenges "up for grabs." On the other hand, the more programmers an open source projects attracts, the more quickly the fun activities are completed. The reason why projects need not burn out once they grow in ranks is that the "fixed cost" that individual programmers incur when the first contribute to the project is sunk and so the marginal cost of continuing to contribute is smaller than the initial cost of contributing.

The institutional self organizing arrangements for prize contests are somewhat different. An example is the DARPA 131.6 mile robot Mohave prize, in which a robot vehicle had to navigate various obstacles (including tunnels) within a ten hour time frame in order to win a $10,000,000 prize. It attracted no fewer than 43 teams, many from university engineering faculties. Stanford took first prize with "Stanley". The next two winners, named "Sandstorm" and "Highlander," were backed by Carnegie Mellon. The fourth, "Kat5" was backed by a Tulane University team sponsored by an insurance company Gray Insurance. Other entrants read like a "who's who" of U.S. engineering schools (among the 20 other university teams were Cornell, Virginia Tech, Auburn, Tulane, and Ohio State). All the non-university teams, with names such as “Overbot” and “Team Banzai,” consisted largely of engineers working for other firms, but who dedicated their free time to the prize competition.

These and other contests, such as the Ansari-X Prize for successful flight to the edge of space, and the Grainger Prize for a low-cost method of removing arsenic from drinking water, have been dominated by enthusiasts, often organized into “mom and pop” organizations. They typically comprise professional engineers working in their leisure time, and university faculties, desiring to use their collective knowledge and bits of know-how in a practical manner. Commercial firms have tended to participate only indirectly. Firms associated with DARPA prize, for example, were (1) small, (2) essentially team sponsors, (3) contributing the vehicles or computer programs involved, or most often all three of the above.

A related incentive system is the development of internet business sites where firms post research problems they have been unable to solve and promise rewards (prizes) to those part time inventors who solve the problems for them, the phenomenon earlier referred to as “crowd-sourcing” Most notable is the InnoCentive.com site devised by Eli Lilly in 2001 to connect with outside company talent. This site has been thrown open to other firms who can post their problems to some 80,000 scientists in over 150 countries (Lakhani *et al.* 2007: 4). Firms using this site now include Boeing, DuPont, and Procter and Gamble. Particular important are rewards offered from “reduce to practice” forms of know-how. Successful solvers get paid anywhere from $10,000 to $100,000. Although Howe describes these as “hobbyists” they are, in fact, leisure time inventors:

> The solvers are not who you might expect. Many are hobbyists working from their proverbial garage, like the University of Dallas undergrad who came up with a chemical to use in art restoration, or the Cary, North Carolina, patent lawyer who devised a novel way to mix large batches of chemical compounds (Howe, 2006: 5).[6]

The internet also facilitates supply-push leisure time invention. The computer program, ‘Second Life,’ which first opened in 2002, allows participants to create a 3-D virtual world

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[6] Nor is Innocentive alone, Procter and Gamble have established two networking sites: YourEncore gives companies access to retired scientists for specific company assignments, and NineSigma is “an online marketplace for innovations, matching seeker companies with solvers in a marketplace similar to InnoCentive (*Ibid*).” What is interesting about all these initiatives is that they are response to the problems confronting the firm, as described in our simple model in section 2.

and share their virtual world (digital creation) with other users. This program has led to leisure time inventors' placing the designs of their inventions on the net where they can be visited by others. An additional attraction offered by 'Second Life' is 'The Marketplace' which allows for the buying and selling of the attractions offered in 'The Creations.' This invention/design commerce uses the Linden Dollar, and can be converted to U.S. dollars on online Linden Dollar exchanges.

3.4. The role of intellectual property rights

By patenting their new products and processes, leisure time inventors can ensure potential buyers that the invention has not been patented by someone else, and can be legally enforced. Such patents can also serve as signals of value to would-be investors and corporate partners, and the basis for licensing agreements (e.g. Cohen *et al.*, 2000, Davis, 2004). While there are no studies of patent use by leisure time inventions, in our opinion, while the leisure time inventor may take out a patent or two, patenting is probably of little importance here.

First, patenting is costly. In particular, the mechanisms for collecting and enforcing patent rights, and licensing royalty income, are complex and impose high transaction costs. The patent covering the Wright brothers invention of the airplane, for example, primarily rested on their warped wing design, but was extended to cover like devices like the aileron devised by Curtis. The patent was deemed not effective in Germany and France. In the U.S., where the Wright patent rights were upheld, the brothers were involved in such long and costly litigation that it was thought that Wilbur's death from pneumonia in 1912 had been provoked by the stress of the brothers' lawsuits.

There are two further reasons why patents may be unsuitable for leisure time invention. For one thing, patents specifically reward indirect utility. To the degree that the inventor is motivated by curiosity, or the love of creating something new, she will not find the guarantee of exclusive rights enshrined in the patent system particularly motivating. She may, perhaps, wish to share the fruits of her inventive efforts freely with others. Moreover, a great deal of leisure time invention is carried out by two or more inventors working together, sometimes in cooperation with inventors in a firm, sometimes not. Two of the variants of our model – broadcasting, and self-organizing invention – may involve quite large numbers of inventors, some of whom work independently of each other, and who may or may not cooperate with each other. The patent system is ill-equipped to govern this type of invention.

There are other, less costly means of securing appropriability. One of the authors of this paper was approached by an engineer who had developed a new, electronic form of solitaire and wished to earn money from his invention. Her advice was to put the game on his home page, apply for a trademark and a domain name, protect the source code by technically blocking access to those parts of the code he didn't want copied, apply for design protection, and work to attract enough players so that advertisers would pay him to have their logos on his solitaire site.

Leisure time inventors can also make it possible for satisfied players to pay them directly via an account on their home page. An example is John McAfee, an engineer who dealt with virus problems for Lockheed. He developed a virus fix and posted it on a computer bulletin board in 1989. McAfee asked the people who downloaded it to send him whatever money they thought his invention was worth. Within a year, he had made $5 million! (Shapiro and Varian, 1999: 90).

4. Firm utilization of leisure time invention

Section 3.2 touched briefly on the significance of leisure time invention for the firm, but did not discuss how a firm can utilize leisure time invention. One can approach this issue through the device of a worker-employer contract.

An employee with a specialized piece of potentially commercially valuable knowledge developed in her leisure time is in possession of private information. She is confronted with a set of choices. She can reveal the information to her employer or keep it to herself, with a view to either starting her own firm, or selling the information to a competing firm. In both cases, she will leave the firm. Alternatively, she can reveal the information to her employer in the hopes of a reward if it is integrated in an internal project, or forms the basis for a firm 'spin-off.' Since her information is a function of her leisure hobby at home, her efforts are unobserved by her employer.

For simplicity's sake, we assume that her employer belongs to one of two categories of firm: a category one firm with a low cost technology whose products or services are unprotected by a strict set of intellectual property rights, and a category two firm with a high cost technology protected by a set of intellectual property rights. The managers of both firms have two problems: picking "winners" from various combinations of firm knowledge types, and keeping inventive workers from leaving the firm, either to start up their own firms or to convey their know-hows to competitors (See, for example, Anton and Yao, 1995; Pakes and Nitzan, 1983; Rosen, 1972; and Moen, 2005).

To these problems we add the two dilemmas of how the firm can derive benefits from worker leisure time know-how: inducing workers to share their private information about their potentially valuable leisure time knowledge; and eliminating what might be termed 'leisure time shirking behaviour' (in which the worker uses firm time and assets to pursue a fruitless line of endeavour connected with her hobby).

Employers in both categories of firms are in a position to offer their workers *ex ante* incomplete contracts, typically contracts with trailer clauses (giving ownership of an invention to the employer if the inventor leaves the firm for a specified period, after which it reverts to the employee), shop rights clauses (conferring ownership of patents to the discoverer simultaneously with conveying a nonexclusive, non assignable and royalty-free license to use the invention to the employer), and other forms of incentive contracts contingent on the firm management's objectives (Aghion and Tirole, 1994: 1187).[7] Yet there are a range of contractual alternatives not available to category one firms. (For example, contracts with shop rights clauses cannot be a feasible alternative in the absence of patent rights).

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[7] Chief among these are contracts with performance bonuses. There are also instances of contracts awarding successful a fixed percentage of the resulting sales revenues (Milgrom and Roberts, 1992, pp. 399-400).

Pakes and Nitzan (1983); and Rosen (1972) suggest two overlapping explanations for successful firm retention of talented workers. Pakes and Nitzan argue that an employer can always make a more attractive offer to a worker with a profitable idea, which can trump any putative worker advantage from leaving the firm and starting up her own company, or selling her idea to a third party. They note that if the innovation makes the firm a true monopolist, it will never pay for the worker and firm to split, in that the sum of rents in a duopoly market would be less than that in a monopoly market. It is therefore in the interests of both to find an internal solution.[8] There are two consequences stemming from this argument. Firstly, those firms where talented workers may be tempted to leave and start on their own will be more likely to patent. Secondly, as a result, such firms will utilize incentive contracts to retain their talented human capital. Both of these consequences have been confirmed empirically (Kim and Marschke, 2001).

Rosen (1972) argues that on the job "learning" should be taken into account when looking at worker retention. Such learning is part of an employment bundle of rights and is valued by the worker, particularly since such learning leads to better jobs and skills. Over time, workers will divide into the 'able learners' and the 'others,' leading to a form of ability distortion.

An implication of both interpretations should be that workers with skilled know-how will be content to commence their employment at low wages, in the anticipation that over time, their wages will increase as they acquire further know-how, a form of bonding. Empirical investigations have confirmed this assertion. Balkin and Gomez-Meija's (1985) investigation of 105 firms in the Route 128 belt around Boston found that incentive pay schemes in (category two) high tech enterprises are more common than in their (category one) lower tech counterparts. Personnel key to these firms' start-ups are given long term stock options. These findings have been further confirmed by Moen's (2005: 81-114) study of the technical staff of the Norwegian machinery and equipment industries.

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[8] There exists a debate as to whether the same situation would occur if there were several workers with the same know-how. See Combes and Duranton (2001).

The problems of retention for the category one firms without IPR walls are of a different order. Given that these firms rely on unprotected knowledge for their competitive advantage, appropriation of a new combination of knowledge types is relatively easy, and the chances that a leisure time inventor would have her ideas appropriated by her firm without compensation are relatively high. Here, commencing with one's own start-up would be the more attractive alternative. One would expect under the circumstances, such firms would rely heavily on trailer clauses in their employment contracts.[9]

Between these two firm categories are firms with many different combinations of capital intensity, skilled and unskilled workers, and different degrees of IPR protection. Clearly, many problems of worker retention can be countered by appropriate employment contract design. Furthermore, there are significant transaction costs attached to outside alternatives which a leisure time inventor could do without, both in terms of selling her idea to another firm, or starting up her own enterprise.

To the problem of retention, we add the leisure time dilemmas introduced above. With regard to the first dilemma, the revelation of potentially valuable privately held leisure time knowledge can be procured by the same incentive contracts designed to enhance firm retention of technical staff. In both cases, the objective is to prevent worker exploitation of her privately held know-how in her own start-up, or in conjunction with a competitor. In both, worker contractual incentives should facilitate workers sharing their privately held information in return for higher compensation.

The second dilemma concerns distinguishing between the acquisition of knowledge more appropriate to the worker's leisure time, and those with more direct relevance to their place of employment, which we have termed 'leisure time shirking.' This 'jointness' problem, endemic to our definition of leisure time invention, can be addressed in two manners. The first, "monitoring," the economic solution to shirking (Alchian and Demsetz, 1972), no doubt

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[9] Oddly enough, we could not find any empirical studies to confirm this impression. There are two possible reasons for this: the use of 'trailer clauses' is so common in both high tech/patent protected industries and low tech/unprotected industries that a contractual pattern is not discernable; or it remains an area for empirical investigation.

can be applied equally well to assuring that inappropriate leisure time inventive activity is minimized in the firm workplace. However, defining of what constitutes ‘appropriate’ makes effective monitoring extremely difficult.

A second approach would be to legitimatize certain leisure time inventive activities within the firm. Given that engineers, scientists and other highly skilled workers initially prefer low wage jobs with higher learning potential (and consequently higher future wages), a solution might be to package what some workers would be doing in their leisure time into the firm worker learning experience. Stern (1999:28), in an analysis of research biologists working in biotech firms, found that researchers allowed to engage in “open science” were willing to “pay a compensating wage differential” for the possibility to do so. Since greater freedom to engage in open science is a form of direct utility, Stern’s findings might have implications for leisure time invention. Workplace generation of what would otherwise be leisure time know-how need not necessarily have negative consequences for a firm’s bottom line, if workers are prepared to settle for less in return for increased learning experience.

5. Conclusion

We have argued, in this paper, that leisure time invention is more important than is generally realized, since the types of knowledge derived from leisure time invention are characterised by jointness with those acquired in the formal workplace. We took issue with the conventional economic approach to the analysis of “puzzling” forms of leisure time invention like open source software, where the motivation is seen as some form of future market compensation. We argued, instead, that leisure time invention can have some of the characteristics of a hobby (“tinkering”) or an artistic pursuit, which yields pleasure to the inventor over and above any expectation of future reward. We contended, further, that while market imperfections make it difficult to govern the relationship between the leisure time inventor and an interested firm, solutions do exist.

Several implications of our arguments might be mentioned. Managers of companies can use the insights from this paper to develop a more nuanced view of innovation, where formal systems such as R&D laboratories and patents can usefully be supplemented by engaging the talents and enthusiasm of leisure time inventors. This paper also provides yet another reason to preserve the independence of university researchers and their ability to engage in research projects of their own choice. While the results of this research cannot necessarily be patented, it still can have enormous value to companies. That leisure time invention may actually be increasing in importance is suggested by the great ferment created in the business world in recent years by the introduction of more open innovation models such as creative commons licensing, and the practices of free-revealing and crowd-sourcing.

A fundamental issue not addressed in this paper concerns how leisure time invention can be measured. The value of leisure time invention does not feature in a country's national accounts. As a result, GNP does not necessarily represent the level of inventive talent in a country. One implication is that comparisons of countries, in terms of their innovativeness, that rely on formal measures such as the number of patents applied for, may be misleading. Another is that countries can potentially make more of the value created by leisure time inventors. Specific industrial policy initiatives might be implemented to this end. To what extent, for example, could prize contests provide a better incentive system to realize the benefits of leisure time invention?

Future research could also address the contractual issues that arise in relation to the other kinds of leisure time invention discussed in Section 2: where two firm employees pursue two types of inventions and utilize each other's knowledges, where the firm broadcasts a particular need and non-employees compete to fill it, and where leisure time invention occurs within the self-organizing group. For example, we argued in Section 4 that firms might have an interest in encouraging employee leisure time invention, even if the benefits do not accrue to them. But what happens if a competing firm acquires the patent rights to the leisure time invention?

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The option value of patent licenses

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ABSTRACT

Patent valuation is one of the most relevant issues within the studies on the management of intellectual property rights. As firms rely more and more on external sources of innovation, the need for reliable measurements of what is traded becomes essential. Patent valuation is especially challenging primary because of the great uncertainty affecting their returns and for the lack of market-based data. The most recent and promising attempts in this research field have been developed within the real option theory (ROT), which recognizes the effect of uncertainty on patent value, and they have taken advantage of the increasing amount of information available about licenses. The aim of this paper is to propose and empirically test a valuation model of licensed patents based on ROT. According to our model, the initial fee paid by the licensee is considered analogous to the premium she is willing to pay to buy an option to commercialize the licensed patents in the future. A fundamental prediction of ROT is that this option value increases with volatility. In order analyze the relationship between volatility and the initial fee of the license, we assume that volatility is primarily determined by market and technological uncertainty. We analyse 105 patent licenses. The results of our regression model show that both market and technological uncertainty positively affect the initial fee paid for a patent license.

Keywords: *patent valuation, licensing agreements, real options*

Acknowledgements: We wish to thank The Financial Valuation Group of Florida, Inc., which provided transaction information developed from The Financial Valuation Group's Intellectual Property Transaction Database, which is copyrighted by and used with the permission of The Financial Valuation Group of Florida, Inc. The financial support of the EVPAT project funded by the European Investment Bank is gratefully acknowledged. We also wish to thank Grid Thoma, Massimiliano Granieri, Toke Reichstein, Markus Reitzig, Salvatore Torrisi for valuable comments and suggestions. All eventual errors and omissions remain of our exclusive responsibility.

1. INTRODUCTION

The recent shift of firms to more open models of innovation based on collaboration and external sourcing of knowledge stands out as one of the most interesting phenomena characterizing the knowledge-based Economy (Kamiyama, Sheehan and Martinez, 2006). However, according to Arora and colleagues (2001) there are still many factors affecting the transaction costs involved in technology exchange. Among others, patent valuation makes the reach of a satisfactory agreement difficult for both the licensee and the licensor. In this regard, well functioning markets for technology require an improvement in the accuracy of any valuation attempts through the provision of "reliable valuation benchmarks" (Rivette and Kline, 2000: 62).

To date, there is an undesirable lack of reliable methods for valuing patents (Rivette and Kline, 2000; Reitzig, 2006; Kamiyama et al., 2006). As pointed out by Pitkethly (2006), the majority of works providing econometric methods of patent valuation generally deal with aggregate values rather than the individual patents. Further, even though some authors have tried to assess the value of patent as stand-alone based, for instance, on patent renewal data (Pakes and Shankerman, 1984; Pakes, 1986), citation data (Trajtenberg, 1990) or survey-based measure (Gambardella, Harhoff & Verspagen, 2006), they only provide indirect measures or estimation of patent value.

According to Reitzig (2006), patent valuation is especially challenging because of the intangible nature of patents and the great uncertainty their returns are subject to. As a consequence, the most recent and promising attempts in patent valuation efforts have been developed within the real options theory (ROT), which potentially recognizes the effect of uncertainty on patent value in a more correct way. Indeed, starting out with Pakes (1986), the idea of valuing patents as real options has gained an increasing attention among scholars (e.g., Marco, 2005; Pitkethly, 2006; Li et al., 2007; Ziedonis, 2007). Nevertheless, there are still many caveats to the valuation of patents as real options that hinder the widespread application of this approach. For instance, the use of the choice of the appropriate option valuation model, the measurement of the option parameters and the empirical validation of ROT based model for patent valuation (Reitzig, 2006).

Some authors have tried to deal with these problems by using the increasing amount of information available on market-based licensing contracts (e.g. Miller and Bertus, 2005; Ziedonis, 2007). The rationale for this choice is twofold. First of all, licensing data provide more objective measures of patent value, based on market data (i.e., payment structure of the licensing contract). Second, the use of these data is consistent with the increasing evidence of the employment of such mechanisms to transfer patents among firms in industries, such as chemicals and pharmaceuticals, electrical, software and ICT (e.g., Grindley and Teece, 1997; Rivette and Kline, 2000; Annand and Khanna, 2000; Gu and Lev, 2001; Arora et al., 2001; Arora and Fosfuri, 2003; Kim and Vonortas, 2006).

The aim of this paper is to test whether patent valuation within a patent licensing transaction is consistent with ROT. The work of Ziedonis (2007) has analyzed the use of option contracts and the adoption of real option reasoning by those firm licensing technologies from the University of California. Our paper offers several specific contributions. First, Ziedonis (2007) focuses on the licensing decision process whereas we analyze the value of the transactions. Second, we consider separately the effect of market and technological uncertainty since previous literature has reported that the two forms of uncertainty can have distinct effects (McGrath and Macmillan, 2002; Oriani and Sobrero, 2007; Anand, Oriani and Vassolo, 2007). Third, we analyze a cross-industry sample of patent licenses, where the licensor is not necessarily an academic institution, since academic licensing present specific characteristics (Jensen and Thursby, 2001). We will deal with these issues modelling the option created by the licensing contract for the licensee and conducting an empirical analysis based on a sample of 105 patent licenses.

The paper is organized as follows. Next section will discuss the theoretical background, the model and the theoretical propositions. Section 3 will present the sample, the data and the variables, while section 4 will show the results of the empirical estimation. Finally, the last section will summarize and discuss the contribution of the paper.

2. THEORETICAL FRAMEWORK

The application of valuation methods based on discounted cash flows, assuming investors' risk-aversion and the non changeability of the firms' actions once planned, normally fails to fully capture the value of highly uncertain and flexible investments (Kogut and Kulatilaka, 1994). More recently, the idea that investments in real assets create opportunities that are analogous to the options traded in the financial markets has been widely accepted by the literature (e.g. McGrath, 1997; Huchzermeier and Loch, 2001). Indeed, starting out with the pioneering studies of Myers (1977), ROT has had an increasing impact on research in strategic management and corporate finance. A main aspect of ROT is that any corporate decision to invest or disinvest in real assets can be conceived as a real option that ensures the firm a right, but not an obligation to take some action in the future (Trigeorgis, 1996; Kogut and Kulatilaka, 2001).

Accordingly, several ROT based models have been elaborated over time for the valuation of R&D projects (e.g. Pennings and Lint, 1997; Perlitz, Peske and Shrank, 1999; Schwartz and Moon, 2000) and patents (Pitkethly, 2006). Since patents normally combine uncertain returns with high flexibility of use, their option nature can be easily appreciated. This is true either from the point of view of the patent holder or the potential patent receiver. Indeed, from the perspective of the technology holder the options embedded in the patent are basically two: the option to use that patent by her own or to license that patent to others. Symmetrically, from the point of view of the technology buyer, patent flexibility is related to the option to use or not the patent to commercialize the underlying technology and the eventual timing of use. However, to the best of our knowledge, existing work has mainly focused on the patent holder's point of view, whereas the perspective of the potential patent buyer has been investigated much less. Moreover, the empirical validation of real option valuation is very limited, mainly due to the difficulty of estimating the option valuation parameters. Zideonis (2007) has empirically analyzed the licensee's decision process, but not the licensee's valuation.

The aim of this paper is to analyse the option value of patents as accrued to the licensee. In doing that, we will refer to the information provided by licensing contracts, as explained in the following paragraph.

2.1 Patent licensing

The analysis of patent licenses is particularly useful to test the option value of patents since they represent a market-based transaction. Licenses could be granted for any type of intellectual property right (IPR), that is, for patents, trade secrets, trademarks, copyrights and so on. Among them, patent licenses are the most frequently used to exchange technologies. Specifically, patent licenses entitle the licensee (technology buyer) to use the patent rights and, in turn, they compel her to pay fees, royalties or both to the licensor (technology holder) on the bases of well defined payment scheme (Granstrand, 1999). The payment structure of a patent licensing contract is sketched in figure 1.

---Insert Figure 1 about here----

The graphic shows the asymmetric condition of the licensor and the licensee before the start, during and after the end of any licensing contract. The underlying assumption is that the licensor does not compete with the licensee in the marketplace. Her stream of revenues, indeed, only stems from the flow of royalties periodically paid by the technology buyer. Instead, the payment and revenue structure of the licensee is more articulated. After the initial payment (up-front payment, down payment, initial fee), the licensee is given the right to fully exploit the licensed patent and thus she starts to produce and sell her products. In order to do that, the licensee sustains a certain amount of operating costs. Besides these costs, the licensee also has to periodically paid royalties (generally set as a percentage of sales) as a compensation for the use of the licensed patent.

Based on these considerations, it is no doubt that the value of license as perceived by the licensee depends on two important features of the contract: first, the duration or term of license that is equal to the number of years the licensee is allowed to exploit the licensed patents; second, the scope of the license conceived, instead, as the overall set of technologies, IPRs and know-how that are exchanged in the transaction. Starting from this baseline, there are also many other contractual provisions that make licensing agreements increasingly more sophisticated and diversified to the detriment of standardization and comparison. These clauses, indeed, affect the value distribution between the licensor and the licensee. Besides the two more common forms of value payments (the licensee agrees to pay to the licensor the up-front payment and the royalty rate namely), there are other many plausible elements making up the complex nature of the license remuneration scheme (see Razgaitis, 2003). Among them, the most significant are minimum annual royalties and milestones payments that are fixed cash payments due on each anniversary of the license or upon the crossing of some milestone events, respectively. As such, they stand as a guarantee of the commitment of the licensee to use her best efforts to bring the licensed technology to market and to continue to a best-efforts marketing program for the licensed technology throughout the life of the license agreement. Moreover, as already advanced, the parties may also agree on a certain number of contractual clauses that impact on the value of the license indirectly. The exclusive clause is one of the more relevant and intriguing examples at hand. Indeed, an exclusive license allows the licensee to fully exploit the licensed technologies without the threat that other licensee may bite the market to the detriment of her profitability.

2.2 The proposed model

Given their structure, patent licenses can be seen as options from the licensee's perspective. In fact, when entering a licensing contract, the licensee pays an initial fee (premium to buy the option) to acquire the right (option) to develop and commercialize the technology protected by the patent. In particular, the licensing contract is analogous to a financial call option. As a call option provides its owner with the right but not the obligation to buy an underlying financial asset at a predetermined exercise price before a given maturity date, the licensing contract provides the licensee with the opportunity to acquire the NPV of the cash flows from the commercialization of the patented technology (underlying asset) paying a development and industrialization cost (exercise price) at some time before the licensing term (maturity). Similarly to the underlying asset of a financial option, the NPV is subject to volatility over time, stemming from different sources of uncertainty.

The initial fee paid to enter the licensing contract is then a critical variable for ROT, since it should reflect the option valuation by the licensee. Following financial options literature (Black and Scholes, 1973), the initial fee paid by the licenses (F), analogous to the premium paid to acquire a call option, can be expressed as a function of the following variables:

$$\mathrm{F} = f\,[NPV, I, \sigma, n, r_f] \qquad [1]$$

where:

NPV = NPV of cash flows from technology commercialization

I = Development and industrialization cost required for technology commercialization

σ = Volatility of NPV

n = term of the license
r_f = Risk-free interest rate

Assuming for the sake of simplicity no further investment after product commercialization and constant annual sales over the licensing period, based on the previous description of the economic structure of a patent license, the NPV can be expressed as follows:

$$NPV = \left[S\left(1 - opc\% - r\%\right)\right] a_{n\neg i} \qquad [2]$$

Where:
S = Annual sales from the licensed patent
$opc\%$ = Incidence of operating costs on sales
$r\%$ = Royalty rate
$a_{n\neg i}$ = Rent factor for n years and discount rate i
i = discount rate (different from r_f)

Based on the proposed model of valuation (expressions [1] and [2]), F positively depends on NPV and then it is affected by the NPV determinants. Moreover, F is positively influenced by the license term (maturity of the option) and risk-free interest rate.

The most interesting role within ROT is, however, plaid by volatility. A fundamental prediction of ROT is that the option value increases with volatility. This is because the downside is limited (premium paid for the option), whereas the upside has not an upper bound (e.g., McGrath, 1997; Kulatilaka and Perotti, 1998; McGrath and Nerkar, 2004; Ziedonis, 2007). If the licensee uses a ROT based model to determine how much she should pay to enter the license, we should then expect F to increase with volatility.

In order to analyze the effect of volatility on F, we isolate the sources of uncertainty that affects volatility. We decompose uncertainty into the market and technological domains, as done by previous studies on real options (eg. MacMillan and McGrath, 2002; Oriani and Sobrero, 2007; Anand et al., 2007). Market uncertainty refers to the volatility of the potential demand for the patented technology. Technological uncertainty concerns the technical and manufacturing performance and feasibility of the patented technology (Huchzermeier and Loch, 2001; Ziedonis, 2007). This uncertainty critically affects the commercial potential of the licensed technology.

Based on that, we expect the following:

Proposition 1. The initial fee of a patent license increases with the degree of market uncertainty

Proposition 2. The initial fee of a patent license increases with the degree of technological uncertainty

3. DATA AND VARIABLES

3.1 Sample and data sources

In order to address the aim of the paper we defined a research design based on license and patent data. For this purpose, as a result of a careful search process, we decided to rely on a database that seemed to better meet our requirements of analysis. We referred to the proprietary Intellectual Property database that has been developed by the Financial Valuation Group (FVG)[1] with the aim to conduct empirical research on intellectual property. This database is a compilation of intellectual property transactions gleaned from publicly available documents. Three primary criteria have been employed by FVG to select the transactions into the database: 1) each license had to involve the exchange of an IPR explicitly; 2) the transaction had been closed; 3) a certain payment structure was agreed upon by the parties, even if those monetary amounts were not disclosed (Financial Valuation Group, 2007). As such, this database records approximately 3,000 licensing agreements concluded from the 1970s to the present, including approximately 40 fields of information regarding such transactions. The dataset mainly includes US organizations. The information provided encompasses document sources, transaction dates, the names of the licensor and the licensee, their SIC and NAICS codes, the type of agreement, the number and the ID number(s) of the patent(s) licensed, a brief synopsis of the transaction, and a detailed description of the remuneration structure.

Since our analysis focuses on patent licenses, we excluded all licenses regarding IPRs different from patents (e.g. trademarks), coming out with an initial dataset of 1,048 licensing agreements, including both technology and patent licenses, for the period 1970-2001. Starting from this sample, we needed al those licenses that disclosed both the details of the remuneration scheme and the number o the patent(s) involved. We then decided to adopt the following two criteria to select the transactions for our final sample: 1) the license had to report the ID-number of the underlying patent(s); 2) the license remuneration structure had to be disclosed and include the payment of an initial fee. This selection criteria decreases our data set to 137 licenses. The main reason of this undesirable cut of the number of licenses is that, due to the strategic relevance and competition sensitivity of licenses, the parties involved very often require a confidential treatment for most of the information included in such contract.

For each license in the new sample, we downloaded the original document from the SEC online website and from the proprietary Thompson Research Dataset in order to clearly identify the patents involved in the transaction. We also retrieved all patent documents from the publicly available sources of patent information (USPTO, Google Patent Search and Freepatentsonline). At the end we had a sample of 449

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[1] **The Financial Valuation Group (FVG)** is one of the leading business valuation consulting and litigation service firms in North America. (http://www.fvginternational.com/index.html, accessed June 2007).

patents pertaining to 137 licenses. Data for these patents were gathered from the original patent documents and from the NBER database (see Hall, Jaffe and Trajtenberg, 2002). Finally, we gathered information on licensors and licensees from proprietary or publicly available data sources (among others, Thomson Research, Compustat and Datastream) and on market data at the industry level from the STAN database released by the OECD.

We finally needed to drop those licenses involving firms whose information about their sectors or their characteristics was not available. At the end we reached a final sample of 106 patent licenses. Table 1 and 2 show the distribution of these transactions per year and industry at the 2digit-SIC level.

--- Insert Table 1 and Table 2 about here ---

3.2. Variables and model specification

Dependent variable

According to the model proposed, we needed the *initial licensing fee* as dependent variable, which we considered analogous to the premium paid by the licensee to buy a call option. To do so, we relied upon the data on the license remuneration structures. When the licensing contract is signed, the licensee is normally required to make an up-front payment, generally in the form of cash payment due within the first days of the license life. It represents the first "use it or lose it" clause in any licensing agreement. From the point of view of the licensor, she requires this payment as a proof of the licensee's commitment in the deal. From the point of view of the licensee, instead, it should reflect the amount of money (premium) she is willing to pay in order to buy the option to develop and commercialize the innovation protected by licensed patents. The measure of the amount of the initial fee paid in U.S. dollars by the licensee is available at the level of each licensing contract examined in this study. Since this variable does not follow a normal distribution, as required by the OLS regression model, we took the natural logarithm of the values in order to achieve an approximation of this distribution.

Independent variables

In order to analyze the impact of volatility on the option value of patent licenses, we decomposed uncertainty into the market and technological domains, as done by previous studies (eg. MacMillan and McGrath, 2002; Oriani and Sobrero, 2007; Anand et al., 2007).

Market uncertainty refers to the potential demand for the licensed technology. An often used measured of market uncertainty is the volatility of the expected demand for the technology underlying the patent license. Thus, consistently with previous research (e.g., Folta and O'Brien, 2004), we measured such variable as the standard deviation of the market growth rate from year *t*-3 to year *t* (the year of the license).[2] In doing so, we encountered two different problems related to the choice of the countries and the industries the market volatility refer to. First, since licensee is allowed to exploit the licensed patents in different territories, under the territorial restrictions clause included in the license, we had to account for the volatility of the expected demand in all these territories. However, for few licenses we were not able to know the exact number of countries involved, so we decided to collect data referring only to the U.S. market, since patents in our sample are granted by the USPTO and thus are in force at least in the U.S. The second problem concerned the choice of the industry. For the sake of simplicity, we decided to refer to the licensee's industry, as identified by the NAICS code or corresponding ISIC code, by collecting information at the 3-digit level. In this way we did not take into account any diversification effect pursued by the licensee. Indeed, licensed product might be sold in markets different from the licensee market.

Technological uncertainty is related to the technical and manufacturing feasibility of the patented technology, which ultimately affects its commercial potential (Huchzermerier and Loch, 2001; Ziedonis, 2007). This may depend on how much distant the licensed technology is from the commercialization stage. Accordingly, following previous studies (Lanjouw and Shankerman, 2001; Ziedonis; 2007), we measured this variable using the number of backward citations contained in the USPTO patents to previous USPTO patents. Each patent cites previous patent that represent the stat of the art at the moment of the patent grant. The number of backward citations is a measure of the newness of the patented technology. The idea is that when there is less prior art to be cited, there is higher technological uncertainty and the commercial potential of the technology is higher (Ziedonis, 2007).

In order to get this information, we merged our dataset with the NBER dataset that collects data on USPTO patents from January 1, 1963 through December 30, 2002 (see Hall et al., 2002, for a detailed description of the database). Since technological uncertainty increases when the number of backward citations decreases, we calculated our measure of technological uncertainty multiplying the number of backward citations by -1. When the license involved the exchange of more than one patent, we calculated the mean of this variable in order to account for the average technological uncertainty associated to the overall set of patents licensed.

Control variables

The most relevant negotiation issue that rises before the conclusion of a license refers to the level of the royalty rate the licensee will be required to pay to the licensor at each anniversary of the license. The common base for the calculation of the annual royalties is the annual amount of net sales regarding the licensed products. According to our model (expression [2]), this variable negatively affects the initial licensing fee since it reduces the NPV of the license. We measured such a variable as the percentage royalty rate reported in each licensing agreement. As anticipated earlier, besides royalties, another form of

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[2] We also calculated the standard deviation over a longer period (4 and 5 years), but the results did not substantially change.

value payments due to the licensor is represented by the *milestone payments* that are fixed cash payments due upon the crossing of some milestone events. They could negatively impact on the price the licensee agrees to pay for the option since they reduce the flexibility of the licensee in the use of the license. We then calculate a dummy equal to 1 if milestone payments are due and 0 otherwise.

We also control for *term of the license* that affect positively the value of the patent for the licensee since a longer license allows her to increase the profits from the licensed patents (Parr and Sullivan, 1996). The term or duration of license is computed as the residual number of years the license is in force.

We also account for the effect played by the growth rate of industry. According to Fosfuri (2004), an increasing market growth may dump the rent dissipation effect for the licensor – the propensity to license out her technologies would be greater, other things being equal - since the competition in that market would be less fierce. From the point of view of the licensee this means that she would be more prone to pay a greater amount of money for an option that gives her the chance to face a lower competition and thus to better exploit the licensed patents. We control for this variable by calculating the growth rate of industry output for a period of time ranging from year t-3 to year t.

Moreover, since some licenses include more than one patent, we include a measure of *license scope* calculated as the number of the patents involved in the transactions.[3] Another important measure that could affect the value of the license is its *geographic scope*. It refers to the number of national territories in which the licensee is allowed to exploit the licensed patents. The computation of this measure left us to handle an important issue. Since geographic scope of license is strictly tied to the patent family size[4] (number of jurisdictions in which the patent is in force) this required us to take into account both. By comparing them, we decided to take the maximum value between the family size of the licensed patents and the geographic scope of the license because this value may reflect better the overall market potential of the license.

In order to account for the appropriability regime and the effectiveness of patent protection and transactions (Kim and Vonortas, 2006), we adopted the distinction between "complex" and "discrete" product industries made by Cohen, Nelson and Walsh (2000). According to the authors, patent licenses should more effective in industries characterized by a discrete technology. In particular, following Cohen and colleagues (2000), we defined a dummy equal to 1 if the licensee´s 2-digit SIC is equal to or above 35 and 0 if the SIC is below.

The value of patent licenses should also be affected by the *exclusive* clause. Exclusive license allows the licensee to exploit the licensed technologies without bearing the competition of other licensees in the market. Its effect on the initial fee is not clear *a priori*. In fact, the traditional view of patent licensing holds that licensee firms prefers to an exclusive license to get the maximum outcome from the licensed patent (Parr and Sullivan, 1996). Everyone can agree on saying that competition will be lower and than the

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[3] The fact that the licensee includes more than one patent may not imply that these patents can be exploited separately depending on the licensee convenience. It may depend on the fact that licensed products are more or less complex and therefore more or less difficult to be commercialized.

[4] For the computation of this value we relied on the procedure used by Hall, Thoma and Torrisi (2006)

exclusive licensee can take advantage of the overall market potential associated to the licensed product. Nevertheless, more recently some authors have pointed out that licensee firms might want to be licensed openly in order to "…prevent, or at least retard, the commercial development of inventions in a particular area" (Agrawal and Garlappi, 2007: 2). This is the case of firms whishing to sponsor particular laboratories – research institution and university- that require to be licensed on a non-exclusive basis only in order to purposely affect the incentives of other – competitive- firms to embark on technological trajectories that are not favourable to them. We control for this effect including a dummy equal to 1 and 0 otherwise.

Studies on patent valuation based on patent data (e.g. Trajtenberg, 1990; Harhoff, Scherer and Vopel, 1999; Reitzig, 2002, 2004) have shown that the value of a patent, in terms of its technological importance and quality, can be proxied by the *number of forward citations* the target patent has received since its grant to date. Since this is a relative measure of such value, depending on how far is the time of its grant from our point of observation, we control for this value by counting the number of citations received till the date of the license. As already anticipated, since some licenses involve more than one patent, we calculate the mean value of this variable. Finally, we accounted for the influence of the identity and nature of the licensor on the initial fee building two dummy variables. The first one is equal to 1 if the licensor is a non-profit organization – University, University or Public Research Fundations –, 0 otherwise. The second variable is 1 if she is an individual (generally, the inventor), 0 otherwise.

3.3 Descriptive statistics and correlations

In Table 3 we report descriptive statistics for each variables included in the equation we estimated. Some interesting points are worth being mentioned. First, the scope of license that reflects the number of patents involved in each transaction sets its mean at around 3. This value is relatively low if compared to the maximum that is 39. This would mean that the majority of licenses imply the exchange of very few patents, generally only one. The distribution is considerably right skewed. Second, the values associated to the term of the license are also very interesting. They show that the average duration of a license is 15 years. Patvalu priorlic captures the number of citations received by the licensed patents until the time of license conclusion – this measure would represent the value of patent as perceived by the licensee. A standard deviation of 16 suggests that licensed patents differ very much in their perceived value. The most valued patent indeed records 113 citations against 0 citation of the less-cited patent ever. The same reasoning applies also for our independent variable called TechUncert that exhibits substantial dispersion ranging from 0 to 213. Again, since this variable reflects the newness of patented technologies, in terms of citation made to other previous patents – this measure assess the distance of the patented technology from the prior state of art- these values suggest that licensed patents differ very much in their radicalness.

--- Insert Table 3 about here ---

Table 4 shows bivariate correlations among all variables included in the regression analysis. From the analysis of Table 4 no serious problems of multicollinearity emerge.

--- Insert Table 4 about here ---

4. RESULTS

In Table 5 we report the results of the OLS regression of the log of the initial licensing fee on the uncertainty variables and the other control variables. In model 1 we introduce all the independent variables, with the exception of market and technological uncertainty, which are included in model 2.

--- Insert Table 5 about here ---

Model 1 shows that several characteristics of the licensing contracts significantly affect the initial licensing fee. As expected, the initial fee is negatively related to the royalty rate and positively related to the number of licensed patents (license scope) and the license term. A higher market growth rate also determines a higher licensing fee (the coefficient is positive and statistically significant at the 10% level). The presence of milestone payments significantly reduces the initial fee, presumably because it limits the licensee's flexibility and it increases her future outlays. Moreover, exclusive licenses have lower initial fees (the coefficient is negative, -.817, and statistically significant at the 5% level). This result is consistent with the recent insights provided by some authors (Agrawal and Garlappi, 2007) suggesting that under certain circumstances firms may even require to be licensed on a non-exclusive basis and then may attribute more value to non-exclusive patent licenses instead of exclusive ones. It is also interesting to notice that the licensing fee required by non-academic institutions and individuals are significantly lower than the those required by firms. While in the latter case this effect can be explained by a lower negotiating power, in the case of non-academic institutions it can be due to the fact that they have the main goal of diffusing the technology rather than making economic profits on it (Ziedonis, 2007). Finally, the number of citations received by the patent at the licensing date does not seem to matter. The same is true for the nature of technology (the coefficient of the variable 'complex' is not significantly different from zero).

In model 2 we introduce the variables of market and technological uncertainty. As predicted by our propositions 1 and 2, they both have a positive and statistically significant effect (at the 5% level of confidence) on the initial licensing fee. This means that, consistently with ROT, the licensees is available to pay a higher price to enter a licensing contract when the downstream market is more volatile and the technological potential of the patented innovation is higher. No remarkable change are observed in the coefficients of the other variables (only the coefficient of milestone payments looses significance at the conventional level of 10%).

5. CONCLUSIONS

As competition pace is increasing and products are becoming more and more complex relying on a greater number of separately patentable elements, the need to increase the efficiency of markets for technology becomes essential. One way to do so is to promote an improvement in the accuracy of any valuation attempts through the provision of "reliable valuation benchmarks" for patent transactions (Rivette and Kline, 2000: 62). Although there is still an undesirable lack of valuation models, several insights have been provided by the developments of ROT. Since patents are characterized by uncertain returns and flexibility of use, the adoption of ROT to assess their value seems to be very suitable. Furthermore, recent work has looked with a growing interest at the increasing amount of information provided by the market-based patent licensing agreements (e.g., Ziedonis (2007).

Following this line of reasoning, the aim of this paper has been to explore the use of ROT for patent evaluation within licensing agreements. Accordingly, we have argued that the initial fee paid by the licensee to sign the licensing agreement can be considered analogous to the premium paid to buy a call option in the financial markets. The licensing agreements, in fact, provides the license with the right (option), but not the obligation, to develop and commercialize the technology protected by the patent. Based on this framework, we predicted that the initial licensing fee should increase with the degree of technological and market uncertainty affecting the transaction.

Empirically, we defined a research design based on patent and license data. We analyzed a sample of 106 licensing agreements. The results of our regression model supported our predictions. Both market and technological uncertainty positively affect the initial licensing fee. This result suggests that the licensee recognizes an option value in the license and she is available to pay more to enter the contract when uncertainty is greater. In fact, in presence of higher uncertainty, her upside potential gain is higher whereas her downside is still limited to the payment of the initial fee. This result supports the use of ROT based model in evaluating patents within licensing agreements.

We have, however, to acknowledge an important limitation of the paper. We are not able to measure all the variables that should be used in a closed option valuation formula. The level of detail required, for example, to determine the strike price (investment for industrialization and commercialization) or the NPV does not allow to calculate these variables for a broad and cross-industry database. Therefore, we have decided not to estimate a closed option valuation formula, but to test the presence of a real option logic in the valuation of the license. Indeed, this is a limitation shared by all the empirical studies trying to test ROT (Lander and Pinches, 1998; Adner and Levinthal, 2004). Notwithstanding that, we believe that our study can encourage new work on the application of ROT to patent valuation.

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TABLE 1
Distribution of Licenses per year

Year	Freq.	Percent	Cum.
1990	1	1	0.94
1991	2	1.89	2.83
1992	4	3.77	6.60
1993	8	7.55	14.15
1994	7	6.60	20.75
1995	18	16.98	37.74
1996	25	23.58	61.32
1997	28	26.42	87.74
1998	6	5.66	93.40
1999	5	4.72	98.11
2000	2	1.89	100.00
Total	106	100.00	

TABLE 2
Distribution of Licenses per industry

dig2sic	Freq.	Percent	Cum.
12	2	1.89	1.89
20	1	0.94	2.83
22	1	0.94	3.77
26	2	1.89	5.66
28	25	23.58	29.25
30	2	1.89	31.13
32	1	0.94	32.08
33	3	2.83	34.91
35	7	6.60	41.51
36	13	12.26	53.77
37	3	2.83	56.60
38	28	26.42	83.02
39	2	1.89	84.91
49	2	1.89	86.79
50	1	0.94	87.74
67	2	1.89	89.62
73	6	5.66	95.28
80	2	1.89	97.17
87	3	2.83	100.00
Total	106	100.00	

TABLE 3
Descriptive Statistics of Variables

	Mean	S.D.	Min	Max
Upfront	12,6365	2,344	8,0064	18,7134
Royalty	0,0293	0,0314	0	0,12
Scope	3,283	5,8971	1	39
Term	15,3236	6,3564	1	40
Patvalue priorlic	7,8453	16,0986	0	113
Milestpayms	0,1132	0,3184	0	1
Excl	0,6415	0,4818	0	1
Nonprof	0,066	0,2495	0	1
Indiv	0,1604	0,3687	0	1
Growthrate	5,9416	7,8395	-53,89	20,3
Geograph	3,5377	5,5792	1	31
Complex	0,5566	0,4991	0	1
MarketUncert	5,0337	11,7143	0,1866	104,265
TechUncert	15,0626	27,7489	0	213,5128

TABLE 4
Variables Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Upfront	1													
2	Royalty	-0,485	1												
3	Scope	0,2519	-0,1244	1											
4	Term	0,1643	-0,1125	0,1176	1										
5	Patvalue priorlic	0,0857	-0,0735	0,0125	-0,2318	1									
6	Milestpayms	-0,156	0,0361	-0,0122	0,0288	0,0292	1								
7	Excl	-0,3056	0,1792	-0,0746	0,2114	-0,2378	0,205	1							
8	Nonprof	-0,2339	0,1271	-0,0387	0,1725	-0,1203	0,1448	0,1988	1						
9	Indiv	-0,3203	0,075	-0,1437	0,0264	-0,1201	-0,1562	0,1123	-0,1162	1					
10	Growthrate	-0,0003	0,1234	-0,436	-0,0402	-0,0203	0,0503	0,0108	0,0344	0,003	1				
11	Geograph	0,1483	-0,0539	0,6093	0,1595	-0,0305	-0,0024	-0,1047	-0,0189	-0,126	-0,273	1			
12	Complex	-0,0897	0,0601	-0,1123	-0,0243	0,1678	0,0792	-0,0336	0,0079	0,131	0,0406	0,0351	1		
13	MarketUncert	0,1429	0,0842	0,2141	0,135	0,2227	-0,0715	-0,0281	-0,0436	0,056	-0,2377	0,1828	0,0727	1	
14	TechUncert	0,0659	-0,1154	0,7262	0,0898	0,0003	-0,019	-0,0678	-0,0538	-0,053	-0,4159	0,5724	-0,105	0,2064	1

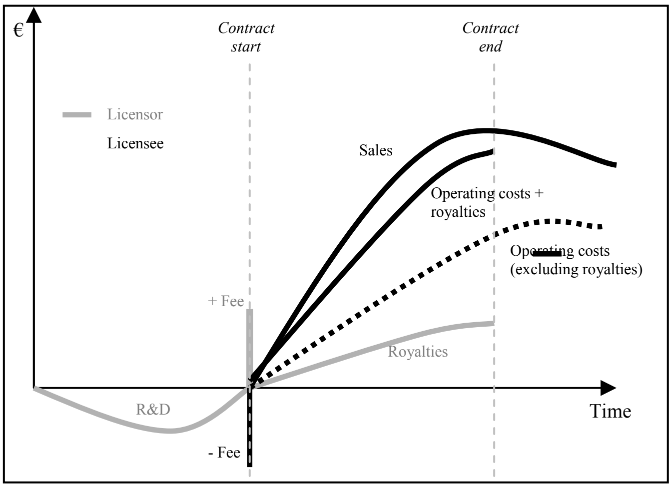
TABLE 5
Results. Dependent variable: log (initial licensing fee)

	Model 1		**Model 2**	
Royalty rate	-27,96	***	-30,58	***
	[5.86]		[5.73]	
License scope	.084	**	.130	***
	[.041]		[.046]	
License term	.072	**	.057	*
	[.030]		[.029]	
Forward citations	.001		-.006	
	[.011]		[.011]	
Milestone payments	-1.008	*	-.900	
	[.579]		[.559]	
Exclusive	-.817	**	-.818	**
	[.405]		[.390]	
Non-profit institution	-1,864	**	-1,831	**
	[.743]		[.715]	
Individual licensor	-1,898	***	-1,887	***
	[.507]		[.492]	
Market growth rate	.045		.046	
	[.025]	*	[.025]	
Geographic extension	-.022		-.004	
	[.041]		[.040]	
Complex technology	-.011		-.081	
	[.368]		[.356]	
Market Uncertainty			.036	**
			[.016]	
Technological Uncertainty			.020	**
			[.009]	
Constant	12,94	***	13,24	***
	[.63]		[.61]	
N	106		106	
r2	.475		.525	
r2_a	.414		.457	

*: p<.1, **: p<.05, ***: p<.01

FIGURE 1

Figure 1. The payment structure of a patent licensing contract



Source: Granstrand (1999)

German University Patenting and Licensing: Does Policy Matter?

Paper submitted to 2nd Annual Conference of the EPIP Association 2007

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Abstract

This paper presents work in progress to a broader research programme on German and European universities' technology transfer activities. We investigate the effects of the German Employee Invention Act (2002) by comparing the patenting behaviour of universities over three distinct time periods before and after the law is introduced to find out whether it constitutes a discernible change in university patenting. In a second model we take a closer look on the institutional determinants of university-to-industry technology transfer under the new law. In the two periods prior the new law the age of the first patent significantly influences the total number of patents significantly; this effect vanishes in the third period, where only the number of patents filed in earlier time periods does have a significant effect. These results suggest that the new law was able to disturb existing path dependencies but still patent experience plays a key role in university-to-industry technology transfer.

1. A Model of University-Industry-Technology-Transfer

Our research programme investigates the early stage (2002-2006) of German university technology transfer under the new law to explore a) the effects of the changed law of university patenting and licensing behaviour and b) the effects of regional, institutional, and organisational determinants on the effectiveness of university-to-industry technology transfer (UITT). We aim to contribute to the broader strand of technology transfer literature by firstly augmenting the international empirical evidence on UITT and secondly by integrating existing knowledge about university patenting and licensing on institutional, organisational and individual level (Phan and Siegel 2006).

The measurement of technology transfer and its effectiveness is a complex business. Not only the term ‘technology’ has to be defined, but also the transfer process delineated and measurement categories have to be chosen (Bozeman 2000). This paper is a first step to a broader research programme on German and European universities’ technology transfer activities; therefore our analysis of UITT is restricted to the effects of the new Employee Invention Act on patenting activities of German Universities. This allows a simple definition of technology (everything that is patentable) as well as the deduction of a simplified linear two step model of the technology transfer process (Friedman and Silberman 2003). Following the findings of Siegel et al. (2003) that invention disclosures are the most important input for UITT as they represent the known pool of transferable technology, the first step covers the process from invention disclosure to patent; the second step covers the process from patent to licence and so crosses the university-industry boundary. This approach allows us to use the number of licences as a simple measure of UITT effectiveness[1,2], because the generation of additional income is the strongest incentive for universities to get involved in technology transfer (Thursby, Jensen and Thursby 2001). We acknowledge the fact that this simplified process-model might not be able to capture the whole context and complexity of university-to-industry knowledge transfer.

According to Carlsson and Fridh (2002) the effectiveness of UITT cannot be described by simplistic input (invention disclosure) -output (patents, licences) -models but is influenced by characteristics of regional, institutional, organisational and individual contexts (Phan and Siegel 2006) which are summarised in Figure 1.

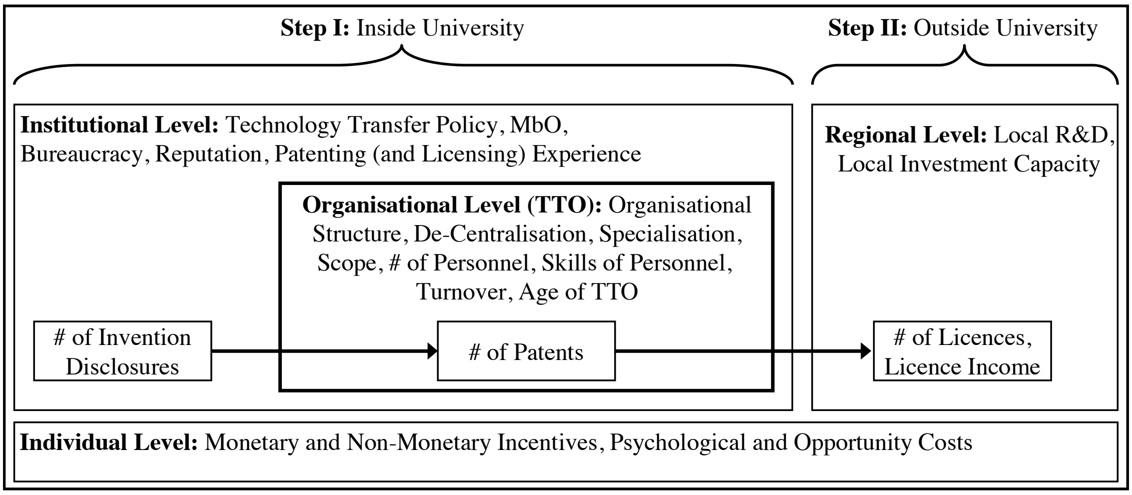

Figure 1: A Model of University-to-Industry Technology Transfer

On a regional level the effectiveness of technology transfer depends on the industry's absorptive capacity for innovation in terms of ability to invest in new technologies and the presence of high-tech firms that create demand for technological spillovers (Carlsson and Fridh 2002; Siegel et al. 2003; Chapple et al. 2005; for Germany see Audretsch et al. 2006, Audretsch and Lehmann 2005a,b).

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[1] This is especially true for the case of German universities as related mechanisms of technology transfer e.g. holding equity positions in private start-up companies (or trading patents, licences or consulting for equity) are forbidden under federal law.

[2] While licences are a measure for technology transfer, patents indicate the existence of transferable knowledge.

The institutional layer of the model is described by the policy of a university and its departments. UITT tends to be more effective if universities actively promote a policy of technology transfer that is documented in the universities' mission statement and in MbO-agreements with the TTO, and if the bureaucratic position (e.g. reporting structures, hierarchical level of TTO Director) of the TTOs allows to influence university policy (Carlsson and Fridh 2002; Friedman and Silberman 2003). At the same time the presence of medical, engineering and scientific faculties is a sine qua non for effective UITT because these departments generate almost all university patents (Jensen, Thursby and Jensen 2001). Furthermore Sine et al. (2003) have shown that universities with better overall reputation are likely to licence more technologies to firms than predicted by their past performance.

The organisation and personnel of the TTO as a moderator of technology transfer effectiveness has received most attention in the literature so far. Bercovitz et al. (2001) have shown the implications of different organisational structures of TTOs concerning information-processing capacity, coordination capability, and incentive alignments and its impacts on technology transfer effectiveness. In a similar way Carlsson and Fridh (2002) discuss the effects of scope of activities and structures. Debackere and Veugelers (2005) suggest central services to support patenting and licensing, as well as specialised and decentralised units that actively stimulate patentable research within the academic departments. Furthermore, both they and others (Carlsson and Fridh 2002; Siegel et al 2003; Chapple et al. 2005) postulate a balanced skill-set of managers, scientists, and lawyers within the TTO personnel. Another important element of patenting and licensing success is the experience and learning of the TTO and the employee turnover (Mowery et al 2002; Siegel et al. 2003).

The individual level of technology transfer effectiveness is solely concerned with the incentives for stakeholders (Friedman and Silberman 2003; Markman et al. 2004). The most discussed aspect is the income-split between inventor and university and its effect on invention disclosures. Moreover there are non-monetary incentives influencing the amount of invention disclosures. Like others, we assume that the likeliness of an invention disclosure is closely related to the expected opportunity and psychological costs an inventor has to bear when starting to participate in UITT. These costs are likely to rise with administrative and communicative barriers (physical distance to TTO, poor expertise of TTO-officers) and are likely to diminish with active support and service by the TTO, a university history of effective patenting and licensing ("success stories"), a competitive but supportive peer group, and scientific reputation from disclosing respectively patenting inventions (Owen-Smith and Powell 2001; Siegel et al. 2003).

After this introduction the paper is organized as follows. Chapter 2 focuses on our current interest within our research programme explained above. Chapter 3 explains the research method employed, and the fourth chapter presents the empirical results. The paper concludes with a short summary.

2. The Effect of the Employee Invention Act on the Institutional Level of University-to-Industry Technology Transfer

The enactment of the so called Bayh-Dole-Act (1980) in the United States allowed universities to patent and licence inventions resulting from federally funded research and simultaneously obliged researchers to disclose all inventions made under a federally sponsored program. This policy created strong incentives to generate licensing income through technology transfer along with the need to efficiently protect intellectual property rights and to coordinate patenting and licensing activities: US universities set up Technology Transfer Offices (henceforth TTOs) as organisational entities to achieve these tasks. (e. g. Bozeman 2000; Agrawal 2001; Bercovitz et al. 2001; Goldfarb et al. 2003)

At about the same time German universities began to take share in patents[3] from faculty researchers and to establish their own TTOs[4] to institutionalise their technology transfer efforts. However incentives similar to the Bayh-Dole-Act did not exist in Germany: German faculty members were free to patent privately with neither the need to disclose their inventions nor to share licensing income with their department or university (Schimank 1988).

Without the strong incentive structure of their US counterparts German TTOs were not understood as university-agents with the task to protect and market intellectual property rights (Coupe 2003; Hoppe and Ozdenoren 2001), but as mediators and industry-relations departments of the university administration. This was done mainly for the benefit of the industry that was trying to utilise new basic technologies to escape the economic recession of the eighties. The main activities of these TTOs were to participate in trade fairs, to collaborate with chambers of commerce or to host round tables for companies and researchers. Accordingly, the TTO's success was measured by ratio of "mediations per employee and year" (Schimank 1988). The history and policy background of German and other Continental-European TTOs (see Goldfarb and Henrekson 2003 for Sweden;

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[3] The first patent held by a German university dates back to 1960. In the period from 1960 to 1982 university-held patents accumulate to 18. In 1983 the yearly patenting activity rose to 22 patents and has risen ever since to an average of 591 patents per year in the period of 2002-2006.

[4] The first German TTO was established in 1976. By 1988 25 of the 56 (West-)German universities had established their own TTO.

Saragossi and Pottelsberghe 2003 for Belgium) significantly differs from the ones of the US and UK TTOs that are subject to investigation in the existing literature.

The situation of German University Patenting changes in 2002 with the amendment of the Employee Invention Act. From now on university researchers are obliged to disclose their inventions to their universities and the universities are entitled to patent and licence these inventions (ArbNErfG 2002). This law was meant to create incentives for universities and university-inventors alike to patent new knowledge from research. Inventors are guaranteed a 30% share of the gross income, while universities have to bear the costs of the patenting process, but are entitled to hold and exploit the intellectual property rights by licensing patents to the industry. This policy change aimed to establish incentives and structures comparable to those in the United States.

The patenting of inventions by universities can be viewed as a preliminary stage of university-to-industry technology transfer: By patenting, new knowledge emerging from research is codified and made transferable. Therefore, patents cannot be used to measure technology transfer itself, but as an indicator for the pool of transferable knowledge. The bigger this pool the more likely UITT will occur. The size of this knowledge-pool is determined by a) the resources contributing to and the barriers impeding the production of new knowledge, and by b) the patenting history of the university (e.g. learning effects).

Resources and Barriers

In university-research the most critical resource is human capital. The accumulation of scientists and engineers in a university implies a higher quantity of available human capital, which is linked to the ability of new knowledge creation

(Powers 2003). Zucker, Darby and Armstrong (2002) have argued that “star” scientists are more able to capture rents from their intellectual capital, and Gregorio and Shane (2003) have shown that an increase in university-wide quality rankings leads to disproportional higher technology transfer. Therefore the *faculty quality* should have a positive impact on UITT. These aspects are moderated by the overall orientation of the university. Obviously a university without medical, science or engineering faculties will not be able to generate large amounts of patentable knowledge (cf. Jensen, Thursby and Jensen 2001).

Another critical resource is third party funding of research activities. It is a well known fact that average budgets for research of public universities are small. Hence research funding by third parties like the industry or national research funds is a prerequisite for knowledge creation and at the same time an indicator for faculty quality. Blumenthal et al (1996) have shown for Life Sciences, that industry funding generates more transferable knowledge (patent applications) and technology transfer (new products). Despite the growing industry interest in supporting basic research, national research agencies, scientific foundations, and EU-research framework programmes are the largest sponsors of research. These providers of research funding are more and more concerned about the spending of their money and the expected value of their money in terms of transferable knowledge (O’Shea et al 2005).

The efficient use of these human and financial resources can be hindered by numerous organisational and individual factors (see above). Amongst those the *teaching workload* of researchers could be seen as one very influential aspect. Every German professor and almost every associate professor and research assistant is expected to spend significant time teaching; pure research posts are relatively rare.

Obviously, the more working hours have to be invested in teaching efforts, the less time remains for research activities.

Furthermore the TTO can be more or less efficient in supporting research staff (e.g. discover patentable knowledge, disclose inventions…) and in fulfilling their task as property rights agents (e.g. deciding to patent or not). Thus, the organisation of technology transfer within the university itself influences the creation of transferable knowledge.

Path Dependence and Experience

It is very likely that a “history and tradition” (O’Shea et al 2005) of patenting leads to more patents in the future. Over time a university accumulates relevant knowledge about the patentability of certain types of technologies and innovations, about patenting processes, marketing, and licences. Phan and Siegel (2006) note the importance of this kind of path dependence: As university bureaucracy and policies tend to evolve slowly, early technology transfer experience creates more technology transfer in subsequent periods (O’Shea et al 2005).

In this paper we are going to investigate the effects of the new law by comparing the patenting behaviour of German universities over three distinct time periods before and after the law is introduced to find out whether or not it constitutes a discernible change in the incentive structure: The early stage (T_1) of patent activities of German universities starting with the beginning accumulation of patents in 1981 and ending in 1993 after the reunification of the Federal Republic of Germany (FRG, “West”-Germany) and the German Democratic Republic (GDR, “East”-Germany), the post-reunification-era (T_2) from 1994 to 2001 which is characterised by a significant rise in patenting activity and the years from 2002 to 2006 after the introduction of the new Employee Invention Act. The patenting behaviour of German universities of the three periods is illustrated in Table 1.

Table 1
Descriptive variables on the patenting activity of German universities

	1981 – 1993	1994-2001	2002-2006	1981-2006
Average age of first Patent	-	-	-	12,1 years
Number of *new* patents	908	1844	2953	5705
Number of universities holding patents	25	44	66	66
Number of *new* patents per university	36,32	41,91	44,74	86,44

We will restrict our analysis to the institutional level of our model to explore the factors of new knowledge production mentioned above, and more importantly the effects of institutional learning and exogenous shocks on technology transfer, independently of other possible influences. Therefore we treat the organisational level as a black box, because the universities' TTO cannot influence the resources and barriers and will most likely not be the cause but a symptom of institutional learning. Likewise we expect the regional level to have impact on licences, but not on patents (we still control for regional GDP). The partial model is visualised in Figure 2.

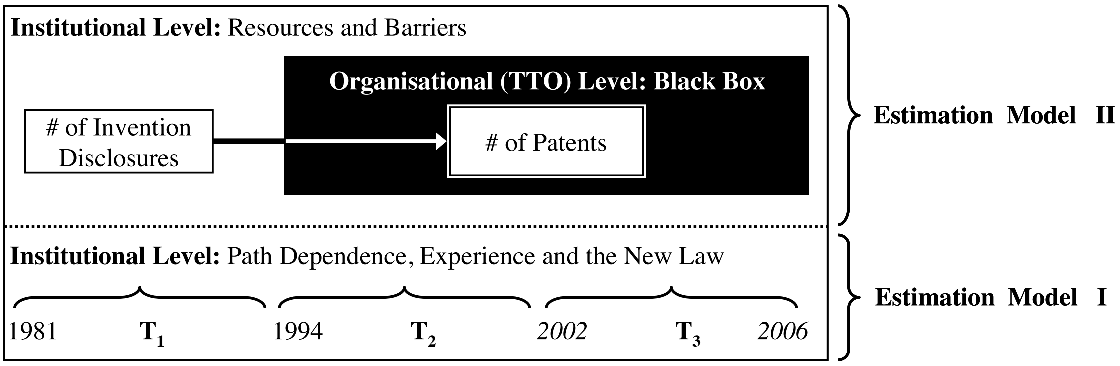

Figure 2: The Institutional Level of University Patents

3. Research Method

To test the impact of the new patent law incorporated in 2002 on patent activities of universities we estimate two different models. The first model describes the link of the number of patents per university to patent experience and changes within this linkage over three distinct time periods. The second model explores further institutional determinants of the number of patents for the third time period.

Sample and data collection

For this study we gathered data from all German universities through database and survey sources. Our input data comes from the internet database of the German Patent Office (www.depatisnet.org), the Federal Office of Statistics (www.destatis.de) and from the research ranking of the Centre for University Development (www.che.de). Additional data was collected from university websites.

The selected sample (66 of 73 universities) consists of all universities that report (on their website) to have institutionalised their technology transfer efforts (via TTO) and have filed at least one patent since 1960. The seven universities that are excluded are mainly universities of fine arts, philosophy, and social sciences, as well as one private[5] medical school (Universitaet Witten-Herdecke) and the University of Bamberg (no patents filed).

Endogenous variable

The number of patents held by each university is used as an endogenous variable in both models. This information is collected from the German Patent Office.

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[5] 70 of 73 German universities are publicly funded; in contrast to the US. There are no land grant institutions or privately funded universities.

We use this variable as the endogenous variable to show whether or not, and how the number of patents is influenced by time periods and by individual characteristics of the universities. In the first model we use three different count numbers for three different time periods: First, the period from 1981 to 1993, the period from 1994 to 2001 and the third period covers the time period after the new patent law from 2001 to 2006.

Exogenous variable (model I)

The exogenous variable (also obtained from the German Patent Office) is the age, measured in years, of the first patent registered. As mentioned earlier, this time span may serve as a proxy for both, path dependences and experience. Furthermore, this variable also shows that the respective university invested in patent activities some time ago. Like said, only 44 of the total of 66 public universities have one or more patents before 2001.

Control variables (model I and II)

The next two variables are introduced to measure the main focus of a university. In particular, we control for the existence of a medical school and engineering faculties. These variables were gathered via the universities websites. Finally we control whether the university is located in the former GDR or, nowadays, in East-Germany.

Additional variables (model II)

As discussed above the number of patents filed might be moderated by the TTO-effectiveness and so we use the number of invention disclosures to the TTO as an additional measure of transferable knowledge. We assume that the number of inventions is shaped by the resources and barriers discussed. A three year average (2002-2004) of the amount of research of grants from industry and public research institutions, the number of publications and citations in SSCI-Journals are used as a proxy for faculty quality. These variables are taken from the 2006 research ranking by the Centre for University Development. The teaching workload is measured by the ratio of students per professor. The number of students and professors per university was obtained through the Federal Office of Statistics. Additionally, we control for the relative performance of the regional industry (GDP per capita), as it might influence third party funding and the number of invention disclosures. Regional GDP and the number of inhabitants were obtained from the Federal Office of Statistics.

Model specification for model I

As the number of patents is not normally distributed and is also censored at the left side (22 universities have no registered patents before 2001), we could apply negative binomial regressions method to estimate the coefficients or a left censored Tobit model. To make the results more comparable, we show the results from the negative binomial regressions instead of the Tobit model, since the endogenous variable is only left censored in the first time period from 1981 to 1993. In particular, we estimate the following model:

$$\text{(I)} \qquad \#\text{patents}(\mathrm{T}=1{,}2{,}3) = const. + \beta_1(age\ of\ the\ first\ patent) + \beta_2(medical\,school) \\ + \beta_3(engineering\ \ faculties) + \beta_4(East - Germany) + \varepsilon$$

with T_1 (1981-1993), T_2 (1994-2001) and T_3 (2002-2006). The results are presented in table 2.

However, to control whether or not the incentives of the patent law are strong enough, we use a second regression model. In this model we also include the number of patents registered in the period before to control for learning and experience instead of new incentives. Thus we use the same regression model as shown above (I), but in addition we include the number of patents from the previous period(s) as new exogenous variables. The results are shown in table 3.

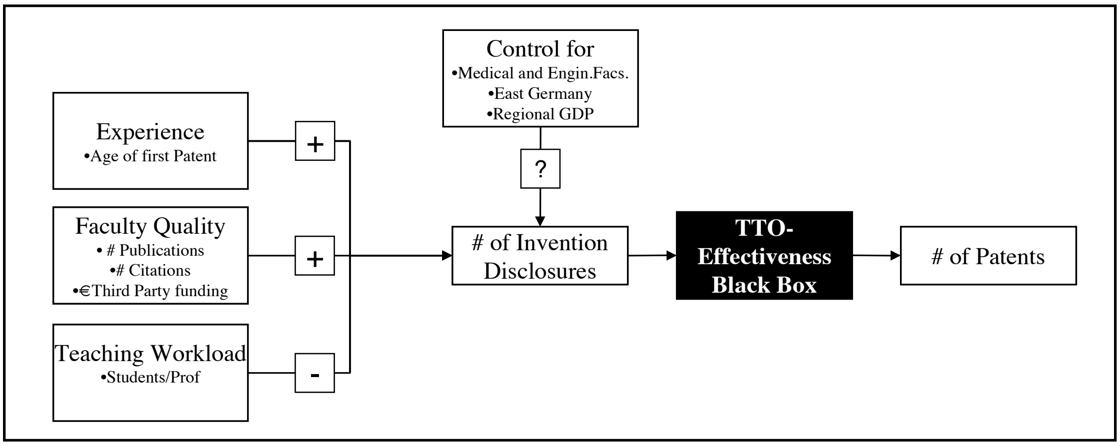

Figure 3: Patents as a Function of Invention Disclosures

Model specification for model II

We use a 2SLS approach to estimate whether or not, and how the number of patents is shaped by determinants others than the type of university. Unfortunately, so far we only have some information about the research and teaching activities for the last time period. We assume that (see Figure 3) the number of patents registered is a function of the number of inventions, and that the number of inventions is positively shaped by the institutional patent *experience* and *faculty quality* and is negatively shaped by the *teaching workload* of the professors. In particular, we estimate the following model:

$$\text{(II)}\quad \#\,patents = const. + \beta_1(\#\,inventions) + \beta_2(medical\ school) + \beta_3(engineering\ faculties) + \beta_4(East - Germany) + \varepsilon$$

and

$$\#\,inventions = f(age\ of\ the\ first\ patent;\ \#\,publications\ per\ year;\ \#\,citations\ per\ year;\ €research\ grants;\ students\ per\ professor, regional\ GDP) + \gamma$$

The results of the Two-Stage Least Square Estimations are shown in Table 4.

4. Empirical Results

Table two shows the results from the first regression. In the first column, the number of patents from the time period 1981 - 1993 is taken as the endogenous variable. During this period, public universities either show patent activities or not. There was no public pressure or pressure from the government for high research activities like the patents or publications in high quality journals in West Germany. During this period it is the individual incentive of each researcher to publish or to invest time in patent activities.

The results show that the age of the first patent enters the regression significantly. We also tested for non-linear effects, including a square term, but the coefficient of the square term remains insignificant in all regressions, so we dropped it. The positive and highly significant effect of this coefficient could be interpreted in two ways. Firstly, it shows that there are some universities which are engaged in patent activities while others are not. Secondly, the number of patents is increasing with the age of the first patent due to learning effects or self selection effects for researchers which are interested in patent activities. The number of patents is also driven by the type of universities, namely that medical schools are the main drivers of patents of public universities.

Another interesting result is the high and significant effect of the dummy variable indicating that a university is located in East Germany. In the former GDR, the government heavily invested in two prestigious universities: The famous Charité located in Berlin (nowadays part of the Humboldt University) and the Technical University of Dresden. While the Charité is focused on the medical sector, the Technical University of Dresden has its focus on engineering. Both universities have a higher number of patents compared to universities in West Germany during that time.

In the second column, the number of patents from the time period 1994 to 2001 is taken as the endogenous variable. As before, the age of the first patent enters the regression significantly. However the absolute value of the coefficient is lower compared to the first regression and also the z-value is lower.

Table 2

Results of the Negative Binomial Estimation: What explains patent registration of public universities?

The endogenous variable is the number of patents registered for each university. [a] *Estimated regression coefficients,* [b] *Absolute (z)-values in parentheses,* $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

N=66	1981 – 1993	1994 -2001	2002 - 2006
Age of the First Patent (years)	0.3421 (5.86) ***	0.1508 (4.83) ***	0.0351 (1.61)
Medical School	1.4231 (2.72) ***	0.800 (2.10) **	0.531 (1.89) *
Engineering Faculties	-0.1923 (1.64) *	0.1617 (1.87) *	0.165 (2.10) **
East Germany	1.0952 (1.96) **	0.490 (0.95)	-0.573 (1.80) *
Constant	-5.262 (5,17) ***	-0.057 (0.13)	2.844 (9.16) ***
LogPseudoLL	-107.109	-233.599	-310.607

The third column shows the results for the period from 2002 to 2006. The positive and significant effect of the age of the first patent disappears. As not shown in table 2, all public universities published at least one patent since 2001. Also the number of all patents increased dramatically. However, medical and engineering faculties seem to be the most important source of new patents, although the absolute value of the coefficients decreases over time. The dummy variable indicating the location in the former GDR changed the sign and now enters the regression negatively and significant.

Summing up, the results show that the new patent law changed the innovation behaviour of public universities as measured by the number of patents. Interestingly, the age of the first patent enters the regression positive and significantly in the periods before 2002. Thus, some universities were very active in patenting new innovations while others were not.

Next, we run the same regressions as above but include the number of patents in the previous periods as exogenous variables.

Table 3

Results of the Negative Binomial Estimation (Robust): What explains patent registration of public universities?

The endogenous variable is the number of patents registered for each university. [a] *Estimated regression coefficients,* [b] *Absolute (z)-values in parentheses,* $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

N=66	1981 – 1993	1994-2001	2002-2006
Patents 1981 - 1993	-	-0.0011 (1.36)	0.0067 (6.06) ***
Patents 1994 - 2001	-	-	0.0021 (4.00) ***
Age of the first patent (years)	0.3421 (5.86) ***	0.1543 (4.65) ***	0.0019 (0.09)
Medical School	1.423 (2.72) ***	0.8143 (2.12) **	0.0991 (0.35)
Engineering Faculties	-0.1923 (1.64) *	0.1586 (1.82) *	0.0422 (0.68)
East Germany	1.085 (1.96) **	0.4896 (0.94)	-0.7815 (3.03) ***
Constant	-5.263 (5.17) ***	-0.089 (0.20)	3.404 (10.66) ***
LogPseudoLL	-107.1091	-233.499	-304.241

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While the first column of table 3 shows the same results as in table 2, the second regression does not really differ from the one presented before in table 2, although the number of patents is included. The third regression provides new results. Now, the number of patents of the previous periods enters the regressions significantly. Their positive sign clearly indicates that those universities with a higher patent activity in the past show a higher patent activity in the period after the new law came into effect.

Table 4
Results of the 2SLS Regression: Institutional Determinants of patent registrations

The endogenous variables are the number of inventions (instrumented) and the number of patents registered for each university in the period 2002-2006. [a] *Estimated regression coefficients,* [b] *Absolute (z)-values in parentheses,* $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

Method	OLS	OLS	2SLS
Endogenous Variable (N=66)	Inv. Discl. 02 - 04	Patents 02 - 06	Patents. Inv. Discl.
Invention Disclosures 02-04	-	0.3675 (1.93)*	0.7009 (3.65)***
Patents 1981 - 2001	0.1839 (3.07)***	0.2708 (3.11)***	Instrument
Age of the First Patent	-1.5094 (-1.84)*	-1.6322 (-1.45)	Instrument
Publications / Year	-0.1657 (-0.28)	0.0947 (1.21)	Instrument
Citations / Year	0.0068 (1.03)	-0.0126 (-1.42)	Instrument
€Research Grants / Year	0.0008 (1.55)	-0.0004 (-0.56)	Instrument
Students / Professor	-0.0795 (-0.40)	-0.7772 (-2.96)***	Instrument
Regional GDP/Capita	-0.3547 (-0.87)	0.1799 (0.33)	Instrument
Medical School	19.9655 (1.29)	12.3366 (0.59)	-8.8747 (-0.45)
Engineering Faculties	-6.2128 (-1.59)	12.9765 (2.43)**	13.7475 (3.29)***
East Germany	-5.5384 (-0.40)	0.0605 (0.00)	24.7481 (1.35)
Constant	48.9756 (2.48)**	55.8654 (2.01)**	-21.1385 (-1.32)
R^2	0.7479	0.5778	0.3113

Table 4 present the results from the 2SLS regression. While the variables for institutional experience and teaching workload show the assumed positive and negative correlations to the number of patents, the results for faculty quality variables are mixed. On the one hand the number of publications enters the regression positive; on the other hand the number of citations is significant and negative. One possible explanation of this puzzling finding could be the often discussed trade-off between publishing and patenting of innovations. The number of citations may depend heavily on the significance of the published knowledge, while the number of publications may depend on additional factors (networks, research paradigm…). So one could imagine that researchers who publish more significant knowledge - as measured by citations – invest less effort into patenting. Furthermore the significant value in table 4 indicates that the number of inventions is a function of inventions.

5. Summary

The results clearly show that the amendment of the Employee changed the innovation behaviour of public universities as measured by the number of patents. In earlier periods the number of new patents can be explained by path dependence: the older the patenting experience the more likely new patents will be filed. The 2002 amendment of the Employee Invention Act interrupted this pattern and so the age-effect is replaced by the prior patenting experience of the universities. The most patents still emerge from the most experienced universities. The new law as a "prescribed incentive" seems to work.

Obviously learning and experience can not be the only determinants of university patenting or technology transfer. As shown above there are additional factors like the faculty quality, teaching workload and invention disclosures. The relation between inventions and patents is moderated by the organisation of technology transfer within the university, in our further research we intend to open this black box.

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Title: Evaluating Alternative IP Mechanisms in Genomic Research

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Abstract:

This paper offers a preliminary review of alternative intellectual property (IP) approaches for results produced by the MORGEN project team which is funded by Genome Canada and centered at the British Columbia Cancer Agency in Vancouver, B.C. The aim of the paper is to summarize results from our research thus far, as they relate to our broader study of the relationship between open science, commercialization and technology transfer offices. The role of technology transfer offices (TTO) is central to our analysis and is viewed as a key factor in implementing Genome Canada policies and principles associated with IP and commercialization.

Keywords: Commercialization, open science, technology transfer

Acknowledgements: W. Maurice Young Center for Applied Ethics, University of British Columbia, Genome Canada, Genome British Columbia

Evaluating Alternative IP Mechanisms in Genomic Research

Authors: Cheryl Power, Ed Levy, Emily Marden, Ben Warren

1. Introduction

This paper offers a preliminary review of alternative intellectual property (IP) approaches for results produced by the MORGEN[1] project team which is funded by Genome Canada and centered at the British Columbia Cancer Agency (BCCA) in Vancouver, B.C. The aim of the paper is to summarize results from our research thus far, as they relate to our broader study of the relationship between open science, commercialization and technology transfer offices. The role of technology transfer offices (TTO) is central to our analysis and is viewed as a key factor in implementing Genome Canada policies and principles associated with IP and commercialization.

2. MORGEN – The Science Project

MORGEN is an extension of a previous project, the Mouse Atlas of Gene Expression[2], which was also funded by Genome Canada. Funding by Genome Canada is administered by regional units, Genome British Columbia in this case. Among the objectives of the MORGEN team is the characterization of gene regulatory mechanisms governing organogenesis with a special focus on the heart, liver and pancreas. The project is involved in upstream, basic research with possible relevance to human development and disease. The MORGEN team has identified potential useful results of research to include, organogenesis genes/products, biological targets, and tools for Stem cell therapies.

3. Balancing the Agenda

One challenge associated with Genome Canada funded work relates to the maintenance of open science norms. Open science refers generally to the effort to widely disseminate results and preserve broader access to science research or results, according to accepted academic practices of releasing them to the public domain. The challenge is to maintain these norms while also honoring the mandate of Genome Canada, which is to ensure that the results of research, such as discoveries contributing to medical products, benefit Canadians. This mandate is generally understood to involve patenting at some stage of research. Thus Genome Canada recipients are in a complex situation in which they are expected to deposit research to the public domain but need to remain mindful of intellectual property and commercialization. Hence, in some measure aims and values clash, and the sophistication of patenting and licensing techniques is becoming increasingly important.

Genome Canada has a number of policies and statements regarding their own perspective on this somewhat complex situation. The publicly funded Genome Canada requires matching funds.[3] That is, Genome Canada funds only half the cost of a project, while the other half must come from other agencies or from private sector donors.[4] This practice is clearly part of an effort to enlist potential commercial partners in research. Genome Canada explicitly asks in its funding Guidelines/Evaluation Criteria, for details surrounding social and economic benefit to Canada, including a proposal for the transfer, dissemination, use or commercialization of proposed research results.[5] Some of Genome Canada's communications have explicitly stated that they don't require commercialization, while simultaneously stating that Genome Canada intends to promote translation to useful applications.[6] Ultimately, the conflicted goals of open science in academia and commercialization make entertaining the alternatives in genomics a challenging and intricate process, and provide an impetus for entertaining licensing schemes that integrate private and public players.

4. Theoretical Background

The controversies over gene patenting provide a backdrop to the current calls for alternative IP mechanisms and efforts to engage in practices consistent with open science. After 1980, legislation such as the Bayh-Dole Act in the United States gave universities, small businesses and non profits control over inventions resulting from federal funding.[7] Subsequently, patenting of genomics became more prevalent, and U.S. Supreme Court decisions, such as *Diamond v. Chakrabarty* [8]*,* that deemed some human made microorganisms patentable, furthered such practices. Tensions over the appropriate extent of gene patenting erupted into the public forum with the well publicized race between the public human genome project and the private company Celera to complete the map of the human genome. One of the most coherent expressions of concern over these developments came in a seminal 1998 paper[9], by Heller and Eisenberg, expressing concern over a "Tragedy of the Anticommons".[10] Little empirical support has emerged for this theory in subsequent years. However, the publication of the paper marked renewed interest in alternative forms of IP. It is in this context that we consider creative licensing strategies used in concert with patenting, open source and patent pools for upstream genomics research.

5. Legal Framework

When funding is awarded by Genome Canada to a researcher in British Columbia, collaborative agreements are set up involving researcher's institutions, researchers, and Genome BC. According to those agreements, control of IP is placed entirely in the hands of researchers and their institutions, although an advisory body, including members appointed by Genome BC, is appointed. In effect then, a primary voice in making decisions about IP is the TTO of the researchers' institution. As such, we have focused our research efforts on governance considerations in technology transfer. Technology Transfer Office's are the center of the process of patenting and commercialization and an essential consideration as we seek to identify the role of alternative IP mechanisms on the research continuum.

The Canadian innovation landscape is a system of devolved governance. There is no parallel in Canada to the U.S. Bayh-Dohl Act of 1980, and there is uncertainty associated with Canada's policy framework. So what policy measures do affect how Genome Canada research moves through the university system? Canadian universities implement a variety of practices. Policies may specify whether the ownership of IP is with the university or its researchers and resultantly whether the investigator must disclose.[11] There are some universities where there are no explicit policies, hence IP ownership is with "creator" and these individuals are thus "not required to disclose IP to their university". [12] The difference in IP approaches make specific collaborative endeavors and partnerships with industry challenging.[13] For example, in B.C., the ownership policies of three lower mainland institutions have differing assignments of ownership and disclosures and serve as a good case example for use in further empirical work.[14]

Although Genome Canada places management of IP squarely in the hands of researchers and their institutions, Genome Canada policies nevertheless can impact management of research results. The Genome Canada funded Principle Investigators (PIs) must sign a Data Release policy when accepting their funding contract.[15] This policy allows both open release, for instance on a publicly available website, and patenting as forms of data release. The Genome Canada commercialization policy is far from definitive. One example of guidelines to commercialize is those from Genome BC on which no signature is required.[16] Hence, in an attempt at balancing these competing policies a variety of alternatives are under consideration.

The IPPRG[17] has been considering how Open Source mechanisms could be adequately developed given the governance context. Innovative legal mechanisms are necessary as we seek solutions to balance the conflicting agendas present in governing policies and procedures. In the MORGEN context, we consider the current implementation of a Creative Commons license.[18] However, we are interested in other models such as the CAMBIA BIOS type license.[19] A version of this could be used if research results are already of a patentable quality. Some academics have raised objections based on the technical and logistical difficulties such license development would create. Further work on the issue is needed.

6. Interim conclusions on alternative intellectual property and upstream genomics research

Against this contextual and legal backdrop our group is trying to identify alternative IP mechanisms that might preserve open science while acknowledging Genome Canada and Genome BC as well as technology transfer office aims. As all are aware, alternative forms of IP are varied and complex. Part of the research process is the development of actual positions on alternatives with which we can move forward. On March 9, 2007, in Vancouver, British Columbia the IPPRG held a interdisciplinary workshop, which allowed for development of research themes within this project.[20]

First of all, emerging from this workshop were overwhelming indications that within a public health care system there is a need to separate health care delivery issues from upstream research issues. Genome Canada mandates delivery of products of benefit to Canadians. Therefore, key to the alternatives debate, is when and where an alternative mechanism encourages access for upstream researchers while at the same time promotes investment towards development of a commercially viable product.

This includes the need for further investigation into research management protocols that adequately represent the public interest. We found that the commercialization policy and the academic norms are hard to balance in practice making the academic – industry interface challenging to manage. This is true particularly when we look at the legislative landscape against which we must perform basic and applied research. The worm model described by the C. Elegans[21] project was a specific, perhaps special place that ignores the commercialization drive and yet thrives in its methods of dissemination and collaboration.

Secondly, we found that TTOs play a critical role in determining what types of IP are applied, and what science is the subject matter of IP protections. Part of our research is looking into how alternative IP may actually be explored and implemented by TTOs. While the consistency of patent protections within TTO's is largely related to the commercial values associated with the research, the use of alternative licensing schemes may be a key factor in the actual translation of research with public/private interests attached. Central to this debate then, is the effectiveness of traditional TTO patenting and licensing models in transferring viable products to market. Given that there are many more good ideas than there are funds for product development alternatives are of primary consideration when we talk about translating research from bench to bedside.

Finally, in the MORGEN context, one can see the complexity of the situation and observe that the type of technology and the timing are critical to thinking through IP. Illustrative is the debate that continues to surround the use of an open source model for genomics. Of interest, is MORGEN's implementation of a license based on open source philosophies. That is, a Creative Commons license requiring attribution of the original source of website data, if the data is used or published. It is far harder than many imagined, to develop an open source licensing approach that would be the basis for further development. One possibility is the development of open source models such as CAMBIA BIOS license, allowing for a merger of public and private interests in furthering commercial potential and the public good. Notable of course is the difficulty in creating such a license. In essence, it would be very demanding of time and resources. In fact, it may be too complex and an Open Source type approach may have to depend on other arrangements, for instance, encouraging development of IP governance, and community building as the proper course of action. For instance, the formation of collaborative networks involving both academics and industry partners can allow for a creative melding of interests in IP models. The question remains as to how and when TTO's would implement such approaches.

7. Points to Consider

In keeping with the mission of the GE^{3}LS[22] program, the next focus of our project is to identify some of the conditions that have hindered or promoted the successful evolution from research to commercialization. The study will begin with institutions in British Columbia.[23] We aim to understand how TTOs might use IP depending on the type of technology, the stage and potential ends of the research, as well as the funding source. Hence, the following are key points when making decisions about alternative IP.

7.1. Type of technology

An important element for evaluating the applicability of alternative IP is the type of technology or research result under consideration. In patenting, alternative choices will be affected by the nature of the invention, whether it is the basic genomic data, intermediate research tools, genomics databases, (associated software and hardware) or late stage platform technologies such as therapeutics, diagnostics, and vaccines. The type of IP to be applied will also vary on a determination of whether a technology has human, environmental or other industrial applications.

7.2. The stage of research

The stage of research is also a relevant consideration in making IP decisions. With earlier stage research, there is less ability to determine its economic value and a less stringent form of IP is likely applied. As such, timeline divisions are necessary as we separate the upstream research issues from the health-care and delivery side issues. Essentially, timelines are important in research commercialization as we consider how, and when, research results are openly released or protected by some form of IP.

7.3. Technology research funding

Finally, the nature and source of research funding can shape the potential application of IP and commercialization by universities, collaborators, and funding agencies. Some of this will depend on contractual terms relating to IP that are tied to funding, as well as how the funding is set up and who is making the IP decisions. When funding comes through a combination of sources the scenario is more complex and the challenge is again in balancing conflicting aims.

8. Conclusions: What are MORGENS alternatives?

The IPPRG at the CAE – UBC is considering a number of alternative mechanisms to full scale traditional patenting. Concepts under consideration include patent pools, public domain, open source and mixed mechanisms. It may be productive for early stage research consortia such as MORGEN to focus their efforts on unique forms of IP application, specifically tailored to individual research products. While seemingly complex, the development of individual licensing schemes based on open source philosophies may be possible. Our research will continue to evaluate whether a TTO would implement such approaches. The conflicting agendas remain and the development of novel schemes to license, not necessarily for free, but in order to preserve access warrants consideration. Following from this, the role of the TTO in future IP management may be best served by industry/academic pooling aiming for an accessible end product. In sum, the actual applications of alternative IP mechanisms are case specific. Given the wide variety of products seen in such a project, varying from basic facts and data, databases, and certain forms of software and hardware, licensing schemas will vary as will the type of IP appropriate to a variety of products. Mechanisms may include a unique blend of the philosophies of copyright, patenting, and contract law, a diversification of ideals, aiming ultimately for balance and a productive social and commercial end.

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[3] Tim Caulfield, "Commentary: An Independent Voice?: Conflicts of Interest and Research on Ethical, Legal and Social Issues, (2005) 13 Health Law Review 114-116 at 114.

[4] Paul Wells, "Our Mad Scientists" *Macleans*, (23 June 2005); Library of Parliament, Online: http:www.parl.gc.ca/information/library/prbpubs/prb0627-e.htm

[5] Online: <http://www.genomecanada.ca/xresearchers/competitions/c3/GuidelinesFinal.pdf> Retrieved Aug 24,2007

[6] As per Genome Canada website, "Genome Canada is not a venture capital firm. We do have an objective to ensure the translation of research into useful applications, but we are not required to promote commercialization and generate financial returns on our investments." Online:http://positionpapers.genomecanada.ca/en/information-meeting-february-2007.php#q01 Retrieved Aug 10, 2007

[7] Online: <http://en.wikipedia.org/wiki/Bayh-Dole_Act>

[8] *Diamond v Chakrabarty,* 447 U.S. 303 (1980)

[9] M.A.Heller & R.S. Eisenberg, "Can Patents Deter Innovation? The Anticommons in Biomedical Research" 280 Science, 698 – 701.

[10] See Caulfield et. al. for further discussion of issues, Caulfield, T. et. al, "Evidence and anecdotes: An analysis of human gene patenting controversies"(2006) 24 Nature Biotechnology, 1091-1094 at 1091.

[11] Afshin, Afshari, " The Academic Technology Transfer Landscape in Canada and Quebec in Particular" (The 7th National Congress on Government-University-Industry Relations for National Development, Iran, December 2003) at 12. Online: < http://www.ea-sciencepark.org.ir/PDF%20Files/44.pdf> Retrieved Aug 2007.

[12] ***Ibid*** at 12.

[13] Andrew F. Christie et. al, Commonwealth Department of Education, Science & Training, Commonwealth of Australia, 2003, *Analysis of the Legal Framework for Patent Ownership In Publicly Funded Research Institutions* (Commonwealth of Australia, 2003) at 53.

[14] For example, differing policies on ownership are summarized as follows: UBC UILO-All staff, students, faculty, or anyone associated with the university who used university funds or facilities must assign all rights to the university → the university can then chose to reassign back to the inventor, undertake patenting and licensing arrangements through UILO; Online:< http://www.universitycounsel.ubc.ca/policies/policy88.pdf>

; SFU-There is no obligation to assign rights to the university. There is, however, an option to do so. All patents belong to the inventor unless there is a written contract that says otherwise; Online: <http://www.sfu.ca/uilo/researchers/property.html>
BCCA- All inventions by BCCA/BCCF employees or associates which result from the use of BCCA/BCCF funds or facilities are the property of the BCCA/BCCF unless there is a prior arrangement with the sponsor of the research. The BCCA can then chose to keep the rights or assign them to the inventor or a university; Online:< http://www.bccancer.bc.ca/NR/rdonlyres/E60548DF-7BBC-4DA1-8166-656B9EE9BF2C/3102/BCCAPatentPolicy.pdf> Retrieved Aug 30, 2007.

[15] Genome Canada Data Release Policy, Online:<http://www.genomecanada.ca/xcorporate/policies/DataReleasePolicy.pdf> Retrieved Aug 30, 2007.

[16] Among the principles that are iterated in *Genome BC's Ethical Principles for Commercialization of Genome BC funded research*, is the obtaining of patents where "strategically advisable" with the financial aid of GBC/GC; GBC funded institutions manage IP within their own and GBC guidelines; non-exclusive and exclusive licensing will be applied where "appropriate"; and IP that comes from GBC funded research "must be developed/commercialized for the maximum public good".

[17] Intellectual Property Policy & Research Group, Center for Applied Ethics, University of British Columbia

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Intellectual property strategy in publicly funded R&D centres – A comparison of university-based and company-based research centres

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August 2007

Abstract:

Recent thinking on open innovation and the knowledge-based economy have stressed the importance of external knowledge sources in stimulating innovation. Policy-makers have recognised this, establishing publicly funded Centres of R&D Excellence with the objective of stimulating industry-science links and localised innovation spillovers. Here, we examine the contrasting IP strategies of a group of eighteen university and company-based R&D centres supported by the same regional programme. Marked contrasts emerge between the IP strategies of the university-based and company-based centres suggesting the potential for very different types of knowledge spillovers from publicly-funded R&D centres in different types of organisations and a range of alternative policy approaches to the future funding of R&D centres.

Acknowledgements:

We are grateful to Invest Northern Ireland for funding the research on which this paper is based. We are grateful too for the time and kindness of staff in the Centres of Excellence during the period of this study. Interpretations and mistakes in the paper are those of the authors alone.

Key words: Public R&D, Intellectual Property, Ireland, Spillovers

Intellectual property strategy in publicly funded R&D centres– A comparison of university-based and company-based research centres

1. Introduction

Recent thinking on open innovation (Chesbrough, 2003), buiness eco-systems (Iansiti and Levien, 2004), and the knowledge-based economy (Cooke and Leydesdorff, 2006) stresses the importance of external knowledge sources in stimulating innovation. Policy-makers have recognised the importance of external knowledge by establishing publicly funded Centres of R&D Excellence with the objective of stimulating industry-science links and localised innovation spillovers (e.g. Feller, 2004; Debackere and Veugelers, 2005; Graversen et al., 2005)[i]. Underpinning the process of technology transfer is the management (i.e. identification, development and exploitation) of IP (Dietz and Bozeman, 2005). For firms, this enables value to be created and sustained. (Coriat and Orsi, 2002; Hanel, 2006). For universities, effective IP management can generate revenue through licenses and spin-out companies (Roper et al., 2004; Siegel et al., 2003; Lee and Win, 2004; and Gloet and Terziovski, 2004).

Our objective here is to explore differences between IP management in publicly funded research centres (PRCs) based in universities and firms and consider how these may influence technology transfer. Our study is based on a real-time monitoring exercise of IP management practices in a group of UK PRCs established since 2002. This localised, and detailed approach, complements the more abstract but broadly based analysis of Guellec and van Pottelsberghe (2004), for example, providing insights into the processes underlying local knowledge transfers. Our paper also helps to answer the need highlighted by Link and Siegel (2005) for more specific micro-evidence on the operation of technology transfer initiatives in different national and regional contexts.

The remainder of the paper is organised as follows. Section 2 outlines our conceptual approach and empirical propositions. Section 3 reviews the policy context for our empirical study, describes our data sources and profiles the PRCs in this study. Section 4 explores the IP management practices of these PRCs and Section 5 draws out key methodological and policy conclusions.

2. Literature and propositions

Our main interest is the contrasting IP regimes adopted by PRCs in the very different organisational settings represented by universities and firms. Inevitably, these IP regimes will reflect the strategic objectives of the organisations in which they are based (Bozeman, 2000), any ambiguities in these organisational objectives (e.g. Jarzabkowski, 2005), and the situation of the specific business unit or department in which the PRC operates.

In terms of university-based PRCs, for example, the historical norm has been the ‘open science’ model, where new knowledge is viewed as a public good and universities placed little priority on IP ownership. EU (2004) argues that this open science model is most effective in stimulating commercialisation where: *“the technology has far reaching implications and where the risks of mis-appropriation by private interests are detrimental to the public interest”* (p.11). The incentive structure in the open science model, suggests that PRCs are likely to adopt an essentially passive approach to IP development and exploitation, instead investing any available resources in additional research activity. Commercialisation then depends on the absorptive capacity of firms, i.e. their ability to identify, absorb and appropriate new technologies developed by PRCs (e.g. Zahra and George, 2002)[ii].

More recently, however, and most notably in US since the Bayh-Dole Act, universities and public research organisations have placed increasing emphasis on their *private* ownership of IP, and consequently adopted a more proactive role in IP development and exploitation. This gives rise to the 'licensing model' (EU, 2004). Here, PRCs engage in basic research, but are proactive, and devote resources to, the identification, development and exploitation of IP- generally through patents and licensing (Siegel et al., 2003; Lockett and Wright, 2005). EU (2004) argue that this approach can generate substantial benefits: *"It is estimated that at least half the new products based on university patents would not have been developed if the results had been put in the public domain without patent protection,"* (p.11)[iii].

Mowery et al. (2004) argue that the increased focus on commercialisation has, however: *"changed the research culture of US universities, leading to increased secrecy, less sharing of research results, and a shift in the focus of academic research away from fundamental towards more applied topics"* (p.1). In this 'innovation model', PRCs both adopt a proactive approach to IP development and exploitation *and* re-orient the type of R&D they are undertaking to bridge the gap between fundamental university research and its commercialisation. EU (2004) argue that the social benefits resulting from the adoption of the innovation model may be larger, and more regionally focused, than those from the licensing model: *"certain PROs have pioneered the implementation of the Innovation Model with conclusive evidence of success in terms of increased new company generation, enhanced relations with industry and licensing activity"* (p.11).

In addition to these three models of university-based PRCs we are also interested in company-based PRCs[iv]. Here, a potentially important distinction exists between PRCs located in locally-owned firms and those located in the local plants of MNEs. Research conducted by indigenous firms, for example, will tend to focus on building internal technological capabilities with results evident in terms of improvements in *"locally anchored technological capability and internationalization,"* (Kumar and Aggarwal, 2005, p.456). By contrast, the increasing globalisation of R&D is likely to mean that PRCs located in MNEs are part of an international R&D endeavour, and therefore the spatial distribution of the commercial benefits of R&D activity may be very different to that of the R&D activity itself (e.g. Reddy, 1997). One implication is that PRCs in locally-owned firms are more likely to need to devote internal resources to the development and exploitation of IP than MNE-based PRCs.

The organisational differences and contrasts between the types of R&D being conducted in these five types of PRC suggest our first proposition:

P1: IP strategy will differ between university and company-based PRCs.

We also anticipate:

> *P1a: IP strategy will differ between PRCs hosted in* locally-owned *and MNE firms; and,*
>
> *P1b: IP strategy will differ between university-based PRCs depending on which IP model they adopt.*

Implementing these strategies, however, focuses attention on the process of IP management (Hanel, 2006). Graversen et al. (2005), for example, suggest that the organisation and management of research centres is as vital to their success as the political and economic climate in which they operate. This suggests our second proposition:

> *P2: PRCs will implement incentives for the creation and protection of IP which reflect the nature of the host organisation and the IP model being adopted.*

As suggested earlier, however, different types of PRCs in different settings are likely to devote differing levels of resources to IP protection and development. PRCs in smaller firms, for example, may find it difficult to invest the level of resources necessary to protect their IP effectively and may adopt alternative commercial strategies to maintain their technological leadership. This suggests:

P3: Use of formal IP protection methods will depend on the organisational background of the PRC and is:

P3a: less likely among PRCs in locally-owned firms than those in MNEs; and,

P3b: more likely among PRCs adopting the innovation and licensing models than those adopting the open science model.

P4: PRCs will use specialist services to support their IP protection and exploitation strategies. Use of these services will reflect the nature of the host organisation and the IP model being adopted.

3. Data and methods

The research centres considered here were established in 2002 as part of the Centres of Excellence programme with support from Northern Ireland (NI) government, with the explicit objective of contributing to regional competitiveness[v]. Eight university and ten company-based centres were established as a result of a six month open call for proposals during 2001. Table 1 gives a brief overview of each centre. Managed by Invest NI- the regional development agency for NI- the programme received public funding of £34m (29.3 percent) matched by additional private sector funding of £82m over three years. As a result of the competitive nature of this programme, the centres' sectoral focus is diverse, with an under-representation of private services which accounted for 10.3 percent of total grant-aid to the company-based centres but 24.3 percent of BERD in NI in 2002 (DETI, 2003, p.10). In terms of manufacturing, pharmaceuticals was over-represented, accounting for around 12.3 percent of manufacturing BERD in the region in 2002 but around a third of the programme expenditure and grant-aid. Programme expenditure is also notably more capital intensive than R&D spending in general in NI, 29.6 percent compared to 7.6 percent, (DETI, 2003). This is not surprising given the infrastructural nature of the programme.

Data used in this paper comprises three main elements. First, each PRC completed a detailed email or postal questionnaire every four months between February 2004 and September 2006. This provided regular quantitative data on the level and type of R&D activity conducted by each PRC, its links to external partners and its commercialisation activities. An overall response rate of 75 percent was achieved. Second, in-depth face-to-face interviews were conducted with each PRC on an irregular basis to validate data being returned in their questionnaires and follow-up issues of particular interest. Finally, in mid-2006 we carried out a series of semi-structured interviews which focussed specifically on IP development and management. Sixteen of the eighteen PRCs in the programme (88 percent) participated in this round of interviews.

Drawing on these interviews, the broader organisational profile, the types of R&D undertaken and their patterns of dissemination we were able to classify the PRCs in terms of the models identified in Section 2. Classification of the company-based PRCs was relatively straight forward as the main differentiation was in terms of company ownership, i.e. whether the PRC was based in a locally-owned firm or the local plant of a MNE. Five company-based PRCs (CoE.9, 10, 15, 17 and 18) were based in locally-owned firms, while five (CoE.11, 12, 13, 14 and 16) were part of larger MNE operations (Table 1).

Classification of the university-based PRCs was more complex. The key distinctions between the models of university-based PRC were the types of R&D they were conducting and their approach to dissemination. As Table 1 shows, all of the university-based PRCs were conducting applied R&D as either a major or minor focus; similarly each PRC (with the exception of CoE.6) was carrying out some developmental research. Only four of the eight university-based PRCs were involved in basic R&D. Therefore the type of R&D undertaken on its own was a relatively poor predictor of the IP model being adopted. Considering the dissemination profile of the PRCs provided more discriminatory power, however. Specifically, we classified the average number of publications and presentations made per employee for each PRC between February 2004 and September 2006 (Table 2). A cluster analysis of the university-based PRCs' dissemination activity together with the extent to which they focussed on basic R&D generated three clusters. This identified four Open Source PRCs (CoE.3, 4, 7 and 8), which were involved in some basic R&D and had fairly low levels of publications and presentations. Two PRCs followed the Licensing Model (CoE.1 and 6), focusing on applied R&D and actively publishing and presenting their work. The two PRCs following the Innovation Model (CoE.2 and 5) focused on developmental R&D and had fairly low levels of publication and presentation activity.

4. Empirical results

4.1 IP strategy

Our discussions with the PRCs highlighted considerable differences in IP strategy between the company-based PRCs and those in universities but less clear differentiation within the group of university-based PRCs. Within the group of company-based PRCs, however, IP strategy did seem to reflect the characteristics of the host organisation with evident differences between locally-owned and MNE-based PRCs.

CoE.15 was relatively typical among locally-owned PRCs, in that the IP strategy was based largely on achieving speed to market. Patents were not seen as providing a huge commercial advantage, but were seen as a potential asset from an investor's point of view (Coriat and Orsi, 2002; Arai, 1999). The company's IP strategy was described as:

> "*partly being driven by our investors who would like more of an IP portfolio… Most of it is; we have a route to exploitation, if we have something, use it as quickly as possible.*"

For the MNE-based PRCs, however, IP strategy was more strongly related to longer-term concerns and IP codification and protection. CoE.12, for example, was concerned with ensuring the company was well placed to utilise future technologies (Roper et al., 2004), and claimed:

> *"We would be more interested in what we call our technology pipeline… If it does have patentability or some form of IP that is a bonus".*

Other MNE-based PRCs emphasised the importance of IP protection, although this also reflected the industry within which PRCs were operating:

> *"It's very critical that everything we develop has IP protection around it. That may be a new product, process, compound or just something new, but we always try to get patent protection on this, especially in our industry."*

As anticipated in P1a we therefore see a clear distinction between the IP strategies of PRCs based in locally-owned and MNE companies, with the latter more likely to engage in formal IP protection (e.g. Blackburn, 2003).

For the university PRCs, IP strategies emphasised knowledge creation and dissemination rather than achieving competitive advantage, reflecting the public good nature of much of their research. As CoE.7 put it:

> *"our main interest is being able to actually publish the work. If we can't publish the work then really we get absolutely no benefit from it."*

Some university PRCs were clearly more engaged in a commercialisation agenda, as CoE.3 explains:

> *"A key focus of the new vision within [the university] is a greater emphasis on knowledge exploitation, technology transfer and commercialisation. [CoE.3] is at the forefront of that."*

However, in the majority of cases where PRCs were engaging in IP exploitation, it was seen as secondary to winning new research grants. According to CoE.4:

> *"there would be a more determined effort to get research council type projects, but there is also a technology transfer type role."*

Other PRCs were seen as an intermediary step towards commercial activities. CoE.6 explained:

> *"The idea behind the Centre was not to do projects which would be immediately commercially viable, but to do projects which, if they work, would give you the basis of a project which would be commercially viable."*

Moreover, industrial links formed by the university-based PRCs through licensing agreements or consultancy work are often viewed as a means of gaining access to a company in order to pursue a particular research agenda. CoE.1 commented:

> *"Our strategy is really to use that model and the qualifications that we have been building up through the funding for the Centres of Excellence programme*

> *in order to get a foot in the door with some local companies and then to start pursuing some research agendas with those companies."*

PRCs following the innovation model, on the other hand were much more focused on the practical application of their research. As the original project proposal explains, the purpose of CoE.5 was to develop:

> *"environmental tools capable of being used to solve a wide range of environmental issues for industry."*

However, in an interview it was pointed out that the PRC's IP is not always commercialised, but often used within 'members companies' who help fund the Centre's research:

> *"our member companies are entitled to royalty-free access… if they are using the technology within their own companies. If they want to use a technology commercially then they have to negotiate a separate licensing agreement with us."*

As P1 suggests therefore we identify profound differences between the IP strategies of the company and university-based PRCs. For company-based PRCs codified IP is a primary source of competitive advantage; whilst for university-based PRCs commercialisation remains secondary to knowledge creation and dissemination.

We also find the anticipated differences (P1a) between the IP strategies of locally-owned and multinational PRCs. While there was some evidence that PRCs following the innovation model were more focused on the practical application of their research, we could identify no clear differentiation in IP strategies of the university PRCs, i.e. no clear support for P1b. This may reflect the limited extent to which the PRCs considered here have adopted the licensing model.

4.2 IP incentives

These contrasts in IP strategy are reflected in the practical steps taken by the different PRCs to develop and protect their IP. Both university and company-based PRCs provided incentives, encouraging staff to engage in IP identification and protection. In the university-based PRCs considered here any revenue from IP (e.g. royalties from licensing agreements) was split between the university, the researcher and the researcher's school or department. No such revenue sharing agreement was evident in the company-based PRCs although some companies, notably the MNEs (i.e. CoE.12, 13, 14 and 16), gave the inventor a bonus or patent award for any invention which the company went on to patent. These awards ranged from a token gesture of $1 in CoE.16 to sizable sums of $1,500 in CoE.13. CoE.12 also had a 'Hall of Fame' for employees with 10 patents; this included a $10,000 bonus.

As well as monetary incentives the PRCs were actively training staff on IP issues. According to CoE.14 this meant that the IP management process had become ingrained in company culture:

> "*I suppose you would say that's the culture within the company. In the engineering departments there would have been training on the process. Therefore team managers would be aware of it and should be encouraging the staff and reminding them of the process. There is also a policy document which is available on the intranet.*"

Training on IP issues was not limited to the company-based PRCs. As CoE.3 explains:

> *"[We] have seminars were people come and talk about IP and about patents and the patent process… The opportunity is there, but if I am being honest they are not terribly well attended. We run them and there might only be a dozen or so people would come along."*

In this sense we therefore find some support for P2 with both university and company-based PRCs having implemented HR practices which actively promote the development and identification of IP. The approaches to incentivising staff clearly differ, however, between company and university-based PRCs. Within the MNE-based PRCs especially- which employed more aggressive IP strategies than PRCs in locally-owned firms- there was a clear financial incentive structure, encouraging the identification and protection of IP. This was less evident in the locally-owned PRCs, which presumably have fewer resources to dedicate to such a scheme. In the university-based PRCs on the other hand incentives were contradictory to promotion criteria, reflecting a conflict in organisational objectives.

4.3 IP protection

In general, the company-based PRCs commercialised their IP internally. The level of protection sought by company PRCs and the formality of that protection depended on organisational objectives, available resources and the type of technology being developed, however. For the MNE-based PRCs IP protection was seen as a competitive strategy used to block imitation. Therefore more formal/ legal methods of protection were used. CoE.16, for example, commented:

> *"The IP really is to protect the product. Although it is an asset and it has commercial viability as a patent in itself. The reason we get it is to stop people coming in and copying our idea. So the patenting is really as a protective measure to ensure the idea cannot be genericised."*

In contrast the locally-owned firms appear to have fewer resources to devote to formal IP protection. As CoE.15 explained:

> *"You can spend an awful lot of time and waste a lot of talented people's time, chasing after something that is not there in the end... You really have to have something pretty good and then you have to defend it... and usually that involves a lot of technical people."*

Formal IP protection was not always appropriate for the type of technology being developed in the PRCs. According to CoE.12:

> *“The technologies that we develop from this site are impossible to reverse engineer from the finished product. Hence they wouldn’t be patented. They [patents] actually put that know-how into the field and once it’s out there it’s at risk from either being reverse engineered or misused.”*

Other organisational mechanisms were used by company-based PRCs to protect their IP. Few staff in the company-based PRCs, for example, gave papers at workshops or conferences. CoE.10 commented:

> *“We don’t actively go out to give papers these days. We would have given papers and we would have written papers in the journals of... technology in the past, but we don’t do that anymore. We are too close to the market in these things. The whole industry has become more commercial and secretive.”*

More specifically among the company-based PRCs, only CoE.15 published any working papers[vi], while all of the university-based PRCs submitted papers for publication.

The majority of university-based PRCs sought to patent their IP where possible and then either license out that IP to a third party or create a spin-out company. The choice of exploitation route was dependent on the route most appropriate for the technology developed and did not appear to be influenced by the model adopted by the PRC. CoE.6 and 8 engaged in both licensing and spin-out activity. CoE.6 explained the choice of exploitation route depends on the project:

> *"There are six major projects running in the Centre: one of them has got sufficiently far enough for us to say that this is definitely going to be a spin-out company; another one of them is in negotiations with relevant food companies, that one would probably go by way of either us providing a service for them or us just selling them the total rights. The other four: one of them seems to be working and will probably go through a patent and then try licensing the patent…One of them is just too early to say and the other two: one of them is almost certainly going to go down the patent route… and the other has taken up a lot of time and hasn't produced anything that we can definitely patent yet."*

However, some university-based PRCs voiced concerns about the cost of patenting, identifying this as a barrier to more rigorous IP protection strategies. One PRC claimed:

> *"It's such an expensive thing to do… You have to be restrictive and try to cherry pick which things to patent… For example, we may not be able to afford to take out a worldwide patent which leaves our IP vulnerable to being exploited."*

CoE.1 and 7 however did not commercially exploit their IP. In these PRCs the main output, in terms of IP, was the publication of papers. Both PRCs undertook commercial consultancy with the primary purpose of engaging companies in research activity which could lead to academic papers.

We therefore find considerable support for Proposition 3, with the majority of PRCs engaged to a greater or lesser extent with IP protection. Clear differences exist between the IP protection strategies of PRCs in multinational and locally-owned firms. The distinction between the university-based PRCs was less clear. This provides partial support for P3a.

4.4 Specialist services

IP protection in the university-based PRCs was carried out in conjunction with the university technology transfer office (TTO) which played a largely reactive role-responding when notified of discoveries with a potential commercial application. The extent to which the university-based PRCs involved the university's TTO in IP management, however, depended on the prior experience of the academic staff involved. Where academic staff were familiar with the patent process then the TTO was simply used to fulfil legal and administrative obligations. Less experienced academic staff tended to contact the TTO at a much earlier stage to seek advice regarding patentability and support throughout the patent process. Similarly if the academic involved had strong links to industry, or if there was an existing relationship with a particular company, then the TTO was only involved at a basic level, i.e. in the signing of contracts or non-disclosure agreements. If, on the other hand, the academic was not well connected they also used the TTO to identify potential licensing partners.

This difference in experience levels was reflected in the use of the TTO by the different types of university-based PRC. Staff working in open science PRCs tended to be less experienced in the patenting process and therefore tended to rely more heavily on the TTO from the initial identification of patentable IP right through to exploitation. CoE.4 detailed their involvement with the university TTOs:

> *"We identified that we had IP that was patentable and through the university we are getting that patent. That was actually done through [the TTO]. Then the ongoing exploitation of that IP is being done in consultation with [the TTO]."*

Where academics have technology transfer experience, they tended to be more involved in the transfer process, using the university TTO to a more limited extent, i.e. to fulfil administrative and legal requirements. This is highlighted by CoE.1 (a licensing PRC) who described their approach to IP management:

> *"What IP management we have, I have taken care of... I negotiated the licenses with an organisation in America… and then took the legal documents along to [the TTO]."*

In terms of IP management in the company-based PRCs, a clear difference emerges between PRCs in locally-owned firms and those which were part of MNEs. In the locally-owned PRCs, IP issues were internally driven, with staff within the PRC taking responsibility for IP identification and codification. CoE.15 explained their process:

> *"This isn't a large group of people so that kind of regular communication is daily. We don't formally sit down and do that, it kind of happens by osmosis."*

IP development and protection in the MNE PRCs involved a wider group of staff either internal to the firm (CoE.11, 12, 13 and 14) or involving external patent lawyers (CoE.16). In CoE.14, for example:

> *"[the Project Engineer for Design and Patents*] *would know all of the inventors… [and] would know if they have any new ideas. Then we have invention disclosure forms, which they would briefly fill in. It is just a rough description. We would time and date stamp that to give us proof of the creation date. We would get in touch with the company's patent lawyers at that stage…*
>
> *There would be some forum were those ideas are discussed and categorised… The way it works means that there is a central or focal point. The engineers know where to go if they have any intellectual property questions or technology questions. It is structured."*

We therefore find considerable support for P4 with all PRCs having access to specialist support services. Again the use of these services depended on the IP model adopted in the university-based PRCs and organisational context of the company-based PRCs.

5. Conclusion

Our data, drawn from a set of eighteen UK R&D centres funded through a single government programme, suggest some contrasts in IP strategy and management between university-based and company-based R&D centres despite their common funding source. To a lesser extent, however, we also observe differences within each group depending on the nature of the firm in which each R&D centre is located and the IP model adopted in university centres.

In terms of IP strategy, we find continuing differences between the IP strategies of company and university-based PRCs. For the company-based PRCs codified IP is a primary source of competitive advantage, which despite their public funding, restricts external dissemination and therefore any positive 'pure knowledge' externalities arising from knowledge transfer (e.g. Beugelsdijck and Cornet, 2001). Of course, IP gains to the firms involved in the programme may still generate private benefits to the organisation and rent-based spillovers as the firm with the PRC interacts with its customers and suppliers[vii]. For the university-based PRCs in our sample on the other hand, IP commercialisation remains secondary to knowledge creation and dissemination, with little clear difference between centres adopting different IP models. For the university-based PRCs therefore the public good aspect of their activities remains predominant, epitomised by extensive dissemination activities.

Therefore we found no evidence of the increasingly secretive culture which Mowery et al. (2004) identified in the US universities. This clearly creates the potential for pure knowledge spillovers. Although the potential for rent based spillovers, evident for the company-based PRCs, is less evident here. This contrast suggests the alternative patterns of regional spillovers which might stem from public funding of university and company-based PRCs: i.e. rent-based spillovers from company-based centres and knowledge spillovers from university-based centres.

What's more within the group of company-based PRCs organisational characteristics, such as size and ownership, did appear to influence their use of formal IP protection. With centres based in MNE's more likely to engage in formal IP protection than those in smaller locally-owned firms. This reflects the availability of resources.

Given the increasing importance of IPR (Hanel, 2006; Coriat and Orsi, 2002; Arai, 1999 and Allen, 2003) it was encouraging to find that all PRCs had clear and well defined IP ownership policies where IP created by the PRC was owned by the sponsoring organisation, thus protecting the organisations' investment in R&D and avoiding unnecessary legal disputes. In addition, many centres, including all of those based in universities, actively encouraged the creation and protection of IP by providing incentives or patent awards and staff training on IP issues. In all university-based PRCs the researcher was awarded a share of the royalties from licensing agreements. Most of the MNE-based PRCs gave inventors financial rewards for patent applications. There was, however, clear evidence that the cost of obtaining and defending patents was prohibitive for some locally-owned and university-based PRCs.

In each case these difficulties are likely to have a negative effect on the longer-term regional benefits of any public investment in R&D either by encouraging secrecy on the part of the company-based PRCs or by creating unprotected intellectual assets in the university-based PRCs.

What was encouraging was that every PRC had access to expert advice on IP management, either from within their sponsoring organisation or through external patent lawyers. This means not only are the PRCs seeking to create advantage by protecting their IP from misuse by other companies, but they are also actively trying to exploit it for their own financial gain. This should have a positive influence on the innovative capacity of the PRCs and therefore on their ability to generate positive regional spillovers (Graversen et al., 2005; Link and Siegel, 2005).

Table 1: Profile of PRCs

PRC	Budget £m	FTE in 2005	Subject Focus	Host Organisation	Types of R&D Undertaken ● Major Focus ○ Minor Element		
					Basic R&D	Applied R&D	Experimental Development
University-Based PRCs							
CoE.1	1.51	2	Software Process Improvement	University		●	●
CoE.2	0.95	5.5	Technology Start-up & Incubation	University		○	●
CoE.3	37.76	110	Electronic Communication Technologies	University	●	●	○
CoE.4	4.20	4	Medical Polymers	University	○	●	○
CoE.5	3.95	22	Environmental Monitoring Technologies	University		●	●
CoE.6	4.00	7	Functional Genomics	University		●	
CoE.7	3.65	10	Aeronautical Technologies	University	○	●	○
CoE.8	11.65	17	Nanotechnology	University	○	●	○
Company-Based PRCs							
CoE.9	2.71	30	Automotive Engineering	Locally-owned SME			●
CoE.10	4.71	22.5	Food Research and Development	Locally-owned firm			●
CoE.11	6.52	23	Electric Power Engineering	MNE operation		○	●
CoE.12	7.97	27.5	Recording Media Substrate	MNE operation		●	
CoE.13	4.99	41	Mobile Software Systems	MNE operation			●
CoE.14	4.50	221[viii]	Electrical Engineering Test Centre	MNE operation		○	●
CoE.15	3.14	15	Scientific Cameras	Locally-owned SME		○	●
CoE.16	7.03	23	Controlled Drug Delivery	MNE operation		○	●
CoE.17	2.89	35[ix]	Proteomics	Locally-owned firm		○	●
CoE.18	4.15	20	Speciality Pharmaceuticals	Locally-owned SME			●

Table 2: Models of technology transfer in PRCs

PRC	Basic R&D Focus	Publication Activity	Presentation Activity	Model
University-Based PRCs				
1	None	High	High	Licensing
2	None	Medium	Low	Innovation
3	Major	Low	Low	Open Source
4	Minor	Medium	Medium	Open Source
5	None	Low	Low	Innovation
6	None	High	Medium	Licensing
7	Minor	Low	Low	Open Source
8	Minor	Low	Low	Open Source
Company-Based PRCs				
9	None	Low	Low	Local Firm
10	None	Low	Low	Local Firm
11	None	Low	Low	MNE
12	None	Low	Low	MNE
13	None	Low	Low	MNE
14	None	Low	Low	MNE
15	None	Low	Low	Local Firm
16	None	Low	Low	MNE
18	None	Low	Low	Local Firm

[i] The effects which publicly funded research centres can have on innovation and economic growth is the subject of a wealth of studies (Link and Scott, 2005; Debackere and Veugelers, 2005; Roper, 2000; Siegel et al., 2003; and Chen et al., 2004).

[ii] This may be a particularly pressing issue in less developed regions where the absorptive capacity of local firms is less well developed (e.g. Rodriguez-Pose, 1999; Fernandez et al., 1996).

[iii] The same report, however, questions whether the adoption of the licensing model has been as successful in Europe as in the US, viz. *"mere application of the licensing model has not been able to generate the same level of financial or economic results [in Europe] as in the US"* (EU, 2004, p. 11).

[iv] Arguments for this type of public investment are often made in terms of market failure which suggests that firms are generally unable to capture all of the benefits of their R&D investments and therefore tend to under-invest in R&D relative to the social optimum (Nelson, 1959; Arrow, 1962; Dasgupta and David, 1994). Empirical support for the value of public investment in private sector R&D comes from a number of studies which suggest a degree of additionality from public support (e.g. Griliches, 1995; Mamuneas and Nadiri, 1996; Luukkonen, 2000).

[v] Specifically: *"The RTD Centres of Excellence programme supports the establishment of R&D centres to stimulate leading edge, industrially exploitable and commercially focused research which will demonstrably improve the competitiveness of Northern Ireland industry,"* (Invest Northern Ireland, 2003).

[vi] The motivation for this was described as follows:

> *"Our publishing is mainly driven by being seen to be active. Remember our customers are researchers. That is where our income comes from. Being associated with that community and seen as part of that community is important. As far as possible we don't publish papers on things that would be useful to our competitors. We come at it from a slightly different angle because researchers are our customers."*

[vii] *"Rent spillovers arise when quality improvements by a supplier are not fully translated into higher prices for the buyer(s). Productivity gains are then recorded in a different firm or industry than the one that generated the productivity gains in the first place. Rent spillovers occur in input-output relations. Pure knowledge spillovers refer to the impact of the discovered ideas or compounds on the productivity of the research endeavours of others. Pure knowledge spillovers are benefits of innovative activities of one firm that accrue to another without following market transactions"* (Beugelsdijk and Cornet, 2001, p.3).

[viii] Centres of Excellence funding did not directly support the salaries of these staff.

[ix] This Centre was not available for interview; therefore the FTE suggested in the original proposal has been used.

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The propensity to patent:
An empirical analysis at the innovation level[*]

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A paper submitted to the EPIP-2007 Conference
Lund, Sweden, September 20-21, 2007

Abstract

This study seeks to shed new light on the complex relationship between innovations and patents. The objective of the study is to contribute to our understanding of which innovations are patented—and which are not—by analyzing the patenting decision for circa 800 Finnish product innovations. The data is drawn from the Sfinno database compiled at VTT Technical Research Centre of Finland. The econometric analysis indicates that various characteristics of the innovation, the market, and the innovating firm have a significant effect on the propensity to patent. First, there appears to be a U-shaped relationship between firm size and the propensity to patent, which can be attributed to a relatively large extent to economies of scale in the patenting activity as well as to the relatively important role of patenting in start-up ventures. Second, the estimation results suggest that larger—that is, more novel and significant—innovations are patented more frequently than smaller ones. Third, technologically very complex innovations appear to be patented less often than others, while the fragmentation of intellectual property rights to cumulatively developing technology seems to entail high propensities to patent.

Keywords: patents, innovations, patenting, propensity.

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[*] This paper is based on the author's Master's thesis (Mäkinen, 2007) submitted to Helsinki School of Economics (HSE). The thesis work was carried out within the CIPCI project at VTT Technical Research Centre of Finland. Financial support from VTT and Tekes is gratefully acknowledged. The paper has benefited greatly from insightful comments by the Master's thesis supervisor Heli Koski from ETLA, Professor Pekka Ilmakunnas from HSE, and the CIPCI project manager Jani Saarinen and others from VTT Innovation Studies. All responsibility for any errors and omissions is solely mine.

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1. Introduction

To patent or not to patent: that is the question innovators face when they succeed in developing novel products or processes. The innovators need to contemplate whether it is better to seek patent protection or strive to appropriate returns to innovation through other means such as secrecy, first-mover advantages, and complementary capabilities. Various scholars have noted that the propensity to patent differs across industries, firms, and kinds of innovations (e.g. Basberg, 1987; Griliches, 1990; Patel and Pavitt, 1995; Archibugi and Pianta, 1996; Kleinknecht et al., 2002). However, precious little is known about the origins of such differences, especially at the level of innovations, and several issues remain ambiguous in both theoretical and empirical literature.

In the theoretical economic literature on patents, the patenting decision is modeled as a profit-maximizing choice between patenting and non-patenting strategies[1] (e.g. Horstmann et al., 1985; Scotchmer and Green, 1990; Waterson, 1990; Gallini, 1992; Takalo, 1998; Denicolò and Franzoni, 2003; Anton and Yao, 2004; Kultti et al., 2007). This literature is primarily concerned with the optimal design and welfare effects of the patent system on a very general level. Hence most theoretical models abstract from the heterogeneity of industries, firms, and innovations, and provide relatively little insight into the determinants of the propensity to patent. And when relevant predictions emerge from the theoretical work, they can be very sensitive to the assumptions of the specific models. The Anton and Yao (2004) model, for instance, implies that small innovations are patented while large innovations are kept secret, whereas the Horstmann et al. (1985) and the Denicolò and Franzoni (2003) models arrive at the opposite conclusion[2].

The empirical studies on the propensity to patent have hitherto been generally confined to the use of industry and firm-level data, and thus we have very little idea of how the propensity to patent varies across different innovations. Moreover, due to different and sometimes problematic definitions of the propensity to patent in these studies, the results are not readily comparable. And when comparisons are attempted, contradictory conclusions seem to emerge. The results of Schmookler (1966), Taylor and Silberston (1973), and Bound et al. (1984), for instance, suggest that the propensity to patent decreases with the scale of operations, while Mansfield (1986), Arundel and Kabla (1998), Duguet and Kabla (1998), and Arora et al. (2003) find support for the opposite conclusion. Hence further empirical research is required to broaden and deepen our understanding of the determinants of the propensity to patent.

The variations in the propensity to patent are not a trivial matter, but they do have important implications for researchers and policy makers with an interest in innovation and technological change. The patent system is an important policy instrument that can be used to affect the allocation of resources for innovative activities and the diffusion of innovations. Variations in the propensity to patent can be indicative of differences in the extent to which the patent system is utilized by different firms to appropriate returns to different innovations. Furthermore, a thorough understanding of the variations in the propensity to patent should be of great value to researchers, policy makers, and others who depend on patent data in drawing conclusions about innovation and technological change.

The fact that not all innovations are patented is often pointed out as a major limitation to the use of patent statistics as an indicator of innovation (e.g. Griliches, 1990; Archibugi and Pianta, 1996; Kleinknecht et al., 2002). As Hall et al. (2001:4) point out:

> "Unfortunately, we have very little idea of the extent to which patents are representative of the wider universe of inventions, since there is no systematic data about inventions that are not patented. This is an important, wide-open area for future research."

Whether small innovations are patented while large ones are kept secret, or vice versa, should have major implications for the utilization of patent data in economic research. Moreover, understanding the relationship between firm size and the propensity to patent is essential in interpreting empirical studies on the Schumpeterian hypotheses[3] that use patents as a measure of innovation.

The objective of this study is to contribute to our understanding of which innovations are patented—and which are not—by analyzing the patenting decision for circa 800 Finnish product innovations contained in a unique innovation database compiled at VTT Technical Research Centre of Finland. With the help of econometric methods, this study aims to shed new light on the following question: *How is the propensity to patent an innovation affected by the characteristics of the innovation, the market, and the innovating firm?*

This paper is structured as follows. Section 2 discusses issues related to the definition and measurement of the propensity to patent. Section 3 lays out the background for the innovation-level analysis by introducing the data and outlining the hypotheses to be addressed in the empirical study. Section 4 presents the econometric modeling and the estimation results. Section 5 concludes.

2. The propensity to patent: definition and measurement

The relationship between ideas, innovations, and patents is not as clear and simple as it appears in the theoretical literature. Ideally, a firm encounters an idea—or an investment opportunity—and decides whether it is worthwhile investing in developing the idea into an innovation. And if an innovation is successfully developed, the firm then decides whether the innovation should be patented. (Cf. Gallini, 1992; Takalo, 1998; Kultti et al., 2007.) In such a stylized context the definition of the propensity to patent as the fraction of innovations that are patented is straightforward and unambiguously defines the relationship between innovations and patents. In reality, however, it is possible that inventions that are not successfully implemented into practice—and thus do not qualify as innovations[4]—are nevertheless patented. On the other hand, not all inventions are patentable even if they are successfully introduced to the market. It can also happen that the innovator decides to patent but the patent examiner deems the innovation unpatentable and denies the application. Figure 1 illustrates the relationship between ideas, inventions, innovations, and patents. Furthermore, a single innovation can sometimes be protected by a myriad of patents, while one patent can protect a set of innovations. This further complicates the relationship between innovations and patents by making a clear-cut one-to-one mapping between innovations and patents impossible. The complexity of the relationship between innovations and patents, together with problems related to the definition and measurement of innovation, give rise to a number of different definitions of the propensity to patent in the empirical literature.

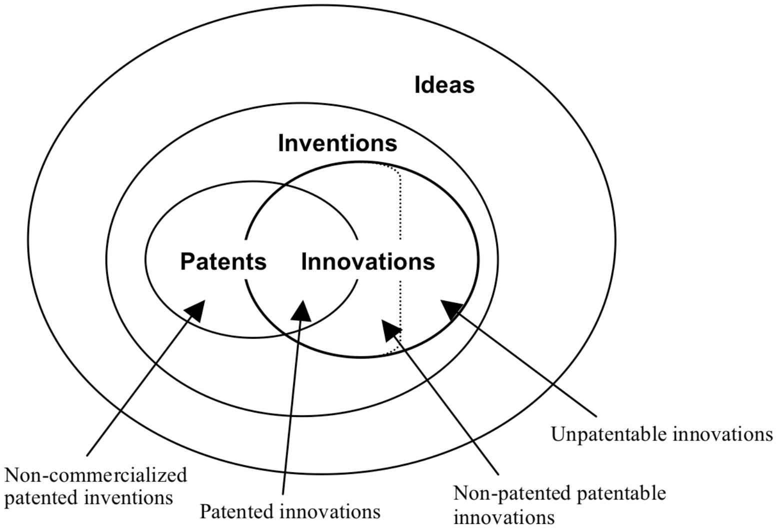

Figure 1. Ideas, inventions, innovations, and patents[5].

Patents, R&D, and the patent production function. Scherer (1965) uses the number of patents received per thousand R&D employees to measure the differences in the propensity to patent, although he acknowledges this to be a crude measure of the patented proportion of the innovation output. Taylor and Silberston (1973) and Scherer (1983) take a relatively similar approach and define the propensity to patent in terms of patents obtained per unit of R&D expenditure. The results on the relationship between patents and R&D are very complex to interpret, however, because they can be affected either by the productivity of R&D or the propensity to patent the results of that R&D[6]. In fact, much of the research on the patents-R&D relationship is primarily concerned with the productivity of R&D, while variations in the propensity to patent are only discussed because they can compromise the interpretability of the results obtained. For instance, it is a matter of speculation whether the negative relationship between the ratio of patents to

R&D and the scale of R&D activities or firm size—observed in a number of studies—arises as a result of declining R&D productivity, decreasing propensity to patent, or something else (e.g. Scherer, 1965, 1983; Schmookler, 1966; Taylor and Silberston, 1973; Bound et al., 1984; Griliches, 1990). In order to distinguish the propensity-to-patent effect from the productivity effects, Brouwer and Kleinknecht (1999) seek to control for the innovation output rather than the innovation inputs by including the sales of innovative products as a control variable in their patent production function.

Survey evidence on the propensity to patent. Instead of seeking to make inferences about the propensity to patent by estimating the patent production function, several innovation surveys have directly asked the firms about the fraction of innovations they generally patent (e.g. Mansfield, 1986; Arundel and Kabla, 1998; Duguet and Kabla, 1998; Cohen et al., 2000; Arora et al., 2003). The survey approach allows for the construction of a direct measure of the propensity to patent that is closely in line with the theoretical definition of the propensity to patent as the fraction of innovations that are patented. Mansfield (1986) defines the propensity to patent as the percentage of patentable inventions that are patented, while the more recent surveys define it as the percentage of innovations for which a patent application is filed[7]. Since in reality a number of patent applications can be filed for a single innovation, the propensity to patent should accordingly be understood as the fraction of innovations for which at least one patent application is filed. This is the definition adopted for the present study.

3. Towards an innovation-level analysis of the propensity to patent

As argued in the introduction, innovation-level data is needed to advance our understanding of the determinants of the propensity to patent. De Melto et al. (1980), Saarinen (2005), and Van der Panne and Kleinknecht (2005) are among the very few studies that have provided innovation-level information on the propensity to patent. These studies, however, do not take the analysis of the propensity to patent very far. De Melto et al. (1980) and Saarinen (2005) address variations in the propensity to patent in the context of Canadian and Finnish innovations, respectively, by cross-tabulating the percentage of innovations patented against other variables of interest. Van der Panne and Kleinknecht (2005) seek to take the analysis a step further by analyzing a sample of Dutch innovations. Their logit analysis, however, is confined by a limited number of observations (N = 216) and explanatory variables (5). The Sfinno database compiled at VTT Technical Research Centre of Finland allows for a detailed innovation-level analysis of the propensity to patent, which simultaneously considers a number of relevant factors hypothesized to affect the patenting decision.

3.1 Sfinno methodology and data

The Sfinno methodology builds upon the object-based method of collecting data on innovative activities directly at the level of individual innovations (cf. Kleinknecht and Bain, 1993). It combines the literature-based method with the expert opinion method in order to produce a comprehensive dataset with a good coverage across different industries and firm size groups (Palmberg et al., 2000). A systematic review of 18 carefully selected trade and technical journals from the period 1985–1998 has been complemented with a review of annual reports of large firms from the same period and with expert opinion-based identification of innovations (Palmberg et al., 1999, 2000; Saarinen, 2005). The review of journals resulted in the identification of some 1100 innovations and the annual reports and expert-opinion yielded about 500 additional innovations giving rise to a dataset of approximately 1600 innovations. In line with the Schumpeterian definitions (Schumpeter 1912) and drawing loosely upon the Oslo Manual (OECD, 1997), the Sfinno approach defines an innovation as an invention that has been commercialized on the market by a business firm or an equivalent, and the inclusion of an innovation in the database requires that the innovation is a technologically new or significantly enhanced product compared to the firm's previous products (Palmberg et al., 1999, 2000). Since the Sfinno-approach relies heavily on public sources in the identification of innovations, it is clearly more conducive to studying product than process innovations. Hence innovations only developed for the firm's internal use are not included in the Sfinno database (Ibid).

In order to collect additional data on the innovations and the development processes, a survey questionnaire was sent to respondents knowledgeable about the innovations in question. Identification of an allegedly relevant respondent was possible for some 1300 innovations and around 800 questionnaires were returned, giving rise to a response rate of over 60 percent (Tanayama, 2002). Moreover, the survey data was complemented with firm-specific data from Statistics Finland and patent data from the National Board of Patents and Registration of Finland. This study is based on a sample of the survey data for which the relevant variables are available. The sample contains 791 innovations from 555 firms. Figure 2 shows the number of firms in the sample with a given number of innovations in the sample. The fact that the data contains several innovations from certain firms suggests that the observations may be subject to within-firm correlation. This issue will be addressed in Section 4.

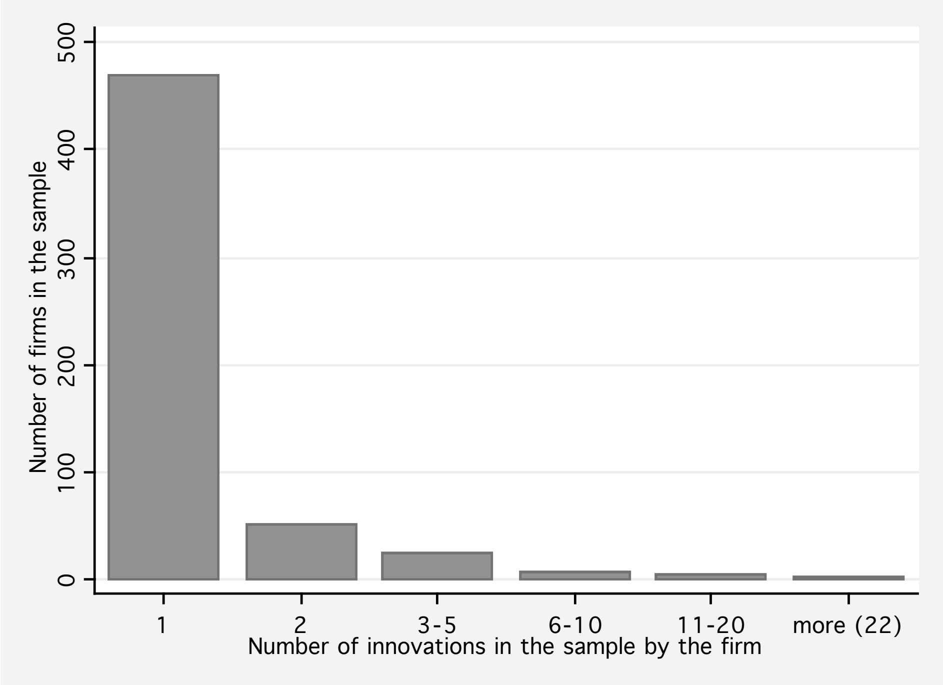

Figure 2. Firms in the sample with a given number of innovations.

An important limitation to innovation-level data collection is that it cannot be based on standard statistical sampling since the population of innovations is unknown (e.g. Palmberg et al., 1999, 2000; Leppälahti, 2000; Palmberg, 2001; Tanayama, 2002; Kleinknecht et al., 2002). Hence, as Tanayama (2002) points out, there is a trade-off between obtaining innovation-level data and collecting data with the desired statistical properties. According to Palmberg (2001:3), data collection in the spirit of the Sfinno approach could instead be described as "a designed census with the aim of identifying all possible products adhering to the specific definition used". Furthermore, Palmberg (2001) argues that "the coverage of the [Sfinno] database in terms of industries and firm size groups is nonetheless relatively representative of innovative activity in Finnish industry" (cf. Leppälahti, 2000; Palmberg et al., 2000). All in all, it can be argued that the Sfinno database is relatively representative of significant Finnish product innovations.

3.2 Hypotheses on the determinants of the patenting decision

Given the innovation-level nature of the data, the dependent variable for the econometric analysis of the propensity to patent takes the form of a binary variable (PATAPP) indicating whether at least one patent application was filed for the innovation. It is of considerable interest as such that patent protection was sought for less than 60 percent of the 791 relatively significant product innovations contained in the sample. This subsection outlines the main hypotheses on the determinants of the propensity to patent emerging from both empirical and theoretical literature, while also introducing the variables designed to capture these determinants. A summary of the variables is provided in Appendix 1.

Firm characteristics. The relationship between firm size and the propensity to patent has been a subject of interest for quite some time, but the evidence remains inconclusive. Even though recent research suggests a positive relationship (Arundel and Kabla, 1998; Duguet and Kabla, 1998; Arora et al., 2003), there are reasons to believe that the relationship might not be as clear-cut as these studies indicate. For one thing, the smallest firms are missing from most of the studies, while the innovation-level studies of Saarinen (2005) and Van der Panne and Kleinknecht (2005) suggest that very small (young) firms can exhibit high propensities to patent. Moreover, firm size might not be independent of the characteristics of innovations. Reinganum (1983) and Henderson (1993), for instance, demonstrate that entrants can have greater incentives to invest in "sufficiently radical innovations". Conversely, Schmookler (1966:35) argues that "one cannot doubt that the largest-scale inventions are usually attempted in large firms". All in all, it seems clear that the differences in the propensities to patent observed in the firm-level investigations might also reflect differences in the characteristics of innovations, not only some inherent firm size-related patenting propensities. Hence it is of great importance to control for the characteristics of innovations when investigating the impact of firm-level factors on the propensity to patent, and vice versa.

A natural explanation for the positive relationship between firm size and the propensity to patent is that economies of scale exist in patenting due to the fixed cost of maintaining a legal department dealing with intellectual property rights (e.g. Scherer, 1965; Lerner, 1995; Arundel and Kabla, 1998; Duguet and Kabla, 1998; Licht and Zoz, 1998; Cohen et al., 2000; Hall and Ziedonis, 2001). Due to their smaller scale of operations, small firms usually cannot spread the fixed costs of patent acquisition and enforcement over as large a volume of inventions as the large firms. There may also be potential for learning curve benefits in the patenting activity. Lerner (1995), for instance, suggests that firms learn to manage internal and external counsel more efficiently when they accumulate experience of litigation. This gives rise to a significant learning curve in the patent litigation process. All in all, it has been argued that small firms cannot utilize the patent system as efficiently as larger firms because obtaining and enforcing patents can be prohibitively costly for many small firms with minimal patent portfolios (e.g. Cohen et al., 2000; Lanjouw and Schankerman, 2004; Parchomovsky and Wagner, 2005). Lanjouw and Schankerman (2004), for instance, find that the litigation risk declines with the size of the patent portfolio. These considerations give rise to the following hypothesis:

Hypothesis 1a: The propensity to patent increases with the scale of patenting.

Despite the problems that a small firm might experience in obtaining and enforcing patents, there are several reasons why small firms might patent more intensively than others. Levin et al. (1987) and Barnett (2003), for instance, argue that small start-up ventures can be more dependent on the patent system than larger firms, because other means of appropriating returns to innovation, such as first-mover advantages and investment in complementary sales and service efforts, may not be viable alternatives. Similarly, Griliches (1990:1676–1677) suggests that for small firms

> "… patents may represent their major hope for ultimate success and hence would lead them to pursue them with more vigor. A well-established major firm does not depend as much on current patenting for its viability or the survival of its market position. Thus, even at an equal underlying inventiveness rates, the propensity to patent may be lower for large firms, at least relative to the successful new entrants in their field."

Small start-ups may often be unable to commercialize their innovations efficiently in embodied form (Cohen and Klepper, 1996), and they thus seek to exploit their innovative technologies through licensing or through a complete transfer of intellectual property. In such situations patents are important for reducing transaction costs and facilitating trade in immaterial property (Arora et al., 2001). Moreover, patents can play an important role as signals of attributes of the firm and the innovations that are deemed positive by outsiders such as venture capitalists and potential collaborators (e.g. Cohen et al., 2000; Kortum and Lerner, 2000; Long, 2002; Hall, 2005). The need for external funding in start-up ventures can also encourage patenting because in order to attract funding the innovator must usually disclose the details of the innovation (Kortum and Lerner, 2000). This can render secrecy a problematic means for appropriation, making formal property rights such as patents an attractive alternative. Hence the following hypothesis is proposed:

> *Hypothesis 1b: Start-up ventures exhibit high propensities to patent.*

The above discussion implies that the relationship between firm size and the propensity to patent may well be non-monotonic. Hence, dummy variables representing four size classes are used to capture the potentially non-linear relationship between firm size and the propensity to patent. The classes of less than 10, 10–99, 100–999, and 1000 or more employees give rise to dummy variables EMP1, EMP2, EMP3, and EMP4, respectively. In order to disentangle the different size-related effects proposed in Hypotheses 1a and 1b, additional variables for the scale of patenting and the start-up status of the innovator are needed.

An innovating firm is defined as an innovative start-up if the idea for the innovation had arisen before or during the year in which the firm was established. The start-up status is coded as a binary variable (STARTUP). Unfortunately, the construction of a measure for the scale of patenting is somewhat problematic because the data does not contain information on the date a patent application was (possibly) filed for the innovation. Hence it is possible that the decision to patent ends up affecting the variable designed to measure the scale of prior patenting, causing simultaneous causality. A measure that should not be very sensitive to such simultaneous causality is the number of patent applications the firm filed (at the National Board of Patents and Registration of Finland) the year before the development of the innovation started (PATENTS). This is based on the assumption that some development work needs to be undertaken before the original idea can be translated into a patentable application. The problem of simultaneous causality will be assessed in Section 4 by testing the exogeneity assumption of PATENTS.

Innovation and market characteristics. The characteristics of the innovation and the market are discussed together since they are highly interdependent and even inseparable. Innovations can redefine existing markets, change the market structure, or even create totally new markets. On the other hand, the value of innovations is determined to a great extent by the characteristics of the market, such as demand and competition.

Theoretical economic literature suggests that the size of an innovation can have an effect on the propensity to patent the innovation. Denicolò and Franzoni (2003) assess the impact of the size of innovations on the propensity to patent in the context of the contract theory of patents and find that under the assumption of a linear demand function, innovations are more likely to be patented if they are large. This is because the rival has a greater incentive to duplicate the innovation if it is large, while patenting can be used to block duplication and secure monopoly profit for the duration of the patent. Horstmann et al. (1985) arrive at a similar conclusion when studying patents as information transfer mechanisms. They model a game of strategic patenting in which the rival can draw inferences about the innovator's private information on the basis of the patenting decision. Their reasoning for the finding is, however, very different from that of Denicolò and Franzoni (2003). Horstmann et al. (1985) argue that, in the context of a cost-reducing innovation, a greater cost reduction raises the innovator's output in the product market and thus makes imitation less attractive. Hence the decision to patent need not convey such a strong signal of unprofitability of imitation and patenting can be allowed to occur more often. Anton and Yao (2004), on the other hand, arrive at the opposite conclusion on the basis of their model of cost-reducing innovation. In the Anton and Yao model, patents offer limited protection while entailing disclosure of enabling knowledge to rivals as well as providing a signal of the total knowledge of the innovator. Anton and Yao (Ibid:3) argue that "… weak property rights imply disclosure incentives that are relatively stronger for smaller innovations, and as a result, larger innovations are protected more through secrecy as a response to the problem of imitation".

Protection from imitation—rather than signaling of cost-efficiency to competitors, which plays a central role in the Anton and Yao (2004) model—is constantly reported as the primary motive for patenting in innovation surveys (e.g. Duguet and Kabla, 1998; Cohen et al., 2000; Blind et al., 2006). Hence the hypothesis about the relationship between the size of innovations and the propensity to patent is based on the findings of Denicolò and Franzoni (2003) and Horstmann et al. (1985), which are also in line with the empirical investigations of De Melto et al. (1980) and Van der Panne and Kleinknecht (2005). This expectation is further buttressed when the assumption of the theoretical models that all innovations are patentable is relaxed. In order to be patentable, an invention has to be industrially applicable and of patentable subject matter, and it needs to satisfy the requirements of novelty and non-obviousness. Consequently, firms are likely to expect that patents be granted for large innovations with a higher probability than for smaller ones. This is probably taken into account when making the patenting decision. On the basis of these considerations, the following hypothesis is put forth:

Hypothesis 2: Large innovations are patented more frequently than smaller ones.

Measurement of the size of innovations or classification of innovations with respect to their size is a problematic issue even from the theoretical perspective. The complex and multidimensional nature of technological change makes it difficult to distinguish between large and small innovations, especially as innovations can be large in some dimensions while being small in others (cf. Henderson, 1993). The size—or radicalness—of an innovation can be defined, for instance, in terms of the technological novelty or magnitude of improvement and the socio-economic impact of the innovation (e.g. Schumpeter, 1912; Freeman and Perez, 1988), the magnitude of cost reduction and the economic implications of the innovation on the market structure (e.g. Arrow, 1962), or the effect the innovation has on the competencies of firms (e.g. Abernathy and Clark, 1985).

Furthermore, even if a certain theoretical definition of the size of an innovation is adopted, empirical measurement of the size is hardly straightforward. In order to address Hypothesis 2, the present study seeks to measure the size of the innovations by introducing four binary variables that capture different dimensions of the novelty and significance of the innovations. The variable NOVFIRM is coded as one for innovations that were specified as entirely new rather than major or minor improvements relative to the innovating firm's existing product by the survey respondent from the firm. Similarly, NOVMARK is coded as one if the innovation was specified to be new on the world market rather than just on the Finnish market. The variable SCIENCE seeks to proxy the technological novelty of the innovation. SCIENCE is coded as one if a new scientific breakthrough was specified as an important or very important (on a four-point Likert scale) factor for initiating the development of the innovation. Finally, the variable SIGNIF is introduced to pick out the truly significant innovations. This variable is based on a survey of experts drawn from industry, academia, and the public sector (see Hyvönen, 2001 for details of the survey and the data). The experts were asked to evaluate the significance[8] of the Sfinno innovations relating to their area of expertise on a four-point Likert scale (1–4). SIGNIF is coded as one if the mean score for the innovation is 3.5 or more.

Another attribute of innovations that can affect the propensity to patent is the complexity. Scherer (1983) and Levin et al. (1987), for instance, suggest that patenting of complex technological systems is more difficult than patenting of more discrete innovations. Levin et al. (1987) argue that the novelty of a discrete innovation can be relatively easily demonstrated in a patent application and infringement is relatively easy to verify when innovations are discrete. This is clearly more difficult to do for complex systems. Moreover, technological complexity can make innovations more difficult to imitate, thus reducing the need for patent protection. These arguments give rise to the following hypothesis:

Hypothesis 3a: Very complex innovations are patented less often than others.

The reasoning that led to Hypothesis 3a drew upon the impact of the technological and physical character of an innovation on the effectiveness and attractiveness of patents as a means for appropriation. On the other hand, complex technologies that are developed cumulatively may be subject to a high-degree of technological interdependence between competing firms (e.g. Cohen et al., 2000; Hall and Ziedonis, 2001). In such environments, firms can be highly dependent on cross-licensing as the intellectual property rights required to market a certain product get fragmented to a number of players. This is because such technological environments give rise to what Shapiro (2000:1–2) calls a patent thicket—that is, "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology". Firms may enter into patent portfolio races in order to improve their bargaining positions relative to others, leading them to patent inventions that would otherwise be left unpatented (Hall and Ziedonis, 2001). Hence the following hypothesis is suggested:

Hypothesis 3b: Cumulative technologies entail high propensities to patent.

In order to disentangle the different complexity-related effects proposed in Hypotheses 3a and 3b, two binary variables are constructed. First, the variable COMPLEX is designed to capture the technological and physical complexity of the innovations relevant for testing Hypothesis 3a. COMPLEX is coded as one if the innovation was classified as highly complex in Hyvönen's 4-category taxonomy (e.g. Tanayama, 2002:56–57; Saarinen, 2005:160–161) by the VTT researchers. Hyvönen's definition of a highly complex innovation is identical to the corresponding definition by Kleinknecht et al. (1993:44). Highly complex innovations are defined as systems consisting of numerous parts or components originating from different disciplines. Second, the variable CUMULTECH is designed to proxy the technological interdependence resulting from fragmentation of intellectual property rights (IPR) to cumulatively developing technologies (cf. Hypothesis 3b). CUMULTECH is coded as one if availability of a license was specified as an important or very important (on a four-point Likert scale) factor for initiating the development of the innovation.

One of the most robust findings emerging from the empirical literature is that the propensity to patent varies across industrial sectors. The origins of such differences are not entirely clear, however, since the variations can arise, for instance, as a result of the technological nature of the innovations or the characteristics of the markets. The software industry, for instance, probably experiences low propensities to patent because of issues related to the patentability of software rather than because of other attributes of the industry such as concentration. On the other hand, Denicolò and Franzoni (2003) argue that tight competition in the product market discourages duplication by the rival and thus makes patenting less attractive relative to secrecy for the innovator. Hence, while acknowledging the importance of controlling for differences in the technological nature of innovations in the empirical analysis, the following hypothesis is put forth:

Hypothesis 4: The propensity to patent declines with product market competition.

Unfortunately, empirical measurement of the degree of competition is a prevailing challenge in empirical industrial organization. This makes testing of Hypothesis 4 problematic. Measures of market concentration such as the Herfindahl–Hirschman index and concentration ratios follow standard definitions and can be objectively measured once the markets of interest are identified. However, such data is usually only readily available for industrial sectors and on a given level of aggregation and thus does not necessarily correspond to the relevant markets of interest. Consequently, a rough proxy emerging from the Sfinno data is used to measure the degree of competition in this study, instead of measures such as concentration ratios[9]. The binary variable PRICOMP is coded as one if price competition was specified as an important or very important (on a four-point Likert scale) factor for initiating the development of the innovation by the survey respondent from the firm. The usefulness of this variable as a proxy for the degree of product market competition hinges on the assumption that the ex post product market competition—that is, competition after the innovation is introduced to the market—correlates strongly enough with the ex ante competition—that is, competition before the market introduction of the innovation.

Control variables. In addition to the potential determinants of the propensity to patent outlined in the preceding hypotheses, several other factors can be expected to influence the propensity to patent. In order not to introduce omitted-variable bias into the estimates, it is imperative to control for such factors in the empirical analysis. The control variables used in this study are outlined below.

First, the results of Brouwer and Kleinknecht (1999), Van der Panne and Kleinknecht (2005), and Peeters and Van Pottelsberghe de la Potterie (2006) indicate that firms that engage in R&D collaboration exhibit higher propensities to patent than others. It is argued that this is due to the need to protect proprietary knowledge in the face of collaborative knowledge sharing and to clarify issues of ownership over co-developed innovations (e.g. Brouwer and Kleinknecht, 1999; Peeters and Van Pottelsberghe de la Potterie, 2006). The answers to the Sfinno survey question on whether the development of the innovation had involved collaboration with external partners give rise to a binary variable COLLAB that can be used to control for such an effect.

Second, it has been suggested that exporting activities tend to have a positive effect on the propensity to patent (e.g. Arundel and Kabla, 1998; Licht and Zoz, 1998). The Sfinno database contains information on whether the innovation has been exported. On the basis of this information, a binary variable INNOEXP is constructed.

Third, sets of dummy variables are introduced to control for differences in the propensity to patent across technology classes and time periods. Ten technology class dummies are constructed on the basis of the technology classification presented in Appendix 2. The dummies refer to the one-digit technology classes with the exception that the two-digit classes of 'agrochemistry and foodchemistry' and 'environmental technology' are picked out from their respective one-digit classes because the propensity to patent in these two-digit classes differs significantly from the propensity to patent in the rest of the one-digit class. Moreover, a set of eleven time period dummies is constructed so that for the early years as well as for the most recent years the time period classes contain more than one year. Such classification is used in order to have a sufficient number of observations in each time period class since the observations are not uniformly distributed in time, as shown in Figure 3. Appendix 1 summarizes all the variables introduced above.

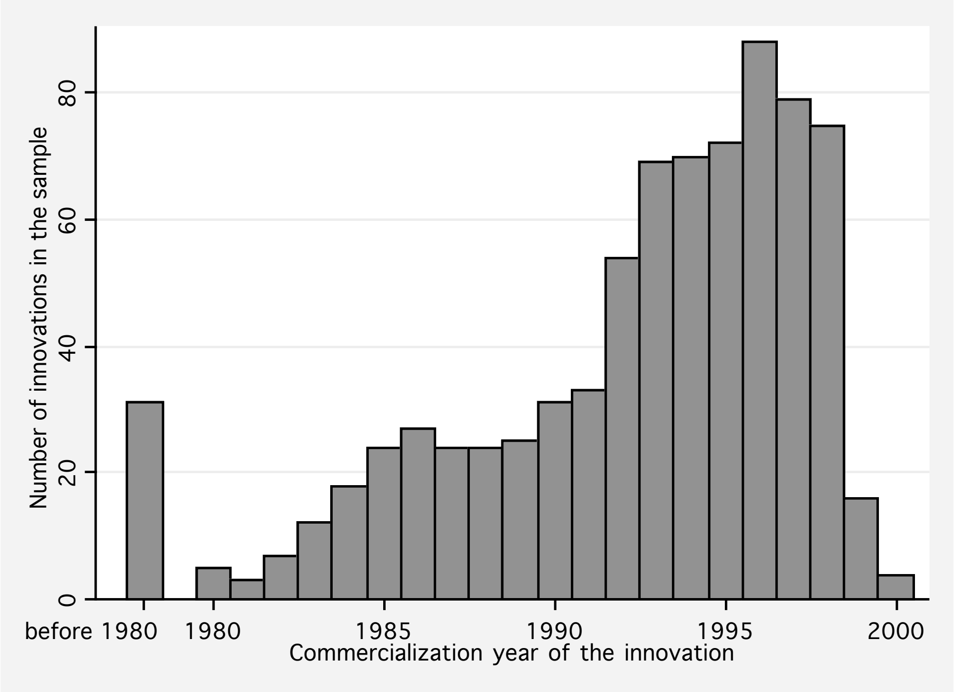

Figure 3. Distribution of observations over time.

4. Econometric analysis

This section lays out the econometric model to be estimated (Subsection 4.1) and presents the estimation results (Subsection 4.2).

4.1 Innovation-level model for the propensity to patent

Formulation of a model for the propensity to patent at the level of innovations requires an innovation-level definition of the propensity to patent. Following the frequency interpretation of probability associated with probability theorists such as John Venn (1876), the probability of an event can be interpreted as the relative frequency of occurrences of the event within a reference class. Hence the definition of the propensity to patent as 'the fraction of innovations for which at least one patent application is filed' gives rise to a corresponding probability interpretation. The propensity to patent can be understood as the probability that at least one patent application is filed for an innovation belonging to a given reference class (cf. Arora et al., 2003:6). More formally, the propensity to patent an innovation can be defined as the conditional probability:

$$\Pr\left[y = 1 \middle| \mathbf{x}\right], \text{ where } y = \begin{cases} 1 & \text{if at least one patent application is filed, and} \\ 0 & \text{otherwise,} \end{cases} \qquad (1)$$

and $\mathbf{x} \equiv \left(x_1, x_2, \ldots, x_K\right)$ is a vector of K variables that determines the reference class.

The probability definition of the propensity to patent allows for a formulation of a model for the propensity to patent in the spirit of random utility models (RUMs). Following Train (2003:18–21), the model is specified as follows:

i. An innovating firm files a patent application for its innovation if the (expected) payoff given the patent application, U_1, is higher than the (expected) payoff when no patent application is filed, U_0.

ii. U_1 and U_0 are known to the innovating firm, but not to the researcher. Instead, the researcher observes $\mathbf{x}$, a vector of observable attributes of the innovation, the market, and the innovating firm.

iii. Following the random utility formulation, the payoffs are decomposed as

$$\begin{aligned} U_1 &= V_1(\mathbf{x}) + \varepsilon_1, \\ U_0 &= V_0(\mathbf{x}) + \varepsilon_0, \end{aligned} \qquad (2)$$

where $V_1(\mathbf{x})$ and $V_0(\mathbf{x})$ are functions that relate the observed attributes, $\mathbf{x}$, to the payoffs U_1 and U_0, respectively, and ε_1 and ε_0 capture the differences between U_1 and $V_1(\mathbf{x})$, and U_0 and $V_0(\mathbf{x})$, respectively. Because ε_1 and ε_0 are not known to the researcher, they are treated as random variables.

iv. The propensity to patent conditional on the observable attributes, **x**, can now be specified as

$$\begin{aligned}\Pr\left[y=1\middle|\mathbf{x}\right]&=\Pr\left[U_1>U_0\right] \\ &=\Pr\left[V_1(\mathbf{x})+\varepsilon_1>V_0(\mathbf{x})+\varepsilon_0\right] \\ &=\Pr\left[\varepsilon_0-\varepsilon_1<V_1(\mathbf{x})-V_0(\mathbf{x})\right] \\ &=F\left(V_1(\mathbf{x})-V_0(\mathbf{x})\right),\end{aligned} \tag{3}$$

where F is the cumulative distribution function of $\varepsilon \equiv \varepsilon_0 - \varepsilon_1$.

Following the conventional practice, $V_1(\mathbf{x})$ and $V_0(\mathbf{x})$ are assumed to be linear in parameters—that is, $V_1(\mathbf{x}) = \mathbf{x}'\boldsymbol{\beta}_1$ and $V_0(\mathbf{x}) = \mathbf{x}'\boldsymbol{\beta}_0$. Moreover, ε_0 and ε_1 are assumed to be distributed independently of **x**, while a natural behavioral assumption for ε_1 and ε_0 is that they are normally distributed. Hence, $\varepsilon \equiv \varepsilon_0 - \varepsilon_1$ is also normally distributed. Furthermore, an innocent normalization of the mean of ε to zero and the variance to unity is now possible as long as the model contains a constant term. Under these assumptions, the model for the propensity to patent becomes the standard probit model for binary choice:

$$\begin{aligned}\Pr\left[y=1\middle|\mathbf{x}\right]&=F\left(V_1(\mathbf{x})-V_0(\mathbf{x})\right) \\ &=F\left(\mathbf{x}'(\boldsymbol{\beta}_1-\boldsymbol{\beta}_0)\right) \\ &=F\left(\mathbf{x}'\boldsymbol{\beta}\right) \\ &=\Phi\left(\mathbf{x}'\boldsymbol{\beta}\right),\end{aligned} \tag{4}$$

where Φ is the standard normal cumulative distribution function and $\boldsymbol{\beta} \equiv \boldsymbol{\beta}_1 - \boldsymbol{\beta}_0$ is the vector of parameters to be estimated.

Owing to the object-based method of data collection, the Sfinno data contains multiple innovations from certain firms (cf. Figure 2); thus the observations are potentially subject to within-firm correlation due to unobserved firm-specific effects. Hence, the standard assumption of independence of observations fails, and the cluster sample characteristics of the data must be accounted for when the model is estimated.

In what follows, as in Wooldridge (2002), i indexes the cluster (i.e. the firm), g indexes the unit (i.e. the innovation), and N is the total number of firms and G_i the total number of innovations by firm i in the data. As the standard assumption of independence of observations fails, the specification of the joint distribution of $\mathbf{y}_i \equiv (y_{i1},\ldots,y_{iG_i})$ conditional on $\mathbf{x}_i \equiv (\mathbf{x}_{i1},\ldots,\mathbf{x}_{iG_i})$ for each cluster i becomes complicated. Hence the traditional maximum likelihood estimator (MLE) based on specification of $f(\mathbf{y} \mid \mathbf{x};\boldsymbol{\beta})$, the full joint density of **y** given **x**, cannot be readily utilized. However, assuming that the univariate densities $f_g(y_g \mid \mathbf{x}_g;\boldsymbol{\beta})$ are correctly specified for each g, the pooled probit model

$$\Pr\left[y_{ig}=1\middle|\mathbf{x}_{ig}\right]=\Phi\left(\mathbf{x}'_{ig}\boldsymbol{\beta}\right), \qquad g=1,\ldots,G_i \tag{5}$$

can be consistently estimated by a quasi-MLE that solves

$$\max_{\boldsymbol{\beta}} \sum_{i=1}^{N} \sum_{g=1}^{G_i} \log f_g\left(y_{ig} \middle| \mathbf{x}_{ig};\boldsymbol{\beta}\right), \tag{6}$$

where $\log f_g\left(y_{ig} \middle| \mathbf{x}_{ig};\boldsymbol{\beta}\right) = y_{ig} \log \Phi\left(\mathbf{x}_{ig}'\boldsymbol{\beta}\right) + \left(1-y_{ig}\right)\log\left[1-\Phi\left(\mathbf{x}_{ig}'\boldsymbol{\beta}\right)\right].$

Wooldridge (2002) calls this the partial maximum likelihood estimator (PMLE). Consistency of the PMLE does not require that $\Pi_g f_g(y_g \mid \mathbf{x}_g;\boldsymbol{\beta})$ is the density of $\mathbf{y}$ given some set of conditioning variables. However, dependence of $y_1,\ldots,y_{Gi}$ results in the failure of the information matrix equality; thus cluster-robust asymptotic variance matrix and cluster-robust test statistics need to be computed instead of the usual ones. (See Wooldridge, 2002:401–410 for details on estimation and inference using the PMLE.)

The parameter estimates that result from the estimation of the pooled model are generally referred to as population averaged since the random effects are averaged out (Cameron and Trivedi, 2005:787). The population-averaged parameters should be expected to differ from those of an unobserved effects model which conditions also on the unobserved cluster-specific effects. However, the partial effects of the pooled model can be interpreted as the average partial effects (APEs)—that is, as partial effects averaged across the population distribution of the unobserved heterogeneity—of the unobserved effects model as long as the cluster-specific effects are independent of the included explanatory variables (see Wooldridge, 2002:22-24, 470–472, 482–490).

4.2 Estimation results

Table 1 contains the partial maximum likelihood estimates for two different specifications of the pooled probit model. The first specification of the pooled probit model (Pooled Probit 1) contains only the firm size dummies and the control variables. The purpose of this endeavor is to check whether the findings emerging from the Sfinno sample are consistent with the previous firm-level studies if the newly introduced variables are ignored. Moreover, estimation of this specification provides a point of reference for examining how the results change when the hypothesized determinants of the propensity to patent are accounted for. The second specification (Pooled Probit 2) contains all the variables introduced in Subsection 3.2 with the purpose of shedding light on the hypotheses outlined in that subsection.

Table 1. Estimation results for Pooled Probit 1 and 2.

Dependent variable: PATAPP	Pooled Probit 1			Pooled Probit 2		
Independent variables	Coef.	Robust Std. Err.	Partial effect◊	Coef.	Robust Std. Err.	Partial effect◊
Firm size classes						
EMP2	-0.3193**	0.1346	-0.1238**	-0.0341	0.1601	-0.0136
EMP3	-0.5223***	0.1471	-0.2046***	-0.2512	0.1804	-0.0993
EMP4	-0.2690	0.2465	-0.1038	-0.2605	0.2575	-0.1028
Other firm characteristics						
PATENTS				0.0160**	0.0070	0.0064**
STARTUP				0.3038**	0.1407	0.1206**
Innovation and market characteristics						
SIGNIF				0.6566**	0.2974	0.2463**
NOVFIRM				0.4636***	0.1306	0.1831***
NOVMARK				0.8850***	0.1148	0.3362***
SCIENCE				0.3118**	0.1483	0.1231**
COMPLEX				-0.5699**	0.2740	-0.2170**
CUMULTECH				0.5651**	0.2281	0.2155***
PRICOMP				-0.2415*	0.1294	-0.0960*
Technology classes (ref. CONSUM)						
ELECTRO	-0.1712	0.3063	-0.0653	-0.1031	0.3329	-0.0411
INSTRU	-0.0997	0.2887	-0.0376	-0.0642	0.3161	-0.0256
CHEM	0.2382	0.3723	0.0837	0.1622	0.4053	0.0644
AGRI&FOODCHEM	-0.4295	0.3431	-0.1677	-0.2988	0.3592	-0.1176
PROCTECH	0.0990	0.2891	0.0360	0.3322	0.3119	0.1300
ENVIRO	1.1122**	0.4614	0.2836**	1.1652**	0.5231	0.3767**
MACH	0.2091	0.2871	0.0740	0.5288*	0.3201	0.2011
EARTH&WATER	0.0601	0.3403	0.0220	0.0773	0.3626	0.0308
SOFT	-1.4929***	0.3834	-0.5155***	-1.4103***	0.4025	-0.4225***
Time periods (10 dummies)	See Appendix 3 for the estimates			See Appendix 3 for the estimates		
Other control variables						
COLLAB	0.1903	0.1416	0.0722	-0.0717	0.1430	-0.0286
INNOEXP	0.2360**	0.1150	0.0885**	0.0552	0.1186	0.0220
Constant	0.0626	0.3204		-1.0853***	0.3652	
Robust Wald tests for joint hypotheses		χ^2 (df)	p-value		χ^2 (df)	p-value
H_0: All coefs zero (exc. constant)		82.21 (24)	0.0000		189.51 (33)	0.0000
H_0: All firm size class coefs zero		13.67 (3)	0.0034		2.60 (3)	0.4570
H_0: All tech. class coefs zero		47.95 (9)	0.0000		50.60 (9)	0.0000
H_0: All time period coefs zero		16.56 (10)	0.0846		22.78 (10)	0.0116
Number of observations		791			791	
Number of clusters		555			555	
Log pseudolikelihood		-461.3642			-393.72924	
McFadden's pseudo R^2		0.145			0.270	
Efron's pseudo R^2		0.187			0.335	
McKelvey and Zavoina's pseudo R^2		0.288			0.472	
Percent correctly predicted						
for observations with PATAPP=1		88.77			86.12	
for observations with PATAPP=0		41.84			66.77	
for all observations		68.77			77.88	

Significance level notation: *** 1%, ** 5%, * 10%.

◊The partial effects are estimated at a point where firm size, technology class, and time period dummies are all zero and other variables are assigned their mean values. The partial effects are computed as discrete changes in the propensity to patent for binary variables and as a partial derivative for the variable PATENTS. The significance level notation for the partial effects is based on standard errors computed using the delta method.

Hypotheses 1a and 1b. The estimation results for Pooled Probit 1 show a non-monotonic U-shaped relationship between firm size and the propensity to patent. This finding can be argued to be in accordance with the survey evidence of the positive relationship between firm size and the propensity to patent (e.g. Arundel and Kabla, 1998; Duguet and Kabla, 1998; Arora et al., 2003) since the firm-level surveys have largely ignored the smallest firms. The results for Pooled Probit 1 suggest that among the relatively large firms, the propensity to patent increases with firm size. While being ignored in the firm-level studies, small start-up ventures are well represented in the Sfinno sample. Pooled Probit 2 provides statistically significant (at the 5 percent significance level) evidence of relatively high propensities to patent in start-up ventures, thus lending support to Hypothesis 1b. Moreover, Pooled Probit 2 lends support to Hypothesis 1a, which holds that the propensity to patent increases with the scale of patenting, by showing a positive and statistically significant (at the 5 percent significance level) effect of the variable PATENTS on the propensity to patent. The U-shaped relationship between firm size and the propensity to patent appears to be captured relatively well by the variables for start-up ventures (STARTUP) and the scale of patenting (PATENTS). Once STARTUP and PATENTS are included in the model, the null hypothesis of the coefficients of the firm size dummies all being zero can no longer be rejected at any meaningful level of significance. Unfortunately, as discussed in Subsection 3.2, the variable designed to account for the scale of patenting may be subject to simultaneous causality. Such endogeneity can compromise the validity of the evidence in support of Hypothesis 1a. However, it is somewhat reassuring that if the variable PATENTS is excluded from the model, the coefficient of EMP4 increases as expected. The exogeneity assumption of PATENTS will be formally tested at the end of this subsection.

Hypothesis 2. The results for Pooled Probit 2 provide support to Hypothesis 2, which proposes that large innovations are patented more often than others. All variables designed to capture different dimensions of the size of innovations (SIGNIF, NOVFIRM, NOVMARK, SCIENCE) display positive coefficients and sizeable positive partial effects. The coefficients and partial effects can be concluded to differ from zero at least at the 5 percent significance level.

Hypotheses 3a and 3b. The estimation results lend support to the hypotheses related to the effect of the complexity of innovations on the propensity to patent. The variables designed to capture the technological complexity of the innovations (COMPLEX) and the fragmentation of intellectual property rights (IPR) to cumulatively developing technology (CUMULTECH) help to disentangle the opposite complexity-related effects discussed in Subsection 3.2. First, the coefficient and partial effect of COMPLEX are negative and statistically different from zero (at the 5 percent significance level), suggesting that very complex innovations are patented less often than others—as proposed in Hypothesis 3a. Second, the coefficient and partial effect of CUMULTECH are positive and statistically different from zero (at least at the 5 percent significance level). The finding that dependence on the availability of a license in the development of an innovation increases the propensity to patent indicates that fragmentation of IPR encourages patenting and supports the proposition of Hypothesis 3b that cumulative technologies entail high propensities to patent.

Hypothesis 4. Pooled Probit 2 shows a negative coefficient for the variable designed as a proxy for the degree of competition in the product market. The coefficient and partial effect appear to differ from zero only at the 10 percent significance level, lending limited support to Hypothesis 4, which proposes that the propensity to patent declines with competition in the product market. Moreover, this result needs to be taken with a grain of salt since price competition in the product market might be expected to trigger product differentiation and incremental change rather than development of large innovations (cf. Tanayama, 2002). If the variables designed to measure the size of innovations fail to capture the effect of the size on the propensity to patent in its entirety, it is possible that price competition is negatively associated with the propensity to patent because it affects the type of innovative activity rather than the propensity to patent directly.

Control variables. The results of Table 1 lend significant support to the assumption that the propensity to patent varies across technologies. As expected, there seems to be a relatively high tendency to patent machinery (MACH) and chemicals and pharmaceuticals (CHEM), and a relatively low propensity to patent software (SOFT). Interestingly, environmental technology (ENVIRO) seems to experience a very high patenting propensity. This may well be because the rising concerns about sustainable development and global warming are making environmental technology increasingly important, and the early innovators in this growing field might seek to secure a share of returns to the later-generation innovations in the course of cumulative development of the technology in the future.

The null hypothesis that the coefficients of all the time period dummies are zero can be rejected in Pooled Probit 1 and 2 at the 10 and 5 percent significance levels, respectively. The estimation results (see Appendix 3) clearly provide no evidence of a general increase in the propensity to patent significant product innovations that would explain the recent surge in patenting (cf. Kortum and Lerner, 1999; Hall and Ziedonis, 2001; and Hall, 2005).

The need to protect proprietary knowledge in the face of collaborative knowledge sharing and to clarify issues of ownership over co-developed innovations has been argued to increase the propensity to patent in firms that engage in R&D collaboration. Peeters and Van Pottelsberghe de la Potterie (2006) refer to this as the ‘need’ effect of R&D collaboration on the propensity to patent. In order to control for such an effect, COLLAB appears as a control variable in both specifications of Table 1. However, the estimation results provide no significant evidence of such a relationship between R&D collaboration and the propensity to patent. This indicates that the finding of a positive relationship between R&D collaboration and the propensity to patent in firm-level studies such as Brouwer and Kleinknecht (1999) might be due to what Peeters and Van Pottelsberghe de la Potterie (2006) call the ‘novelty’ effect—that is, the tendency of R&D collaboration to lead to the generation of more ‘fundamental and breakthrough knowledge’ than in-house R&D[10]. Since the present study seeks to control for the effect of the size of innovations on the propensity to patent directly, the ‘novelty’ effect should be captured by the innovation-size variables rather than the R&D collaboration variable.

Similarly, the positive relationship between exporting activities and the propensity to patent observed, for instance, in Licht and Zoz (1998) and Arundel and Kabla (1998) may result from exporting firms developing larger innovations—or better yet, firm’s with larger innovations choosing to export them—rather than having an inherently higher propensity to patent. Such an argument is supported by the observation that in Pooled Probit 1 the control variable INNOEXP appears to have a positive and statistically significant (at the 5 percent significance level) effect on the propensity to patent, but once the size of innovations is controlled for, evidence of such an effect no longer exists (cf. Pooled Probit 2).

Testing for the exogeneity assumption of PATENTS. The exogeneity assumption of PATENTS is tested by a two-step procedure in the spirit of Smith and Blundell (1986) and Rivers and Vuong (1988). In practice, the test can be applied as follows (see Wooldridge, 2002:472–478 for details). First, the potentially endogenous variable is regressed (using the standard OLS method) on the exogenous variables of the probit model and at least one additional instrument. Second, the probit model is estimated with the exogenous variables, the potentially endogenous variable, and the residuals of the first-stage regression as explanatory variables. Then the test of the null hypothesis of exogeneity can be based on the significance of the residual in the second-stage probit. Since the distribution of the first-stage error term plays no role under the null, such a test is valid without assuming normality or homoscedasticity of the first-stage error term and the test can be applied very broadly, even if the potentially endogenous variable is not continuous (Wooldridge, 2002:474).

Identification of the second-stage probit requires that at least one of the explanatory variables of the first-stage regression be excluded from the probit model. The firm size dummies are natural candidates for instruments to be excluded from the probit model since they are important determinants of the scale of patenting but are not expected to affect the propensity to patent directly. The size-related hypotheses of Subsection 3.2 propose that the start-up status and the scale of patenting are responsible for the association between size and scale and the propensity to patent, while the null hypothesis that the firm size dummies can be excluded from the innovation-level model for the propensity to patent cannot be rejected once these factors are controlled for (cf. Table 1). Furthermore, firm size should not be subject to simultaneous causality that threatens the patenting-scale variable since the decision of whether or not to patent an innovation hardly affects the size of the innovating firm—at least in the short run.

Table 2 presents the results for the test of the exogeneity assumption of PATENTS. The test results indicate that the null hypothesis of exogeneity of PATENTS cannot be rejected at meaningful levels of significance. This supports the validity of PATENTS as a measure of the scale of patenting in the model. The validity of the test naturally hinges on the assumption that the instruments for the potentially endogenous variable are themselves exogenous.

Table 2: Testing the exogeneity assumption of PATENTS.

Dependent variable in the probit model: PATAPP	
Explanatory variables in the probit model	
Potentially endogenous variable	PATENTS
Exogenous variables	STARTUP
	SIGNIF
	NOVFIRM
	NOVMARK
	SCIENCE
	COMPLEX
	CUMULTECH
	PRICOMP
	Technology class dummies (9)
	Time period dummies (10)
	COLLAB
	INNOEXP
Instruments	Firm size dummies (3)
Test of exogeneity of PATENTS	
H_0: Coef of the OLS residual zero in the probit model	
Robust asymptotic t-statistic	0.89
p-value	0.373

5. Conclusion

Thus far most of the empirical investigations into the propensity to patent have been confined to the use of industry and firm-level data, and the failure to control for innovation-level factors has made the interpretation of the results somewhat problematic. The observed variations in the propensity to patent across industries and firms might reflect differences in the characteristics of innovations developed in these industries and firms rather than some inherent differences in the propensity to patent. Moreover, the absence of innovation-level variables has rendered innovation-related hypotheses emerging from the theoretical literature untestable in the industry and firm-level studies. This study seeks to shed new light on the propensity to patent at the innovation level, while also contributing to the long tradition of research on the relationship between firm size and the propensity to patent. By taking the analysis to the innovation level, this study also brings the empirics closer to the theoretical work on the propensity to patent.

The present study set out to cast new light on the question of how the propensity to patent an innovation is affected by the characteristics of the innovation, the market, and the innovating firm. The innovation-level model for the propensity to patent was derived in the spirit of random utility models, and the emerging probit model was estimated on a sample of 791 Finnish product innovations drawn from the Sfinno database compiled at VTT Technical Research Centre of Finland.

The results from the econometric analysis indicate that various characteristics of the innovation, the market, and the innovating firm have a significant effect on the propensity to patent. First, there appears to be a U-shaped relationship between firm size and the propensity to patent, which can be attributed to a relatively large extent to economies of scale in the patenting activity as well as to the relatively important role of patenting in start-up ventures. Second, the estimation results suggest that larger—that is, more novel and significant—innovations are patented more frequently than smaller ones. Third, technologically very complex innovations appear to be patented less often than others, while the fragmentation of intellectual property rights to cumulatively developing technology seems to entail high propensities to patent. Fourth, the econometric analysis produces weak evidence on a negative relationship between the propensity to patent and the product market competition. This evidence needs to be taken with a grain of salt, however, since intense price competition in the product market might indirectly affect the propensity to patent by affecting the size of the innovations rather than by having a direct impact on the propensity to patent. Furthermore, certain factors—such as R&D collaboration and exporting activities—that have appeared to have an impact on the propensity to patent in the firm-level studies fail to exhibit a statistically significant effect once the innovation-level factors are controlled for. This might be indicative of such variables having only an indirect effect since they may well be associated with the size of innovations rather than affecting the propensity to patent directly. While this study seeks to capture different dimensions of the size of innovations with some success using a number of qualitative variables, development of more accurate measures of the size of innovations should make it easier to disentangle the direct effects from the indirect effects that influence patenting through the size of innovations.

The results outlined above should be of obvious interest to those who depend on patent data in drawing conclusions about innovation and technological change. The finding that larger product innovations are patented more frequently than smaller ones should be comforting news from the perspective of using patents as an economic indicator of innovation since it implies that large innovations enter the patent indicator at a relatively high probability. However, the study also points to the weaknesses of patent data by demonstrating that the propensity to patent varies significantly across firms and technologies. For instance, the evidence in favor of the hypotheses proposing that the propensity to patent increases with the scale of patenting and that start-up ventures exhibit high propensities to patent suggests that patents are a rather problematic measure of innovations in the context of testing the Schumpeterian hypotheses.

Moreover, the size-related hypotheses suggest that small start-up ventures are more dependent on patent protection than larger firms while experiencing a disadvantage in obtaining and enforcing patents. This should have important implications for the optimal design of the patent system since it is highly probable that not all valuable ideas originate in the large corporations and thus also small entities need to be provided with sufficient incentives for developing their ideas into innovations. Harnessing the innovative capacity of small firms is clearly an important challenge for any economy.

Because in reality an innovation can be protected by a number of patents, a single patent can cover numerous innovations, and not all patents relate to innovations, a complete investigation of the extent to which patents are representative of different innovations is beyond the scope of this study. Furthermore, the nature of the data used in this study does not allow for consideration of process innovations only developed for the firms' internal use. Clearly, further research is needed to paint a clear picture of the relationship between innovations and patents and to answer the question of the extent to which patents are representative of the wider universe of innovations. All in all, the study provides a rather encouraging perspective of the potential of innovation-level investigations in contributing to our understanding of the features and patterns of technological activities. This study is just a small step in trying to shed light on the complex relationship between patents and innovations that has been remained extremely elusive thus far. Nevertheless, the results indicate that this line of research can prove a very valuable complement to different industry and firm-level investigations.

NOTES

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[1] Much of the theoretical work on patents leaves the decision to patent unmodeled and assumes that all (patentable) innovations are patented.

[2] Following the relevant theoretical literature (Denicolò and Franzoni, 2003; Anton and Yao, 2004), the term *size* (large vs. small) of an innovation is adopted in the present study instead of relatively synonymous alternatives such as the *radicalness* (radical vs. incremental) of an innovation.

[3] Two famous hypotheses associated with Schumpeter (1942) claim that (1) innovation increases more than proportionally with firm size and (2) there is a positive relationship between innovation and market concentration.

[4] This study follows the Sfinno-project in defining an innovation as an invention that has been commercialized on the market by a business firm or an equivalent (Palmberg et al., 1999:38, 2000:10; Saarinen, 2005:19–20).

[5] Figure 1 is a refined version of the figure in Basberg (1987:133).

[6] The results may also be biased due to the shortcomings of R&D expenditure as an indicator of innovation inputs; formal R&D is only one of the innovation inputs and standard innovation surveys tend to underestimate the R&D activities of small firms (e.g. Patel and Pavitt, 1995; Kleinknecht et al., 2002).

[7] Using the percentage of innovations, rather than inventions, overcomes the drawback—inherent in Mansfield's definition—that many inventions are never commercialized and hence have little economic significance. Moreover, the innovations of interest should not be limited to patentable innovations because the propensity to patent figures are of interest as an indicator of the extent to which patents represent the whole population of innovations. (Arundel and Kabla, 1998.)

[8] The definition of a significant innovation adopted for the survey is that the innovation has to be economically and technologically significant and apart from economic success may have had significant impact on the industry (Hyvönen, 2001:4).

[9] Concentration ratios (e.g. CR3, CR5, CR10) based on the NACE classification (General Industrial Classification of Economic Activities within the European Communities) at the three-digit level were also tested as measures of product market competition but they failed to be statistically significant in any of the specifications by a wide margin.

[10] Peeters and Van Pottelsberghe de la Potterie (2006) argue that the 'need' effect should dominate in collaboration arrangements with competitors, while the 'novelty' effect should dominate in partnerships with scientific institutions. Mäkinen (2007) further disaggregates COLLAB into collaboration with universities and research institutes, competitors, subcontractors, and customers, and finds that only collaboration with universities and research institutes has a statistically significant effect on the propensity to patent. This could be interpreted as evidence that it is the 'novelty' effect rather than the 'need' effect that drives the results in the firm-level studies.

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APPENDIX 1: Summary of the variables

Dependent variable	Definition	Type	Mean	St. Dev.
PATAPP	Patent application was filed for the innovation (yes/no)	1/0	0.5740	0.4948

Explanatory variables				
Firm characteristics				
EMP	Number of employees in the firm at the year of the commercialization	#	1113.873	2495.891
EMP1	0-9 employees in the firm at the year of the commercialization (yes/no)	1/0	0.3552	0.4789
EMP2	10-99 employees in the firm at the year of the commercialization (yes/no)	1/0	0.2149	0.4110
EMP3	100-999 employees in the firm at the year of the commercialization (yes/no)	1/0	0.2048	0.4038
EMP4	1000 or more employees in the firm at the year of the commercialization (yes/no)	1/0	0.2250	0.4179
STARTUP	The firm was defined as a start-up developing an innovation (yes/no)	1/0	0.3603	0.4804
PATENTS	Number of patent applications filed by the firm the year before the development of the innovation started	#	3.4083	11.5773
Innovation and market characteristics				
SIGNIF	The innovation was specified as very significant by experts (yes/no)	1/0	0.0518	0.2218
NOVFIRM	The innovation was entirely new to the firm (yes/no)	1/0	0.6157	0.4867
NOVMARK	The innovation was new to the world market (yes/no)	1/0	0.7206	0.4490
SCIENCE	Scientific breakthrough was important for initiating the development of the innovation (yes/no)	1/0	0.1555	0.3626
COMPLEX	The innovation was specified as very complex by experts (yes/no)	1/0	0.0291	0.1681
CUMULTECH	Availability of a license was important for initiating the development of the innovation (yes/no)	1/0	0.0582	0.2342
PRICOMP	Price competition was important for initiating the development of the innovation (yes/no)	1/0	0.2781	0.4484
Technology classes				
CONSUM	The innovation belongs to 1-digit technology class 60 'Consumption goods and equipment' (yes/no)	1/0	0.0329	0.1784
ELECTRO	The innovation belongs to 1-digit technology class 10 'Electrotechnology' (yes/no)	1/0	0.0860	0.2805
INSTRU	The innovation belongs to 1-digit technology class 20 'Instruments' (yes/no)	1/0	0.1416	0.3489
CHEM	The innovation belongs to 1-digit technology class 30 'Chemistry, pharmaceutical technology' excluding 35 (yes/no)	1/0	0.0594	0.2366
AGRI&FOODCHEM	The innovation belongs to 2-digit technology class 35 'Agrochemistry, foodchemistry' (yes/no)	1/0	0.0544	0.2269
PROCTECH	The innovation belongs to 1-digit technology class 40 'Process technology, special equipment' exluding 48 (yes/no)	1/0	0.2579	0.4378
ENVIRO	The innovation belongs to 2-digit technology class 48 'Environmental technology' (yes/no)	1/0	0.0253	0.1571
MACH	The innovation belongs to 1-digit technology class 50 'Mechanical engineering, equipment' (yes/no)	1/0	0.1884	0.3913
EARTH&WATER	The innovation belongs to 1-digit technology class 70 'Earth construction and hydraulic engineering, mining' (yes/no)	1/0	0.0367	0.1881
SOFT	The innovation belongs to 1-digit technology class 80 'Software' (yes/no)	1/0	0.1176	0.3223
Time periods				
PRE1986	The innovation was commercialized before 1986 (yes/no)	1/0	0.1264	0.3325
YEARS86-87	The innovation was commercialized in 1986-87 (yes/no)	1/0	0.0645	0.2458
YEARS88-89	The innovation was commercialized in 1988-89 (yes/no)	1/0	0.0619	0.2412
YEARS90-91	The innovation was commercialized in 1990-91 (yes/no)	1/0	0.0809	0.2729
YEAR1992	The innovation was commercialized in 1992 (yes/no)	1/0	0.0683	0.2524
YEAR1993	The innovation was commercialized in 1993 (yes/no)	1/0	0.0872	0.2824
YEAR1994	The innovation was commercialized in 1994 (yes/no)	1/0	0.0885	0.2842
YEAR1995	The innovation was commercialized in 1995 (yes/no)	1/0	0.0910	0.2878
YEAR1996	The innovation was commercialized in 1996 (yes/no)	1/0	0.1113	0.3146
YEAR1997	The innovation was commercialized in 1997 (yes/no)	1/0	0.0999	0.3000
POST1997	The innovation was commercialized after 1997 (yes/no)	1/0	0.1201	0.3253
Other control variables				
COLLAB	Collaboration was associated with the development of the innovation (yes/no)	1/0	0.8698	0.3368
INNOEXP	The innovation had been exported (yes/no)	1/0	0.6523	0.4765

APPENDIX 2: Technology classification, VTT Innovation Studies

Technology class	IPC-class
10 Electrotechnology	
11 Electrical machinery and equipment, electric energy	F21; G05F; H01B,C,F,G,H,J,K,M, R,T; H02; H05B,C,F,K
12 Audiovisual technology	G09F,G; G11B; H03F,G,J; H04N-003,-005,-009,-013,015,-017,R,S
13 Telecommunications	G08C; H01P,Q; H03B,C,D,H,K, L,M; H04B,H,J,K,L,M,N-001,-007,-011,Q
14 Information technology	G06; G11C; G10L
15 Semiconductors	H01L
20 Instruments	
21 Optics	G02; G03B,C,D,F,G,H; H01S
22 Analysis, measurement, and control technology	G01B,C,D,F,G,H,J,K,L,M,N,P,R,S,V,W; G04; G05B,D; G07; G08B,G; G09B,C,D; G12
23 Healthcare technology	A61B,C,D,F,G,H,J,L,M,N
24 Nuclear technology	G01T; G21; H05G,H
30 Chemistry, pharmaceutical technology	
31 Organic chemistry	C07C,D,F,H,J,K
32 Macromolecule chemistry, polymer chemistry	C08B,F,G,H,K,L; C09D,J; C13L
33 Pharmaceutical technology, cosmetics	A61K
34 Biotechnology	C07G; C12M,N,P,Q,R,S
35 Agrochemistry, foodchemistry	A01H; A21D; A23B,C,D,F,G,J, K,L; C12C,F,G,H,J; C13D,F,J,K
36 Petrochemistry, basic material chemistry	C09B,C,F,G,H,K; C10B,C,F,G,H,J, K,L,M; C11B,C,D

40 Process technology, special equipment	
41 Chemical process technology	B01B,D (excl.-046 - -053),F,J,L; B02C; B03; B04; B05B; B06; B07; B08; F25J; F26
42 Surface material technology, coatings	B05C,D; B32; C23; C25; C30
43 Material technology, metallurgy	C01; C03C; C04; C21; C22; B22
44 Processing of materials, textiles (*)	A41H; A43D; A46D; B28; B29; B31; C03B; C08J; C14; D01; D02; D03; D04B,C,G,H; D05; D06B,C,G,H,J,L,M,P,Q
45 Pulp and paper (*)	D21
46 Printing technology, packaging material	B25J; B41; B65B,C,D,F,G,H; B66; B67
47 Agricultural produce and food technology, machinery and equipment	A01B,C,D,F,G,J,K,L,M; A21B,C; A22; A23N,P; B02B; C12L; C13C,G,H
48 Environmental technology	A62D; B01D-046 - -053; B09; C02; F01N; F23G,J
50 Mechanical engineering, equipment	
51 Machine tools	B21; B23; B24; B26D,F; B27; B30
52 Engines, pumps, turbines	F01B,C,D,K,L,M,P; F02; F03; F04; F23R
53 Thermal engineering, processes and equipment	F22; F23B,C,D,H,K,L,M,N,Q; F24; F25B,C; F27; F28
54 Mechanical components	F15; F16; F17; G05G
55 Transport equipment	B60; B61; B62; B63B,C,H,J; B64B,C,D,F
56 Space technology, weapons technology	B63G; B64G; C06; F41; F42
60 Consumption goods and equipment	A24; A41B,C,D,F,G; A42; A43B, C; A44; A45; A46B; A47; A62B,C; A63; B25B,C,D,F,G,H; B26B; B42; B43; B44; B68; D04D; D06F, N; D07; F25D; G10B,C,D,F,G,H,K

70 Earth construction and hydraulic engineering, mining	E01; E02; E03; E04; E05; E06; E21
80 Software	(not IPC-class compatible)
81 Applications software	
82 Artificial intelligence	
83 Databases	
84 Data processing	
85 Security technology	
86 Data management systems	
87 Network software, network management	
88 Programming and programming languages	
90 'Problems'	
91 Ambiguous case	
92 Classification not applicable (service etc.)	
99 No information	

Sources:
10–70 Fraunhofer ISI / Jan 17, 1997 (* = own classification)
80 Vereinigung der Technologiezentren Österreichs:
http://www.tcs.co.at/vtoe/firmen/tcc/tcc.htm
IPC-classification: http://www.wipo.int/eng/clssfctn/ipc/ipc6en/index.htm

APPENDIX 3: Estimation results for the time period dummies

	Pooled Probit 1			Pooled Probit 2		
	Coef.	Robust Std. Err.	Partial effect	Coef.	Robust Std. Err.	Partial effect
Time periods						
(ref. POST1997)						
PRE1986	0.5070**	0.2030	0.1642**	0.6651***	0.2129	0.2465***
YEARS86-87	0.0651	0.2523	0.0238	0.1370	0.2531	0.0545
YEARS88-89	0.2361	0.2218	0.0830	0.4057	0.2550	0.1573*
YEARS90-91	-0.0235	0.2235	-0.0087	0.1484	0.2325	0.0590
YEAR1992	0.3408	0.2166	0.1163	0.6260***	0.2393	0.2339***
YEAR1993	0.2670	0.2181	0.0931	0.4594**	0.2184	0.1767**
YEAR1994	0.3250	0.2256	0.1114	0.4941**	0.2329	0.1891**
YEAR1995	0.0450	0.1992	0.0165	0.1966	0.2168	0.0779
YEAR1996	-0.0139	0.2039	-0.0052	0.0757	0.2079	0.0302
YEAR1997	0.0022	0.2036	0.0008	0.1651	0.2234	0.0655

Knowledge, competition and appropriability: Is strong IPR protection always needed for more and better innovations?

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SECOND INCOMPLETE DRAFT - September 2007

Abstract

The economic theory of intellectual property rights is based on a rather narrow view of both competition (i.e. the perfect competition model of neoclassical microeconomics) and technological knowledge (i.e. knowledge is reduced to free flowing information). In this paper we suggest some ways of enriching this framework with a more realistic and empirically based view of both and, by means of a simulation model, we investigate some consequences that different appropriability regimes could have in such a richer framework. Our main conclusion is that the implications of intellectual property rights for technological and industrial evolution and for social welfare are very much dependent upon specific characteristics of the competition process and of the underlying technological knowledge.

1 Introduction

It is a piece of undisputable evidence that product, process and organizational innovations are key to economic growth and that a major strength of capitalistic free-market systems has been their unrivalled capacity to promote both the growth of technological knowledge and, perhaps even more, its use for economic purposes, i.e. its translation into better marketable products and cheaper production processes. Market capitalism combines decentralization (and therefore multiplicity and diversity of innovative efforts) with strong incentives to producing innovation, as innovators are – most of the times – rewarded by considerable gains.

However, it sounds like a kind of paradox that the prototype of free market, i.e. perfect competition, does not look at all appropriate to provide such incentives, at least in the theoretical elaborations of economists. In perfect competition the competitive advantage acquired by means of an innovation gets quickly eroded as price falls to the industry's marginal cost and profit to its "normal" level. But the industry's marginal cost does not include the innovator's sunk costs of research and development (R&D). Thus forward looking potential innovators would never invest in R&D, knowing that returns to innovation would quickly disappear and that they could never pay back the R&D investment.

At a closer scrutiny this argument rests upon a set of explicit or implicit assumptions, which can be roughly summarized into three items. The first fundamental assumption is that competition in the real world is correctly (albeit in a stylized manner) described by the economists' model and that, in particular, all market mechanisms should be compared to the ideal of static efficiency of perfect competition. The second assumption is that the innovator's advantage quickly vanishes because superior knowledge cannot be effectively appropriated for its nature of quasi public good, that is non rival and hardly excludable. In turn this hypothesis has two corollaries: that innovative knowledge "naturally" tends to diffuse at a relatively fast rate and that IPRs are the only effective way to prevent this diffusion and allow appropriation. The third implicit assumption is that potential innovators must be enough forward looking to anticipate that their advantage will be quickly eroded, if in fact advantages were actually eroded but potential innovators were myopic enough to underestimate such erosion, incentives to innovate would be at least partially preserved.

In this paper we will try and challenge some of the lines of reasoning behind the common wisdom on some of the assumptions in the former two categories. For the time being we will leave aside the third one, though some reasonable doubts could be raised on its validity as well, witness the ample evidence on the so-called over confidence bias that "affects" entrepreneurs.[1] Our main point is that once we take into account that market is not only a static allocation of resources to their most efficient use and that technological knowledge cannot be reduced to freely flowing information, the economic issues at stake with property rights are not just striking a balance between static monopoly deadweight losses and dynamic lack of incentives. Within the broader picture we outline in this paper the links between the strength of IPR protection and the dynamic properties of an industry cannot be univocally determined but are very much dependent upon market

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[1] For instance, empirical studies show that the vast majority of new firms do not survive more than a few years. This evidence should discourage entrepreneurial entry if the latter was based on a correct estimates of the probability of success. On the contrary, entry remains consistently high also under this regime of weak incentives, probably because entrepreneurs are over-confident, i.e. they believe their entrepreneurial idea is "better" than the others' and that they are therefore located in the survivors' queue of the distribution. It seems quite reasonable to suppose that also innovators are likely to be subject to the same bias.

specific and technology specific factors. In other words we claim that industry matters a lot and probably the incentive problem, which is indeed there, should be solved by means of less universal and more industry specific devices rather than universal legal rights.

The paper is structured as follows: in section 2 we develop the main theoretical arguments. Then in section 3 we provide a very synthetic overview of empirical studies, broadly supporting the view that there is no clear-cut evidence that stronger IPR protection leads to more innovation and more dynamic efficiency and that the effects of patents are very much dependent upon technology specific and market specific factors. In section 4 we outline an evolutionary simulation model in which we try and analyze the dynamic properties of different patent regimes within a formal framework that, albeit still very stylized, tries to account for richer properties of market competition processes and of technological knowledge. The first main feature of the model is that we focus upon product innovation and that the latter is essentially creation of new products which get "experimented" in the market through the creation of ever new sub-markets only loosely competing (or not at all if very innovative) with existing products. We show that IPRs do indeed have an impact not only on the incentives to do research and development but also on the directions in which research moves and that directions induced by a given IPR arrangement might not be dynamically optimal. The second feature is that we give a central role in the model to variables describing technological knowledge, such as knowledge complexity, technological opportunities and cumulativeness and show that IPRs have a very different impact depending on these knowledge dimensions. In section 5 we describe the main results we get from simulating the model and, finally, in section 6 we draw some tentative conclusions and policy implications.

2 Knowledge, competition and innovation: the failure of market failure.

The economic foundations of both theory and practice of IPRs rest upon a standard market failure argument. The proposition that a positive and uniform relation exists between innovation and intensity of intellectual property protection in the form of legally enforced rights such as patents holds only relative to a specific (and highly disputable) representation of markets, their functioning and their "failures", on the one hand, and of knowledge and its nature on the other. The argument falls within the realm of standard "Coasian" positive externality problem (Coase 1960), which can be briefly stated in the following way. There exists a normative set of efficiency conditions under which markets perfectly fulfill their role of efficient allocative mechanisms. The lack of externalities is one of such conditions because their appearance amounts (e.g. with positive externalities) to under-investment and under-production of those goods involved in the externality itself. Facing any departure from efficiency conditions, a set of policies and institutional devices must be put in place with the aim of re-establishing them in order to achieve social efficiency. Knowledge generation is one of the *loci* entailing such an externality: since knowledge is (to a good extent) a public good[2], it will be underproduced and will receive insufficient investment. Hence an artificial scarcity is created to amend non-rivalry and non-excludability in its use, yielding an appropriate degree of appropriability of returns from investments in its production. As usual in a Coasian perspective, the attribution and enforcement of well-defined private property rights is viewed as the key to the solution of an externality problem. But in this case there is an additional problem that the object of property rights is by definition a resource that is unique and does not have close substitutes. Property therefore generates monopoly of a resource which otherwise could enjoy the heavenly condition of non-scarcity. The core of the matter then becomes one of balancing out the detrimental effect of the deadweight loss implied by a legally enforced monopoly, on the one hand, and the beneficial effect of investments in R&D and more generally in knowledge generation, on the other.

A number of general considerations can be made about this argument which concern both the idea of market and the idea of knowledge implicit in this it. Let us elaborate on both starting from the market.

First, the argument fundamentally rests upon the existence of a theoretical (but hardly relevant in terms of empirical and descriptive adequacy) benchmark of efficiency against which policy and institutional interventions should be compared as to their necessity and efficacy. Second, the efficiency notion employed is a strict notion of static efficiency which brings with it the idea that markets do nothing except (more or less efficiently) allocate resources. Third, a most clear-cut distinction between market and non-market realms is assumed, together with the idea that non market (policy, institutional) interventions can re-establish perfect competition using purely market-based "tools".

However, if one starts questioning that markets solely allocate resources one may begin to consider them as performing a wider set of activities such as being the places in which "novelty" is (imperfectly) produced, (imperfectly) tested and (imperfectly) selected. In this alternative perspective, it becomes hard to reduce any efficiency consideration to static efficiency so that, for instance, it is not necessarily true that allocative patterns which are efficient from a static perspective have the same property from a dynamical point of view. In particular, there are two issues we want to focus upon. First, IPRs in a Coasian perspective are only a way to internalize externalities and solve a misallocation problem and in this respect, Coase himself has shown, the allocation of IPRs is in prin-

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[2] Non rivarly of technological knowledge and its commonly understood implications have sometimes been questioned. For instance Boldrin and Levine (2002) claim that non rivarly is not the appropriate category, and that knowledge and information are rather characterized by (infinite) expansibility (David 1992), that is they are not jointly consumed like pure public goods but can indeed be replicated. Replication requires some (though possibly very short) time and involves some (though possibly very low) costs and this is enough to ensure, they show, that competitive markets price innovation positively and provide incentives to innovators.

ciple immaterial to the efficiency of the final allocation as they only provide the correct incentives to induce agents to achieve it. The implicit underlying assumption is that a whole range of *independent* technological opportunities are given and are available to be harvested and the only issue is to provide firms with the correct cost benefit structure to induce them to reap good ones and discard bad ones.

However if we consider a richer picture in which technological opportunities have to be constructed by firms and, in general, are not independent but present complementarities, interdependencies and dynamic path-dependence, then – we will argue in this paper – IPRs are no longer immaterial to the direction of technological progress. They in fact do not only provide incentives, but also set opportunities and constraints for the directions of technological advances and market testing. In particular if technological opportunities are not mutually independent then by foreclosing some firms' research in some directions, patents may on the whole hinder research rather then stimulate it. The issue has been already tackled in the literature in the case of cumulative, sequential or complementary technological advances showing that in these cases patents can in the long run deter innovation and give rise to such hold-up phenomena as the so-called patent thickets and tragedy of the anti-commons (Bessen and Maskin 2000, Shapiro 2000, Heller and Eisenberg 1998, Scotchmer 1991, O'Donoghue 1998). In this paper we analyze the more general case of interdependencies in technological knowledge. We show, also building upon some previous work of ours (Marengo and Dosi 2005, Marengo, Pasquali, and Valente 2005), that the definition of IPRs are not immaterial to determining which kind of innovation undergo the market testing and selection process. One issue which appears crucial in our analysis is what we call the "coarseness" of patents (cf. the related phenomenon of the tragedy of the anti-commons), i.e. whether IPRs are defined on product systems in their entirety or on components, sub-components, and so on with finer and finer IPRs. In a Coasian perspective the latter solution (i.e. very finely defined property rights) should in principle – if it wasn't for transaction costs – increase efficiency, in our framework instead it decreases the number of technological opportunities which can be created and exploited.

A second point we investigate about the function of markets is that nowadays a growing share of innovations are product innovations whose main purpose and effect are to create sub-markets (Sutton 1998, Klette and Kortum 1984, Klepper and Thompson 2007) which only loosely compete with existing submarkets. The perfect competition benchmark seems therefore more and more inappropriate as a description of the actual mechanisms of technological competition as it describes a hardly relevant steady state of processes which in reality are ever upset by pushing competition elsewhere. Again, the pace and directions of the creation of submarkets may be highly influenced by the definition and attributions of IPRs and this effect – we will argue – might be more important than their effect upon an hard to reach static efficiency.

All in all, the institutional attribution of property rights (whether efficient or not in a static allocative perspective) may strongly influence the patterns of technological evolution in directions which are not necessarily optimal or even desirable. In this sense, any question about the appropriate level of IP protection and degree of appropriability would be better grounded on a theory of innovative opportunities and productive knowledge (issues on which the theory of allocative efficiency is rather silent: cf. Winter (1982), Stiglitz (1994) from different angles).

Finally, viewing markets as embedded and depending upon a whole ensemble of non-market institutions allows to appreciate the fact that technological innovation is highly dependent on a variety of complementary institutions (e.g. public agencies, public policies, universities, communities and of course corporate organizations with their rich inner structure) which can hardly be called “markets” and hardly can they be regulated by pure market incentives. Precisely this institutional embeddedness of innovative activities makes it very unlikely that a “market failure” approach such as the one we sketched above could provide any satisfactory account of the relationship between appropriability and propensity to innovate.

Concerning now technological knowledge, the standard implicit assumption is that the nature of “knowledge” is totally captured by the notion of “information” thus setting the possibility of institutionally treating it in uniform ways, neglecting any dimension of knowledge which relates to its “non public good” features. According to this perspective, the transformation of the public good “knowledge” in the private good “patent” will perfectly set incentives for its production by way of legally enforced conditions and possibilities of appropriability. Two important questions arise in this respect: first, the transformation of information into useful productive knowledge involves an ensemble of fundamental cognitive and procedural devices which are to a large extent tacit and embedded in organizations and are in any case strongly dependent on the specificities of each technological paradigm (which hardly can be reduced to “information” categories). Second, and related, there exist a wide range of devices for appropriating knowledge, themselves high technology and sector specific, among which intellectual property protection is only one of the many and according to many empirical studies (cf. the next section) not even a prominent one in many industries and technologies.

On the first point, note that any satisfactory description of “what technology is” and how it changes must also embody the representation of the specific forms of knowledge on which a particular activity is based and cannot be reduced to a set of well-defined blueprints (Winter 1982). It primarily concerns problem-solving activities involving - to varying degrees - also tacit forms of knowledge embodied in individuals and in organizational procedures. The notion of technological paradigm (Dosi 1982), in this respect, is precisely an attempt to account for the nature of innovative activities. Paradigms entail specific heuristic and visions on ”how to do things” and how to improve them, often shared by the community of practitioners in each particular activity (engineers, firms, technical societies, etc.), i.e. they entail collectively shared cognitive frames. Paradigms often also define basic templates of artifacts and systems, which over time are progressively modified and improved. These basic artifacts can also be described in terms of some fundamental technological and economic characteristics. For example, in the case of an airplane, their basic attributes are described not only and obviously in terms of inputs and production costs, but also on the basis of some salient technological features such as wing-load, take-off weight, speed, distance it can cover, etc. What is interesting here is that technical progress seems to display patterns and invariances in terms of these product characteristics. Hence the notion of technological trajectories associated with the progressive realization of the innovative opportunities underlying each paradigm. In turn one of the fundamental implication of the existence of such trajectories is that each particular body of knowledge (each paradigm) shapes and constraints the rates and direction of technical change, in a first rough approximation, irrespectively of market inducements, and thus also irrespectively of appropriability conditions.

All in all, any analysis of the conditions for appropriation and diffusion of knowledge cannot abstain from considering the specific features of the knowledge itself. Knowledge complexity, cumulativeness, tacitness, replicability, and degree and location of technological opportunities are fundamental dimensions for understanding the dynamics of productive knowledge (Winter 1987).

On the second point, diversity of knowledge characteristics is reflected into diversity of appropriability regimes. For instance, Teece (1986) rightly claims that an innovation is never an isolated well defined entity, but it is dependent upon a series of complementary assets whose control is often more fundamental for reaping the economic returns to innovation than the regime of legal protection of the rights of the “innovator”.

In conclusion, one can observe many fact instances of innovations that in spite of not being patented (or patented under very weak patent regimes) have most definitely produced considerable streams of economic value both to the innovator and to society. Relevant examples can be drawn from those technologies forming the core of ICT. For instance, the transistor, while being patented from Bell Labs, was liberally licensed also as a consequence of antitrust litigation and pressure from the US Justice Department: its early producers nonetheless obtained enough revenue to be the seeds of the emergence of a whole industry (Grandstrand 2005). The early growth of the semiconductor industry had been driven to a good extent by public procurement in a weak IP regime. The software industry, certainly a quite profitable one, similarly emerged under a weak IP regime. The telecom industry was largely operated by national monopolies until the 90’s who were undertaking also a good deal of research, and IPRs played little role in the rapid advance of technology in this industry. Mobile telephony also emerged under a weak IP regime (until the late 1980s).

3 A concise view of empirical evidence

Needless to say, such a lack of any robust theory-backed relation between IPRs and rates of innovation, puts the burden of proof upon the actual empirical record.

Indeed, the past two decades have witnessed the broadening of the patent domain including the application of "property" to scientific research and its results. This has been associated with an unprecedented increase in patenting rates. Between 1988 and 2000, patent applications from US corporations have more than doubled.

The relation between the two phenomena, however, and - even more important - their economic implications are subject to significant controversy (for discussion, see Kortum and Lerner (1998), Hall (2005), Lerner (2002), Jaffe and Lerner (2004) and Jaffe (2000)).

A first hypothesis is that the observed "patent explosion" has been linked to an analogously unprecedented explosion in the amount and quality of scientific and technological progress. A "hard" version of that hypothesis would claim that the increase of patents has actually spurred the acceleration of innovation, which otherwise would have not taken place. A "softer" version would instead maintain that the increase of patents has been an effect rather than a cause of increased innovation, as the latter would have taken place also with weaker protection.

The symmetrically opposite hypothesis is that the patent explosion is due to changes both in the legal and institutional framework and in firms' strategy with little relation to the underlying innovative activities.

While it is difficult to come to sharp conclusions in absence of counterfactual experiments, some circumstantial evidence does lend some support to the latter hypothesis. Certainly part of the growth in the number of patents is simply due to the expansion of the patentability domain to new types of objects such as software, research tools, business methods, genes and artificially engineered organisms (see also Tirole (2002) on the European case). Moreover, new actors have entered the patenting game, most notably universities and public agencies (more on it in Mowery, Nelson, Sampat, and Ziedonis (2001)). Finally also corporate strategies vis-à-vis the legal claim of IPRs appear to have significantly changed.

First, patents have acquired importance among the non physical assets of firms as means to signal the enterprise's value to potential investors, even well before the patented knowledge has been embodied in any marketable good. Under this respect, the most relevant institutional change is to be found in the so called "Alternative 2" under the Nasdaq regulation (1984). This allowed "market entry and listing of firms operating at a deficit on the condition that they had considerable intangible capital composed of IPRs".

At the same time, patents seems to have acquired a strategic value, quite independently from any embodiment in profitable goods and even in those industries in which they were considered nothing more than a minor by-product of R & D: extensive portfolios of legal rights are considered means for entry deterrence (Hall and Ziedonis 2001) and for infringement and counter infringement suits against rivals. Texas Instruments, for instance, is estimated to have gained almost one billion dollars from patent licenses and settlements resulting from its aggressive enforcement policy. It is interesting to note that this practice has generated a new commercial strategy called "defensive publishing". According to this practice, firms who find too expensive to build an extensive portfolio of patents tend to openly describe an invention in order to place it in the "prior art" domain, thus preserving the option to employ that invention free from the interference of anyone who might eventually patent the same idea.

Kortum and Lerner (1998) present a careful account of different explanations of recent massive increases in patenting rates, comparing different interpretative hypothesis.

First, according to the "friendly court hypothesis", the balance between costs related to the patenting process (in terms e.g. of loss of secrecy) and the value of the protection that a patent affords to the innovator had been altered by an increase in the probability of successful application granted by the establishment in the USA of the Court of Appeals for the Federal Circuit existence (CAFC) specialized in patent cases - regarded by most observers as a strongly pro-patent institution (cf. Merges (1996)).

Second, the "regulatory capture" tries to explain the surge of US patent applications tracking it back to the fact that business firms in general and in particular larger corporations (whose propensity to patent has traditionally been higher than average) succeeded in inducing the US government to change patent policy in their favor by adopting a stronger patent regime.

The third hypothesis grounds the interpretation into a general increase in "technological opportunities" related, in particular, to the emergence of new technological paradigms such as those concerning information technologies and biotechnologies.

Remarkably, Kortum and Lerner (1998) do not find any overwhelming support neither for the political/institutional explanations nor for the latter one drawing the surge in patenting to changes in the underlying technological opportunities. At the same time there is a good evidence that the cost related to IP enforcement has gone up together with the firms' propensity to litigate: the number of patents suits instituted in the US Federal Courts has increased from 795 in 1981 to 2573 in 2001. Quite naturally, this has lead to significative increases in litigation expenditures. It has been estimated by the US Department of Commerce that patent litigation begun in 1991 led to total legal expenditures by US firms that were at least 25% of the amount of basic research by these firms in that year.

What is the effect of the increase in patent protection on R & D and technical advance? Interestingly, also in this domain the evidence is far from conclusive. This is due at least to two reasons. First, innovative environments are concurrently influenced by a variety of different factors which makes it difficult (both for the scholar and the policy-maker) to single out patent policy effects from effects due to other factors. Indeed, as we shall argue below, a first order influence is likely to be exerted by the richness of *opportunities* irrespectively of appropriality regimes. Second, as patents are just one of the means to appropriate returns from innovative activity, changes in patent policy might often be of limited effect.

At the same time also the influence of IPR regimes upon knowledge dissemination appear to be ambiguous. Hortsmann, Mac Donald, and Slivinski (1985) highlight the cases in which, on the one hand, the legally enforced monopoly rents should induce firms to patent a large part of their innovations, while, on the other hand, the costs related to disclosure might well be greater than the gain eventually attainable from patenting. In this respect, to our knowledge, not enough attention has been devoted to question whether the diffusion of technical information embodied in inventions is enhanced or not by the patent system.

The somewhat symmetric opposite issue concerns the costs involved in the imitation of patent-protected innovations. In this respect, Mansfield, Schwartz, and Wagner (1981) find, first, that patents do indeed entail some significant imitation costs. Second, there are remarkable intersectoral differences. For example, their data show a 30% in drugs, 20% in chemicals and only 7% in electronics. In addition, they show that patent protection is not essential for the development of at least three out of four patented innovations. Innovators introduce new products notwithstanding the fact that other firms will be able to imitate those products at a fraction of the costs faced by the innovator. This happens both because there are other barriers to entry and because innovations are felt to be profitable in any case. Both Mansfield, Schwartz, and Wagner (1981) and Mansfield (1986) suggest that the absence of patent protection would have little impact on the innovative efforts of firms in most sectors. The effects of IPR regimes on the propensity to innovate are also likely to depend upon the nature of innovations themselves and in particular whether they are, so to speak, discrete "stand alone" events or "cumulative". So it is widely recognized that the effect of patenting might turn out to be a deleterious one on innovation in the case of strongly cumulative technologies in which each innovation builds on previous ones. As Merges and Nelson (1994) and Scotchmer (1991) suggest, in this realm stronger patents may represent an obstacle to valuable but potentially infringing research rather than an incentive.

Historical examples, such as those quoted by Merges and Nelson on the Selden patent of a light gasoline in an internal combustion engine to power an automobile and the Wright brothers patent on an efficient stabilizing and steering system for flying machines are good cases to the point, showing how the IPR regime probably slowed down considerably the subsequent development of automobiles and aircrafts. The current debate on property rights in biotechnology suggests similar problems, whereby granting very broad claims on patents might have a detrimental effect on the rate of innovation, insofar as they preclude the exploration of alternative applications of the patented invention. This is particularly the case with inventions concerning fundamental pieces of knowledge: good examples are genes or the Leder and Stewart patent on a genetically engineered mouse that develops cancer. To the extent that such techniques and knowledge are critical for further research that proceeds cumulatively on the basis of the original invention, the attribution of broad property rights might severely hamper further developments. Even more so if the patent protects non only the product the inventors have achieved (the "onco-mouse") but all the class of products that could be produced through that principle ("all transgenic non-human mammals") or all the possible uses of a patented invention (say, a gene sequence), even though they are not named in the application.

More generally, the evidence suggests that the patents/innovation relation depends on the very nature of industry-specific knowledge bases, on industry stages in their life-cycles and on the forms of corporate organizations.

Different surveys highlight, first, such intersectoral differences and second, *on average*, the limited effectiveness of patents as an appropriability device for purpose of "profiting from innovation". Levin, Klevorick, Nelson, and Winter (1987), for instance, reports that patents are by and large viewed as less important than learning curve advantages and lead time in order to protect product innovation and the least effective among appropriability means as far as process innovations are concerned.

Cohen, Nelson, and Walsh (2000) present a follow-up to Levin, Klevorick, Nelson, and Winter (1987) just cited addressing also the impact of patenting on the incentive to undertake R & D. Again, they report on the relative importance of the variety of mechanisms used by firms to protect their innovations - including secrecy, lead time, complementary capabilities and patents. The percentage of innovations for which a factor is effective in protecting competitive advantage deriving from them is thus measured. The main finding is that, as far as product innovations are concerned, the most effective mechanisms are secrecy and lead time while patents are the least effective, with the partial exception of drugs and medical equipment. Moreover the reasons for the "not patenting" choice are reported to be (i) demonstration of novelty (32%), (ii) information disclosure (24%) and (iii) ease of inventing around (25%).

The uses of patents differ also relative to "complex" and "discrete" product industries. Complex products industries are those in which a product is protected by a big number of patents while discrete product industries are those in which a product is relatively simple and therefore associated with a small number of patents. In complex product industries, patents are used to block rival use of components and acquire bargaining strength in cross-licensing negotiations. In discrete product industries, patents are used to block substitutes by creating patent "fences" (cf. Gallini (2002), Ziedonis (2004)).

It is interesting also to compare Cohen, Nelson, and Walsh's (2000) with the old Levin, Klevorick, Nelson, and Winter (1987) which came before the changes in the IPR regime and before the massive increase in patenting rates. Still, also in Cohen, Nelson, and Walsh (2000) patents are not reported to be the key means to appropriate returns from innovations in most industries. Secrecy, lead time and complementary capabilities are often perceived more important appropriability mechanisms.

It could well be that a good deal of the increasing patenting activities over the last two decades might have gone into "building fences" around some key invention thus possibly raising the private rate of return to patenting itself (Jaffe (2000)) without however bearing any significant relation with the underlying rates of innovation. This is consistent also with the evidence discussed in Lerner (2002) who shows that the growth in (real) R & D spending *predates* the strengthening of the IP regime.

The apparent lack of effects of different IPR regimes upon the rates of innovation appears also from broad historical comparisons. So for example, based on the analysis of data from the catalogues of two 19^{th} century world fairs: the Crystal Palace Exhibition in London in 1851, and the Centennial Exhibition in Philadelphia in 1876, Moser (2003) finds no evidence that countries with stronger IP protection produced more innovations than those with weaker IP protection and a strong evidence of the influence of IP law on sectoral distribution of innovations. In weak IP countries firms did innovate in sectors in which other forms of appropriation (e.g. secrecy and lead time) were more effective, whereas in countries with strong IP protection significantly more innovative effort went to the sectors in which these other forms were less effective. Hence, the interesting conclusion that can be drawn from Moser's study that patents' main effect could well be on the directions rather than on the rates of innovative activity.

The relationship between investment in search and innovative outcomes is explored at length in Hall and Ziedonis (2001) in the case of the semiconductor industry. In this sector, the little role and effectiveness of patents - related to short product life-cycles and fast-paced innovation which make secrecy and lead time much more effective appropriability mechanisms - also makes the surge in patenting (dating back to the 80's) particularly striking. As Hall and Zidonis report, in the semiconductor industry patenting per R&D dollar doubled over the period 1982-92. (Incidentally note that, over the same period, patenting rates in the US were stable in manufacturing as a whole and did decline in pharmaceuticals).

Semiconductors are indeed a *high-opportunity* sector whose relatively *low* propensity to patent is fundamentally due to the characteristic of the knowledge base of the industry. Thus it could well be that the growth in patents might have been associated with the use of patents as "bargaining chips" in the exchanges of technology among different firms. Such a use of (low quality) patents – as Winter (2002) suggests – might be a rather diffused phenomenon: when patents are used as "bargaining chips" i.e. as "the currency of technology deals" all the "standard requirements" about such issues as non obviousness, usefulness, novelty, articulability (you can't patent an intuition), reducibility to practice (you can't patent an idea per se), observability in use, turn out to be much less relevant. In Winter's terms, "if the relevant test of a patent's value is what it is worth in exchange, then it is worth about what people think it is worth – like any paper currency. 'Wildcat patents'[3] work reasonably well to facilitate exchanges of technology. So, why should we worry?" One of the worries, concerns the "tragedy of anti-commons". While the quality of patents lowers and their use bear very little link with the requirements of stimulating the production and diffusion of knowledge, the costs devoted to untie conflicting and overlapping claims on IP are likely to increase together with the uncertainty about the extent of legal liability in using knowledge inputs. Hence, as convincingly argued by Heller and Eisenberg (1998) and Heller (1998) a "tragedy of anti-commons" is likely to emerge wherein the IP regime gives too many subjects the right to exclude others from using fragmented and overlapping pieces of knowledge with no one having ultimately the effective privilege of use.

In these circumstances, the proliferation of patents might turn out to have the effect of discouraging innovation. One of by products of the recent surge in patenting is that, in several domains, knowledge has been so finely sub-divided into separate property claims (on essentially complementary pieces of information) that the cost of reassembling constituent parts/properties in order to engage in further research charges a heavy burden on technological advance. This means that a large number of costly negotiations might be needed in order to secure critical licenses, with the effect discouraging the pursue of certain classes of research projects (e.g. high risk exploratory projects). Ironically, Barton (2000) notes that "the number of intellectual property lawyers is growing faster than the amount of research".

While it is not yet clear how widespread are the foregoing phenomena of a *negative* influence of strengthen IPR protection upon the rates of innovation, a good deal of evidences does suggest that, *at the very least*, no monotonic relation is there between IPR protection and propensity to innovate. So, for example, Bessen and Maskin (2000) observe that computers and semi-conductors while having been among the most innovative industries in the last forty years, have historically had weak patent protection and rapid imitation of their products. It is well known that the software industry in the US experienced a rapid strengthening of patent protection in the 80's. Bessen and Maskin suggest that "far from unleashing a flurry of new innovative activity, these stronger rights ushered in a period in which R&D spending leveled off, if not declined, in the most patent-intensive industries and firms". The idea is that in industries like software, imitation might be promoting innovation and that, on the other hand, strong patents might inhibit it. Bessen and Maskin argue that this phenomenon is likely to occur in those industries characterized by a relevant degree of sequentiality (each innovation builds on a previous one) and comple-

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[3] Winter here is pursuing an analogy between patents and "wildcat banknotes" in the US free banking period (1837-1865).

mentarity (the simultaneous existence of different research lines enhances the probability that a goal might be eventually reached). A patent, in this perspective, actually prevents non-holders from the use of the idea (or of similar ideas) protected by the patent itself and in a sequential world full of complementarities this turns out to slowdown innovation rates. Conversely, it might well happen that firms would be better off in an environment characterized by easy imitation, whereby it would be true that imitation would reduce current profits but it would be also true that easy imitation would raise the probability of further innovation to take place and of further profitable innovations to be realized.

A related but distinct question concerns the relationship between IPR's, the existence of markets for technologies and the rates of innovation and diffusion (see Arora, Fosfuri, and Gambardella (2001) for a detailed analysis of the developments). While it is certainly true that some IPR protection is often a necessary condition for the development of markets for technologies, no clear evidence is there suggesting that more protection means more market. And neither there is general evidence that more market drives higher rates of innovation. Rather, the degree to which technological diffusion occurs via market exchange depend to a great extent on the nature of technological knowledge itself, e.g. its degree of codifiability (Arora, Fosfuri, and Gambardella 2001).

So far we have primarily discussed the relations between the regimes of IPR protection and rates of innovations, basically concluding that either the relation is not there, or, if it is there it might be a perverse one, with strong IPR enforcement actually *deterring* innovative efforts. However we know also that IPT protection is only one of the mechanism for appropriating returns from innovation, and certainly not the most important one. What about then the impact of appropriability in general?

Considering together the evidence on appropriability from survey data and (cf. Cohen, Nelson, and Walsh (2000) and Levin, Klevorick, Nelson, and Winter (1987)), the cross-sectoral evidence on technological opportunities (cf. Klevorick, Levin, Nelson, and Winter (1995)) and the evidence from multiple sources on the modes, rates and directions of innovation (for two surveys, cf. Dosi (1988) and Dosi, Orsenigo, and Sylos Labini (2005)), the broadbrush conclusion is that also appropriability conditions *in general* have only a limited effects on the pattern of innovation, if any. This clearly applies above a minimum threshold: with perfectly zero appropriability, the incentive to innovate for private actors would vanish, but with few exceptions such strict zero condition is hardly ever encountered. And the threshold, as the open source software shows, might be indeed very low.

4 The model

4.1 technology space

We model products as systems made of n components $\{x_1, x_3, \ldots, x_n\}$. Each component can take one out of a countable set of values $x_j = \{0, 1, \ldots\}$, which are labels for different and progressively "better" – in a mere technological sense – types of components (e.g. different CPU types, different wing shapes, different brake cooling systems, etc.). We call X the set of all the possible products, i.e. of the vectors $x^i = [x^i_1, x^i_2, \ldots, x^i_n]$ with $x^i_j = \{0, 1, \ldots\}$.

This product space has a natural structure which describes the diversity of products. In particular, we will use two notions of distance between products: horizontal diversity and vertical distance, which are useful to measure, respectively, the horizontal and vertical scope of patents. The horizontal diversity of between two products x^i and x^j is given by the share of components in which x^i and x^j are not identical:

$$H(x^i, x^j) = \sum_{\nu=1}^{n} h(x^i_\nu, x^j_\nu)/n$$

where $h(x^i_\nu, x^j_\nu) = 0$ if $x^i_\nu = x^j_\nu$ and $h(x^i_\nu, x^j_\nu) = 1$ if $x^i_\nu \neq x^j_\nu$.

The vertical distance is instead the average of the distances between single components:

$$V(x^i, x^j) = \frac{\sum_{k=1}^{n} |x^i_k - x^j_k|}{n}$$

Products have some exogenously given performance measure, where performance is a function of the specific combination of components. We suppose that quality is measured by a non negative scalar: $f : X \mapsto R^+$.

How does the performance of a product change when components are modified? It depends upon the "complexity" of the product space, that is the presence, extent and direction of interdependencies among the components forming a product-system. In particular, with respect to the presence and direction of interdependencies we will consider the following cases:

- *without interdependencies*: if $\frac{\partial^2 f}{\partial x_i \partial x_j} = 0 \; \forall i \neq j$
- *with monotonic interdependencies* (or complementarities): if f is super-modular, i.e. $\frac{\partial^2 f}{\partial x_i \partial x_j} \geq 0 \; \forall i \neq j$
- *with non-monotonic interdependencies*: if $\frac{\partial^2 f}{\partial x_i \partial x_j} \gtreqless 0 \; \forall i \neq j$

With respect to the extent of interdependencies, we distinguish among the following case:

- *decomposable*: if the system can be decomposed into subsystems such that components within a subsystem are interdependent with each other but independent from components belonging to a different subsystem. The size of such subsystems is an an indicator of the extent of interdependencies. If each component forms such a subsystem we are in the case without interdependencies.
- *nearly-decomposable* (or "modular") if the system can be decomposed into subsystems such that most interdependencies are within individual subsystem whereas different subsystems are not fully independent (as in the previous case) but weakly interdependent.
- *non decomposable*: if all components interact with each other and independent or nearly independent subsystems cannot be found.

The reader is referred to Marengo, Pasquali, and Valente (2005) and Marengo and Dosi (2005) for a more detailed and formal treatment of these cases and their properties.

To summarize, at one extreme we have the most restrictive and least realistic case of full separability: the performance contribution of each component is independent of the value taken by other components. Each component can be improved in isolation of the others and the resulting performance surface is smooth.

In the more general case we have instead diffused non-monotonic interdependencies, i.e. an improvement in one component may increase or decrease the overall performance of the system depending upon whether some (possibly all) other components are co-adapted or not. The degree and extent of these interdependencies may vary and render the performance surface more or less rugged.[4] On the one hand interdependencies may be more or less broad: single components may interact with just a few others, or viceversa all n components may interact together. A special but important case is when interactions have a modular or quasi-decomposable structure (Simon 1969, Baldwin and Clark 2000), i.e. when the set of components is divided into subsets characterized by strong interactions within each subset and weak interactions among subsets.

Moreover a further, and related, indication of the intensity of interdependencies is given by the correlation structure of the performance surface. Take product x^i and its performance level $f(x^i)$, then suppose "small" local innovations are made, i.e. only single components are mutated, leaving unchanged the other $n-1$, i.e. find all the neighbors of x^i and their performance. Are such performances very close to $f(x^i)$ or on the contrary small changes in the product components determine large changes in performance? In the former case the performance surface is highly correlated and smooth, in the latter instead correlation is weak and the search for better performing products will be much more complex as the consequences of small local changes will be more abrupt and unpredictable.

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[4] The reader may notice the similarities, but also some important differences, with Stuart Kauffman's rugged fitness landscapes and his NK-model (Kauffman 1993).

All in all, the features of the performance surface describe the *difficulty*[5] of the innovation process. At one extreme we have the case without interdependencies and with high correlation among the performances of similar products, in which autonomous local (i.e. on single components) improvements can generate a stream of steady innovation. Innovation can be effectively decentralized and innovators can specialize on single components or small modules, whereas coordination is effectively ensured by market selection forces. At the other extreme we have non-monotonic widespread interactions which generate uncorrelated performance surfaces. In this case autonomous local changes are ineffective and innovation requires coordinated search on many, possibly all, components together and a deliberate re-designing of the system. Decentralization is highly ineffective in the latter case (see Marengo and Dosi (2005) for a more detailed and formal development of these arguments).

In addition to difficulty (or complexity from interdependencies), it is relatively easy to construct indicators for two other important dimensions of technological knowledge: opportunities and cumulativeness. The former can be modelled as the degree to which performance can be fast improved by innovation in some components of the system. Technological opportunities are high whenever $\frac{\partial f}{\partial x_i} \gg 0$ for some i. Cumulativeness instead indicate that there are increasing returns to research in some components: $\frac{\partial^2 f}{\partial x_i} \gg 0$ for some i.

Finally, we suppose that each product type x_i has an associated variable cost of production c_i which is an increasing function of quality with some random error:

$$c_i = a + bf_i + \epsilon_i$$

where ϵ_i is an idiosyncratic normally distributed error. For the sake of simplicity we set production fixed costs to zero.

4.2 demand

Demand depends upon price, quality and positioning of products in the space of product characteristics. We follow the literature on discrete choice model for products defined in the space of characteristics, and in particular Anderson, De Palma, and Thisse (1989). We assume there exist a finite set C of consumers. Each consumer purchases at most one unit (possibly none) of a differentiated good. Each consumer has an ideal product profile, i.e. his or her type $t^i = [t^i_1, t^i_2, \ldots, t^i_n]$ with $\sum_{i=1}^{n} = 1$. A profile is therefore an ideal combination of characteristics the consumer would prefer to purchase.

A consumer's utility depends upon four factors: product performance, the distance between the product profile and the consumer's ideal one, price and, finally, a normally

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[5] This is only one of the many possible sources of difficulty or complexity of technological innovation, the one which stems from the interdependencies between the parts of the technological system and of the underlying knowledge. Other possible sources are not modelled here.

distributed error. We assume that the elasticities of utility with respect to the first three factors are consumer specific.

All in all, the utility of consumer i buying product x^j is given by:

$$U_i(x^j) = A f_j^{w_i^f} (1/p_j)^{w_i^p} d_j^{w_i^d} \epsilon$$

where f_j and p_j are performance and price of product x^j, d_j is the distance between the product's profile and consumer's i type t_i, $\epsilon \sim \mathcal{N}(0, \sigma)$ is a normally distributed error. Finally, w_i^f, w_i^p and w_i^d are consumer specific elasticities with respect to performance, price and distance and A is a constant.
We call the market space of product x^j the set of consumers:

$$M_{x^j} = \{i \in C; U_i(x^j) \geq U_i(x^h)\} \ \forall h \neq j$$

Demand for product x^j is thus given by the cardinality of the set M_{x^j}.

We assume that consumers are potentially utility maximizers, but also that there is some inertia in their decision, i.e. we suppose that each iteration only a few consumers (in the simulations below we normally set this parameter equal to 1/4 of the population of consumers) may choose to but the product which maximizes their utility, while all the other consumers simply buy again the same product as they did in the previous iteration.

4.3 firms

Firms produce only one type of product exactly in the amount demanded by the market and take decisions on prices and R&D investment. Concerning R&D investment decisions, we follow the philosophy of evolutionary models of technical change and industrial dynamics (Nelson and Winter 1982, Winter 1984, Winter 1993) and assume that firms take routine decisions by applying rules-of-thumb, and in particular that they invest in R&D a given share of their profits. As to price decisions instead we assume that firms are more rational than usually assumed by evolutionary models [6], in particular we make the hypothesis that they are myopically rational. We also assume that prices are sticky and can be modified only after some random intervals.

4.3.1 price decisions

At every iteration one firm is randomly chosen and can modify its price. Also firms launching a new product in the market can fix a new price following to the same procedure. All other firm keep instead their prices unchanged.

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[6] This departure from the philosophy of evolutionary models was chosen because of the main purpose of this model: we want to analyze the advantages and disadvantages of patents, and among the former are the possibility for firms holding important patents to exploit their monopoly power, make large profits and invest them in further R&D and innovation. Setting high prices when possible (and especially when launching an innovative product) is therefore a crucial ingredient of the pro-patent argument.

We assume that the price setting procedure is rational, i.e. is based upon deliberate profit maximizing calculations, but myopic, in the sense that is based upon the assumption that the other firms will not modify their prices and that all and only the consumers for whom the product maximizes their utility will buy it.[7] In brief, we assume that the price setting procedure is the following: the price setting firm computes the highest price at which each individual consumer would buy from the firm itself and then computes the profit maximizing price.

4.3.2 R&D and innovation

Firms invest a share of their gross profits (for simplicity we assume that no external financing is available) in R&D. There can be two types of R&D investment: imitative R&D and innovative R&D. Let us call r_i^M the share on profits of the former and r_i^I the one of the latter, total R&D expenses of firm i will be $(r_i^M + r_i^I)\pi_i$.

We model imitative search (which can take place when not precluded by patent protection norms) in a straightforward way: the imitator can observe the characteristics of the product of the most profitable firm with which it competes and imitate part of it. The number of components which can be imitated is a function of the money invested in imitative R&D, i.e. $r_i^M\pi_i$.

As to innovative R&D, firms may have more or less specialized R&D activities, meaning that they can concentrate their research effort only on one or a few components or viceversa make extensive search on the entire vector of components. We call the scope of R&D of firm i, $1 \leq \theta_i \leq n$ the number of components on which money for innovative R&D is spent. Given the amount invested in R&D and the scope of research, firms engaged in innovative R&D make random draws in the space of components in the neighborhood of their current value, where the size of the neighborhood is directly proportional to the money invested and inversely proportional to the scope θ_i.

Finally, routine decisions on how much to spend into the two types of R&D are subject to adaptive learning, according to a procedure that we basically borrowed from Winter (1984) and is based upon a simple "satisficing" heuristic. Very simply, if a firm has higher then average cumulated profit will keep coefficients r_i^M and r_i^I unchanged. Otherwise it will adaptively adjust them in the direction of the industry's average but with random disturbances:

$$r_i^M(t+1) = (1-\beta)r_i^M(t) + \beta\overline{r}^M(t) + \epsilon_i^M(t)$$

$$r_i^I(t+1) = (1-\beta)r_i^I(t) + \beta\overline{r}^I(t) + \epsilon_i^I(t)$$

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[7] In other words we assume that firms do not act strategically and that they base their pricing decision upon the long term potential profit (though, as we mentioned before, consumers do not immediately all switch to their utility maximizing product) under the assumption that competitors will not modify their decisions.

where $\overline{r}^M(t)$ and $\overline{r}^I(t)$ are the industry average at time t and $\epsilon_i^M(t)$ and $\epsilon_i^I(t)$ are normal i.i.d. random errors.

4.4 patents

In the framework outlined so far it is quite easy to introduce the role of patents. We will first compare a world without patents with one in which patents are legally enforced and than test different strengths of the patent system.

When a firm introduces a new product x^i it can immediately (and costlessly) obtain a patent on it if and only if it meets the patentability standards, i.e. if it differs sufficiently from all products already protected by a patent both horizontally and vertically. In particular, two conditions have to be met for product x^i to be granted a patent:

1. $H(x^i, x^P) \geq H_P$ far all products x^P holding a patent
2. and $V(x^i, x^P) \geq V_P$ far all products x^P holding a patent

The parameters H_P and V_P are called, respectively, the horizontal and vertical patentability standards.

If a product x^P is patented we assume that no other firms can produce any product which is similar enough to it. Thus any new product x^j has two satisfy the following two conditions in order to be marketed:

1. $H(x^j, x^P) \geq H_A$ far all products x^P holding a patent, except those of firm j
2. and $V(x^j, x^P) \geq V_A$ far all products x^P holding a patent, except those of firm j

The parameters H_A and V_A are called, respectively, the horizontal and vertical amplitude of patents and are the outcome of legislation and judicial practice.[8]. Such amplitude parameters are important indicators of the strength of the patent system: the ampler a patent the stronger the protection from imitation and the stronger the legal monopoly power granted to the patent holder. Notice that, in general, $H_P \neq H_A$ and $V_P \neq V_A$, that is the requirements for obtaining a patent and those for legally selling a product both without infringing an existing patent may be different, if anything because usually different subjects are called to decide on the two questions (see again O'Donoghue (1998) for an analysis of the possible consequences of such differences).

Finally, all patents have a finite life as they expire after a number L_P of iterations.

4.4.1 "coarse" vs. "fine" patents

Our model of products as complex systems of interdependent components allows us to tackle the issue of the coarseness of patents. Patents are "coarsest" if they are granted only

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[8] See for instance O'Donoghue (1998) for a detailed analysis of the relationships between standard and amplitude of patents and their consequences for sequential innovation.

on the whole product, if instead they are granted not only on the product but also on each single component they are "finest". In the latter case suppose that firm i introduces a new value for components x_h^i and patents it. As a consequence, no other firm will be allowed to market a product whose $h-th$ component x_h^j is within a distance $|x_h^j - x_h^i| \leq V_A$ from it, nor to patent a product containing a component x_h^j within a distance $|x_h^j - x_h^i| \leq V_P$ from it.

Finer patents place more restrictions on imitation. In fact whereas a patent on a single component x_h^i prevents all other firms from selling products containing that or a similar component, if patents are instead granted only on whole products, that same component could be sold by other firm without breaching the patent, provided it is part of product sufficiently diverse from the patented one. Thus the granting of finer patents is also a sign of an institutional framework more inclined to providing stronger IPR protection.

As already mentioned above, in a Coasian perspective and abstracting from transaction costs, finer property rights should inevitably lead to higher efficiency as they increase the internalization of knowledge externalities.

5 Simulation results

The model outlined in the previous section is relatively rich and complex, with many elements which interact to produce the dynamics of the industry. For the time being we present a few simulations[9] which capture some fundamental properties of the model. For the sake of clarity we begin with a synthesis of the main results obtained so far, then we provide some details for each of them in the following subsections.

The main results can be summarized as follows:

- **product complexity** is an important cause of inefficiency for a strong patent system. In our model innovating firms are capable of exploiting their competitive advantage, reap high profits and re-invest them in further R&D activities. If product complexity is low, this virtuous mechanism determines indeed a loss of efficiency due to prices which persistently remain above the competitive level and determines higher concentration, but in the long run these effects are more than outweighed by higher rates of innovation, higher product quality and higher overall consumers' welfare. If on the contrary product complexity is high, a strong patent system, in addition to leading to higher prices and concentration, is also a cause of lower overall rates of innovation and product quality growth.

- **patent coarseness** is also an important complexity related issue. Are patents

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[9] All simulations are run in the L.S.D. (Laboratory for Simulation Development) platform developed by Marco Valente. The platform may be downloaded along with manuals and tutorials at: http://www.business.aau.dk/ mv/Lsd/lsd.html. Programs for the simulations described in this paper may be obtained from the authors upon request.

granted only on whole products or also on single components? We show that in the latter case patents are much more likely to generate long run inefficiencies even in environments characterized by low complexity.

5.1 The effect of product complexity

The first question we address is whether product complexity is a factor affecting the efficiency of different patent regimes. We mentioned above that concerns have been raised on the possibility that in complex technologies a strong patent system may stifle technological progress because of such phenomena as tragedies of the commons, patent thickets and the like. Our model allows to test this concern in a more fundamental sense and within a dynamic model of industry evolution.

We ran a bunch of simulations in which we tested the properties of different patent regimes in industries characterized by either low or high product complexity. The following figures report the time series of some key variables in an industry without interdependencies among product components respectively with or without the possibility of patent protection (holding equal all other parameters).

In the absence of product interdependencies patents do indeed, in our model, increase overall efficiency and welfare. Although our firms do not choose the level of R&D investment with forward looking rationality but by routinely investing a share of their profits, the higher profits that can by reaped by innovators lead to higher R&D and further innovation.[10] Overall product quality rapidly increases and so does social welfare, in spite of higher prices and concentration. Notice also that in the absence of interdependencies product innovation is relatively “simple”, in the sense that each component can be improved independently of the others: putting more money into R&D therefore increases the probability of finding some better components, and better components inevitably result into better products because of the separability of the product system.

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[10] Notice however that in our model firms are rational enough to exploit the competitive advantage given by product differentiation through innovation and maximize long-term profits. If we dropped this hypothesis and let also pricing decisions be routinized, conclusions on the efficiency of patents might be be different as in Winter (1993).

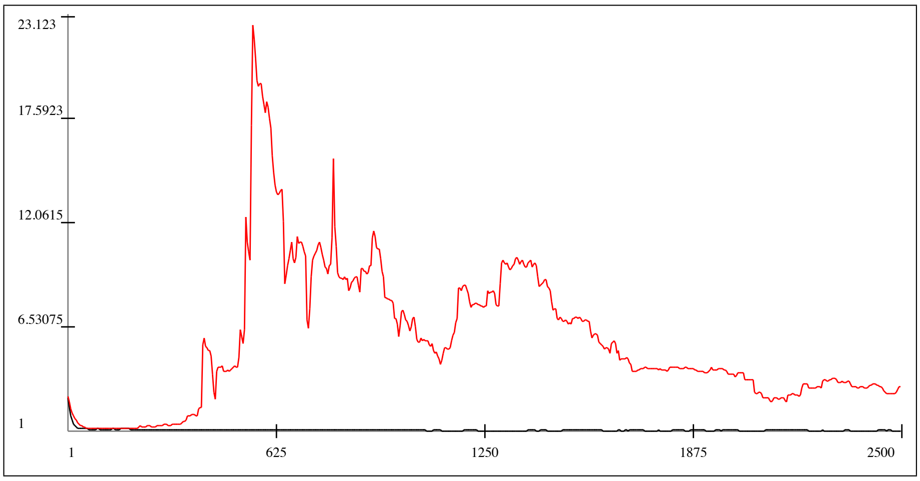

Figure 1: Average price, with patents (red) and without patents (black). (N=10, no interdependencies)

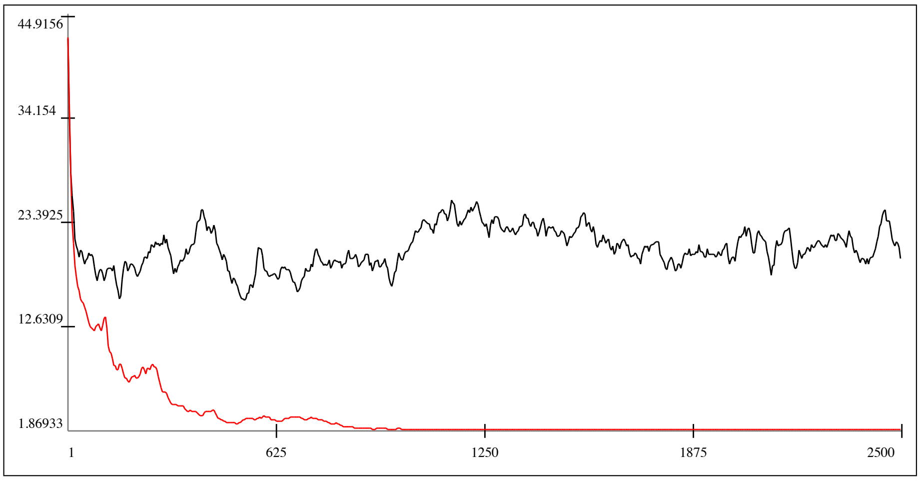

Figure 2: Industry concentration (inverse Herfindal index), with patents (red) and without patents (black). (N=10, no interdependencies)

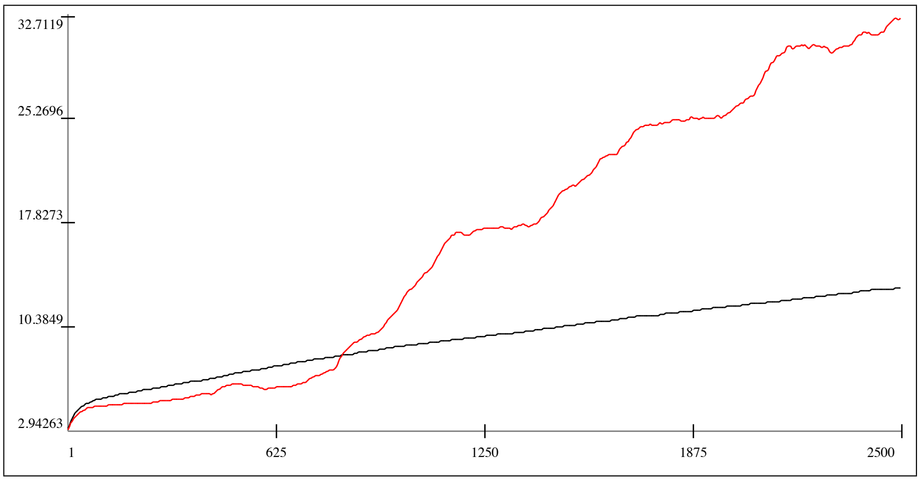

Figure 3: Consumers' welfare, with patents (red) and without patents (black). (N=10, no interdependencies)

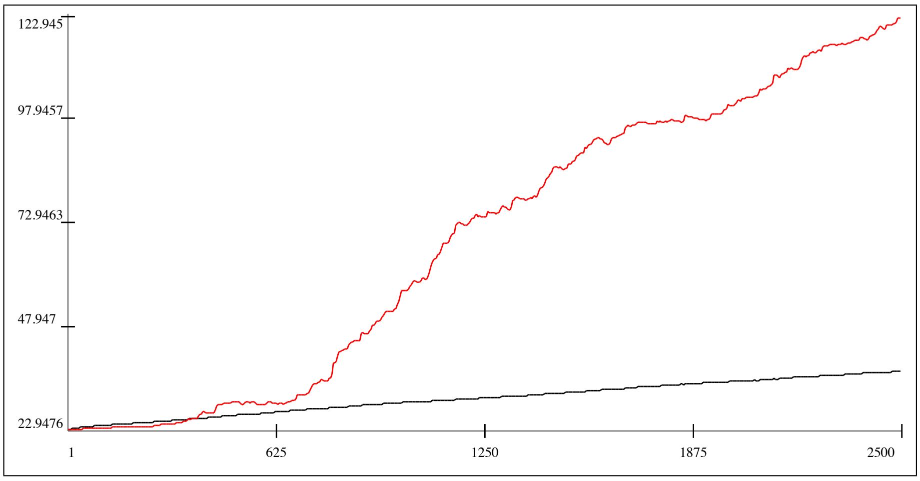

Figure 4: Average product quality, with patents (red) and without patents (black). (N=10, no interdependencies)

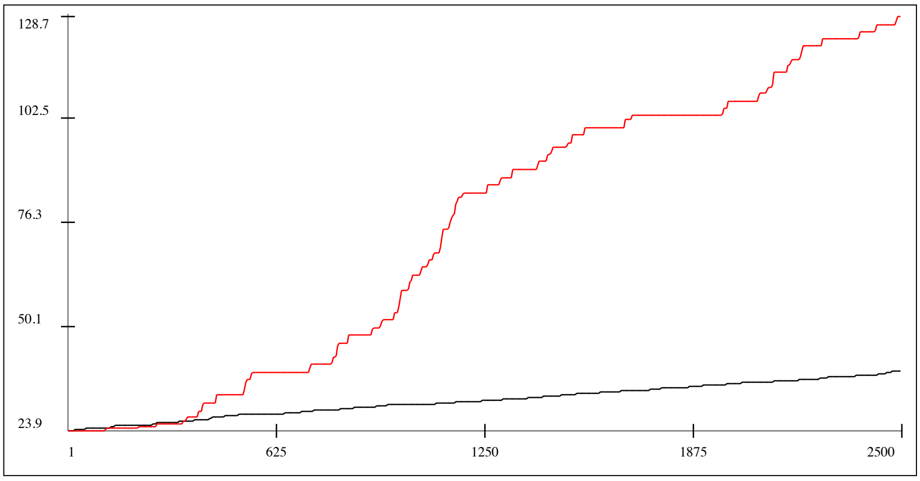

Figure 5: Maximum product quality, with patents (red) and without patents (black). (N=10, no interdependencies)

The following figures present the same variables for an industry characterized instead by high technological interdependencies. It can be noticed that in this case in the absence of patent protection not only are prices and industry concentration lower, but also innovation and product quality show a consistently higher level and therefore consumers' welfare is obviously higher without patent protection.

In the presence of high interdependencies, innovation is far more complex a process: finding better components does not necessarily increase overall product quality, because components have to fit together in some specific way. Holding a patent on a product configuration may therefore *de facto* block many more innovative paths than what established *de jure*. If for instance product $x^* = x_1^* x_2^* \ldots x_n^*$ is a patented innovation and H_A^* and V_A^* are respectively the patent's horizontal and vertical amplitudes prescribed by the legal and judicial system, when products are made of independent component only products which are outside the boundaries around x^* determined by the amplitudes. If instead the product system is characterized by interdependencies, many local innovations may decrease the performance of the product if the rest of the product is not co-adapted, this implies that feasible innovative paths are much fewer than in the case without interdependencies and when such paths pass through a configuration protected by the patent, the entire path may be blocked.

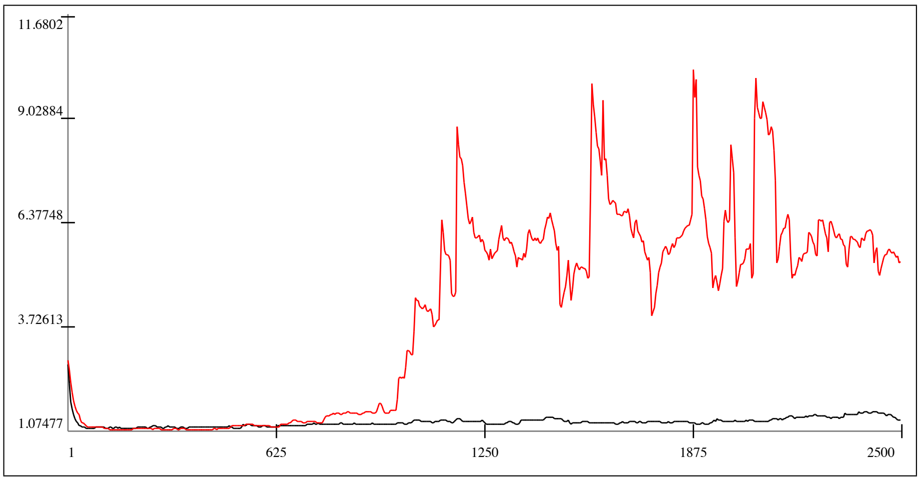

Figure 6: Average price, with patents (red) and without patents (black). (N=10, high interdependencies)

5.2 Coarse vs. fine patents

What is the granularity of patents? That is, can firms patent the whole product, modules thereof or each single component? Coarse patents, granted only on whole products or large modules prevent the marketing of products which are too close (horizontally or vertically) in the whole product (or modules) space, while if each single component is a patent *per se*, a product containing only one components which is similar enough to a

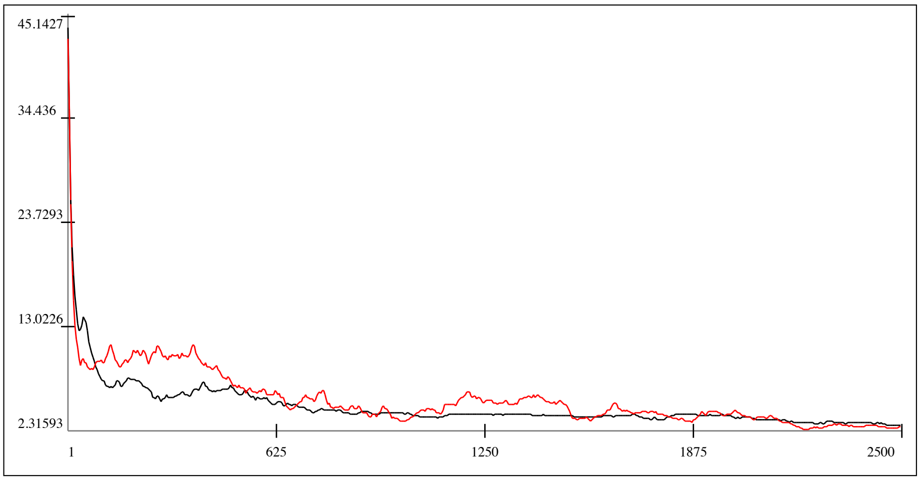

Figure 7: Industry concentration (inverse Herfindal index), with patents (red) and without patents (black). (N=10, high interdependencies)

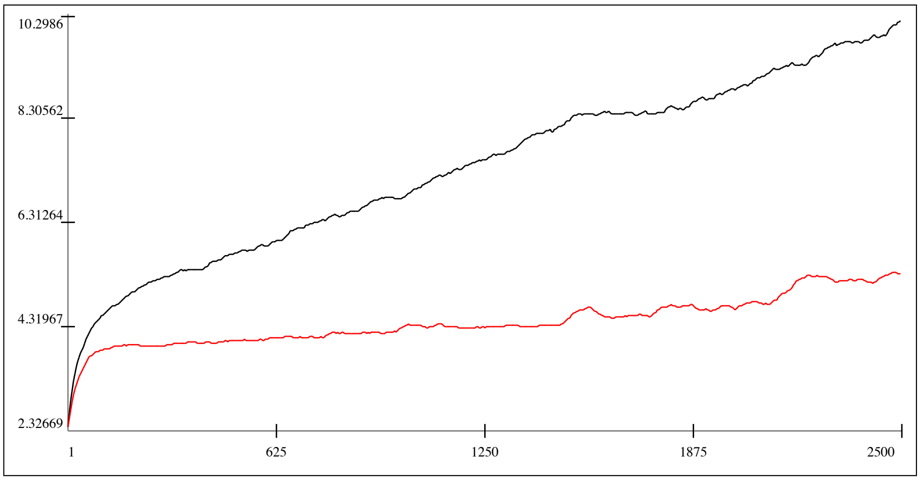

Figure 8: Consumers' welfare, with patents (red) and without patents (black). (N=10, high interdependencies)

patented one can be prohibited.

This phenomenon, which is similar to the tragedy of the anticommons and to the patent thicket problem described by the empirical literature, usually connected to the complexity of products, can indeed emerge also in "simple" highly separable products, as indicated by the following two graphs which report consumers' welfare and average product quality in an industry characterized by full separability with two different patents regimes: one in which only whole products can be patented, and one in which each single components can be granted a separate patent. We can see that in the latter regime both consumers' welfare and average product quality are inferior in spite of the separability of product components.

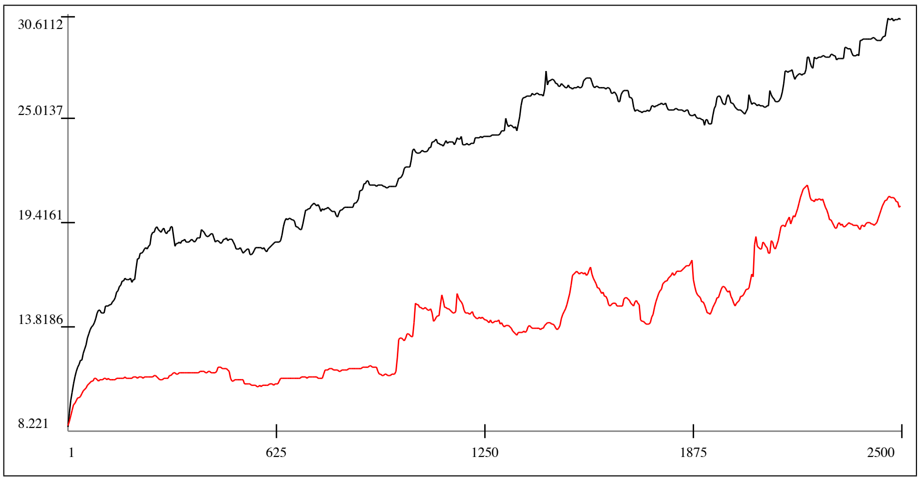

Figure 9: Average product quality, with patents (red) and without patents (black). (N=10, high interdependencies)

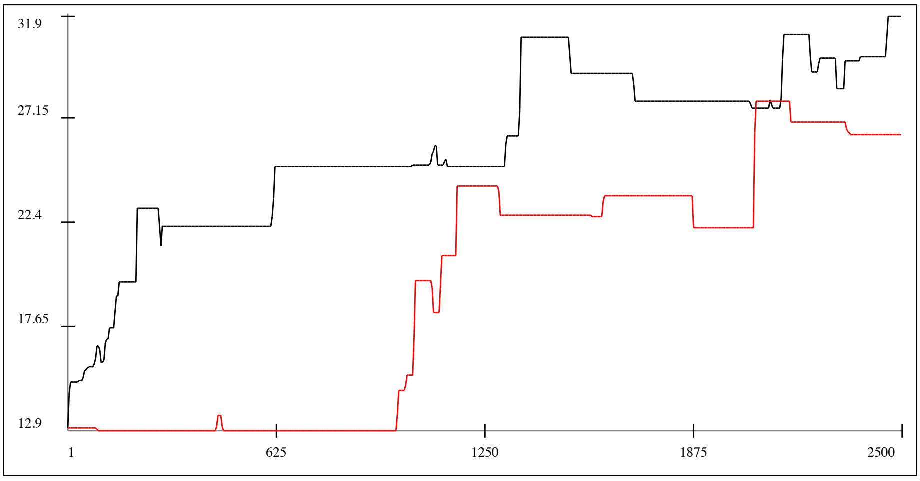

Figure 10: Maximum product quality, with patents (red) and without patents (black). (N=10, high interdependencies)

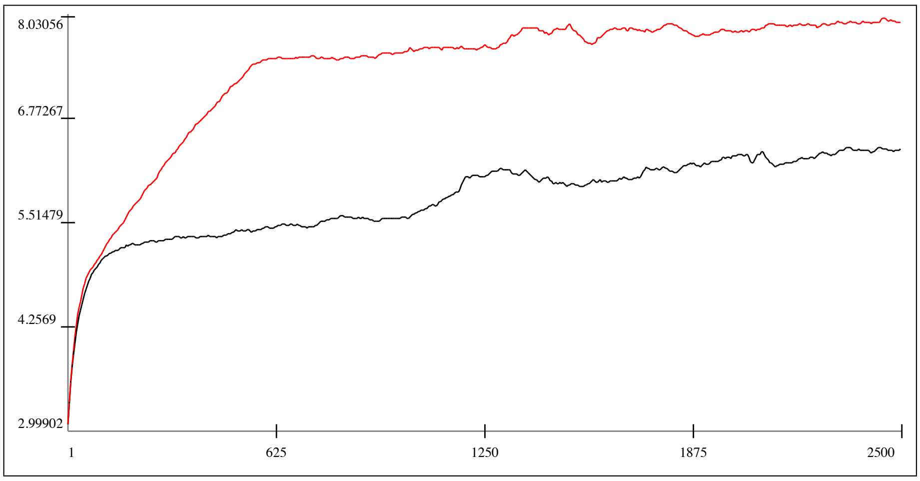

Figure 11: Consumers' welfare, with coarse patents (red) and fine patents (black). (N=10, low interdependencies)

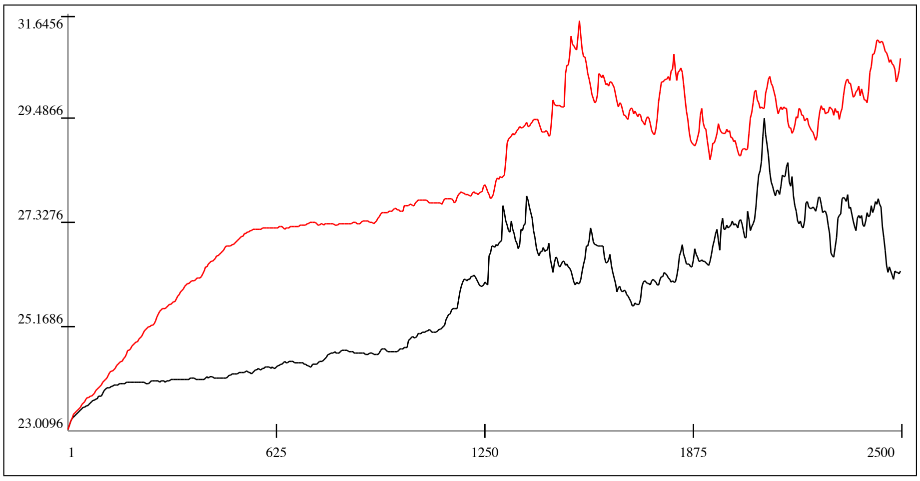

Figure 12: Average product quality, with coarse patents (red) and fine patents (black). (N=10, low interdependencies)

6 Conclusions

Evolutionary models of industry dynamics have greatly contributed to the understanding of the sources and consequences of technical change, but have mostly concentrated on process innovation. Product innovation has attracted a considerable amount of empirical work, but remains relatively understudied in formal models: this is indeed a heavy limitation of evolutionary theory, as product innovation is certainly playing a key role in the current historical phase.

Product innovation poses a few important challenges: the role of demand, the role of product diversification and the creation of submarkets through which firms escape the curse of competition. An important dimension concerns product complexity: many important products are actually complex systems of components and characteristics. How does such complexity influence the dynamics of industry evolution?

Finally, when considering product innovation the role of patent appears more paramount than with respect to process innovation: patents directly confer a monopoly power within a submarket and prevent imitators from serving it directly. Moreover, if the product space is complex, favoring or blocking innovation in single components through patents has effects which propagate throughout the entire product system in ways which are difficult to predict.

In this paper we have approached the study of the effects of patents on the dynamics of an industry and on consumer welfare by means of an evolutionary model of product innovation where firms adaptively search in a complex space of product characteristics and where consumers are characterized by ideal types and look for low prices, high quality and low distance from their ideal type. We show how patents influence the dynamics of industry evolution in this more realistic setting. Our main conclusion is that product / technological complexity is a key factor determining the long run efficiency or inefficiency of the patent system. Within complex product industry patents show in general a wealth reducing effect.

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WORKING PAPER

IP Indices: A difference between principles and practice? A comparative analysis of UK firms' investment decisions into India and China

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Abstract

This paper develops and compares 'experience-based' intellectual property (IP) indicators for two large, emerging markets, namely India and China. Experience-based indicators are often absent in the development of indices of IP strength, which tend to employ more factual indicators based on legislative frameworks, terms of protection, cost of protection and enforcement processes. This paper asserts that the inclusion of experience-based indicators in an IP index provides a more holistic measure of the strength or weakness of a nation's intellectual property institution (IPI) and can provide a valuable insight into whether a nation's IPI is as efficacious to firms in practice as it is in principle.

This paper proposes additional 'experience-based' IP indicators extracted from case-study interviews of fourteen interviewees from ten UK firms who have invested, or have considered investing, in India or China, or both. Both China and India are signatories to the TRIPs agreement and have committed to minimum standards of IP legislation. However, results from the interviews show that there are significant differences in the IPIs of these two nations in practice, particularly concerning the extent to which UK firms are able to protect IP; their perceptions of IP enforcement and the prospect of effective remedies.

Keywords:
IP Indices, FDI Location Strategy, Experience Indicators, Comparative analysis, India and China

Acknowledgements:
The author would like to thank the interviewees from the ten firms who participated in the case-study interviews and for taking the time to share their views and experiences of how the IPIs of China and India have affected their strategic business decisions into these markets.

IP Indices: A difference between principles and practice? A comparative analysis of UK firms' investment decisions into India and China

1. Introduction

This paper compares how differences in the Intellectual Property and enforcement regimes, referred to as the Intellectual Property Institution (IPIs), of India and China, impact the location and investment decisions of UK firms into both markets. On a global scale, innovative businesses with intellectual property (IP) to protect can face risk of imitation, reverse engineering, counterfeiting and piracy in both domestic and world markets. There is already much empirical research to show that the strength of a nation's IP framework impacts on the strategies of businesses concerning location selection and mode of entry (Dunning 2005). The strengthening of a nation's IPI can be an effective means of attracting additional inward foreign direct investment (FDI), not only in terms of location decisions, but also the composition and volume of FDI (Lee, 1996; Smarzynska, 2002). However, it is also recognised that a nation's IP regime is only one of a number of factors that will influence a nation's investment climate and the decisions of firms to enter a particular foreign market. Other factors include labour costs, market liberalization, deregulation, technology development policies and competition regimes (Maskus, 1998). It is, however, not possible to completely separate these factors from a nation's IP framework, because often market liberalization, policy making and regulation are the very factors that drive the efficacy and successful implementation of the IP legislation itself. These factors are potentially more influential in terms of a business making a strategic decision to enter a foreign market. It may be the case that the necessary IP legislation complying with minimum TRIPs standards is in place but enforcement policies, regulations, public commitment and remedial measures must also be visibly in place and working in order for a firm's IP to be adequately protected. This is particularly the case in developing countries where counterfeiting, piracy and reverse engineering practices are high. The ability to bring enforcement actions and obtain effective remedies within a reasonable cost and timescale are important elements of a nation's IPI and, it follows, its investment climate. It follows that IP enforcement has the potential to significantly impact the location decisions of firms.

Much empirical research has been undertaken to quantify and compare the strength of a country's IPI through the development of IP indices (Maskus, 1998). IP indices are used in econometric studies as tools to provide measures for assessing the level of IP protection in a given country and particularly the quantity and type of foreign direct investment, trade and technology a nation attracts from abroad (Pugatch, 2006). As nations become more industrialised the use of their IP systems by firms and individuals increase which tend to indicate growth in investment activity. Much empirical research has been undertaken to show that increasing IPR has a positive effect on inward direct investment levels. As IP legislation strengthens, FDI and licensing increases, although the impact varies by industry. There is a strong influence in sectors such as oil and gas, electronics, information and communication technologies, media and pharmaceuticals (Park and Lippold, 2004).

Mansfield (1996) has researched the relationship with a developing country's system of IP protection and the volume and composition of US foreign direct investment into that country. This study showed that the risk that a firm would take by investing in a market with weak IP would be more dependent on the industry, and not the type of investment it was making. Mansfield also recognises that even if IP laws are passed, there is a time–lag before perceptions are dispelled, and the IP protection and enforcement framework must be convincing. This paper investigates whether the IP frameworks of India and China are convincing to UK firms. To explore this, this study proposes additional 'experience-based' IP indicators to provide a more holistic measure of the strength or weakness of the IPIs of these two nations.

This study extracts the 'fact-based' IP indicators from the most widely accepted IP indices (Pugatch, 2006, Ginarte & Park, 1997, Lesser, 2001, Ostergard, 2001) and incorporates experience-based data from firms investing or considering investing in, China and / or India. Fact-based indicators include: the term of patent protection, restrictions on the use of compulsory licences in patented products, level of piracy and effective remedies and enforcement, enforcement mechanisms. Experience-based indicators include: investment risk-orientation, perception and knowledge of IP laws, piracy and enforcement, levels of financial loss and loss of market share. IP 'indices' tend to be developed using macro-level data, taking a 'fact-based' approach founded on the supranational and national characteristics of nations with respect to matters such membership status of IP-related international conventions and agreements and the state of IP law as it appears in statutes. A patent index, for example, will typically include proxies that capture aspects of primary patent law, signatory status to the Patent Cooperation Treaty and the patent enforcement environment of a nation. Most indices do not adequately incorporate experience-based, micro-level data obtained from foreign firms that engage, either directly or indirectly, with the IPI of nations. Since a unitary value is assigned to a nation's IPI, current IP indices also fail to capture properly how the IPI impacts on different functional areas within a firm. This research uses the framework of existing IP indices and identifies additional 'experienced-based' indicators for both India and China that influence the location and investment decisions of UK firms. Experience-based firm data is obtained from interviews conducted in ten UK based firms which have either invested in and/or are considering investing in India and China. Experience-based data is extracted from interview transcripts taken from departments across the organisational structure including R&D, production, sales, marketing, finance and human resources. It is important for researchers to understand better how different parts of a firm's activities are affected differently when it engages with a nation's IPI. Such an approach minimises individual bias within a firm and provides analysis of how, and at which stages, a firm engages with a nation's IP framework. For example, and R&D department is most likely to be concerned about the legislative characteristics of a patent framework, and a sales department engages with contract manufacture or compulsory licensing. A finance department engages at the enforcement and dispute stages and a marketing department with approvals for information flows and marketing authorisations.

Furthermore, current indices often lack comparative country data which is necessary to predict and compare the quantity of FDI, the composition of FDI and the relative position of a nation's IPI between nations.

1.1 Purpose of the paper

The purpose of this paper is to identify additional ‘experienced-based’ indicators of a nation’s IPI that are extracted from the actual experiences and perceptions of a sample of UK firms investing or considering investing in two specific markets, India and China. The indicators identified in this paper strengthen existing IP indices which are primarily based on ‘fact-based’ data, providing a more holistic and ‘complete’ measure of the IPIs of India and China. The complete indices for both China and India, enables the author to identify and compare the similarities and differences in the IPIs of both countries. Finally, this paper demonstrates that there are both similarities and differences in the experience-based data on IP protection and enforcement disclosed for India and China. Existing indices tend not to provide comprehensive data on cross-country differences, and in particular, is not comparative for India and China.

1.2 Structure of the paper

This paper firstly outlines the justification for a focus on India and China, including why these two nations have been chosen and the need for comparative research. This is followed by a review of the existing academic literature which this paper seeks to enhance. This is followed by an overview of the selection of firms and research methodology. Finally there is a presentation of the proposed indicators for experienced-based data to enhance the existing IP indices, tentative conclusions and indications of the differences between the experience-based data in China and India.

2. Justification for a comparative analysis for India and China

Both China and India are rapidly developing economies and are often grouped together (commonly along with Russia and Brazil, for example, under the expression ‘BRIC countries’) with the assumption that they are similar, particularly in terms of economic size, growth, risk investment and market entry barriers.

Both India and China have over recent years enjoyed significant economic growth and have been identified as ‘priority emerging markets’ potentially offering long term investment and trade opportunities for UK businesses. Both countries have strong industrial sectors, dynamic export orientated economies and are engaged in high technological activity (Lall, 2003). The technological capabilities, together with the current low costs of skills and raw materials, position both India and China as highly competitive economies.

There are strong investment policies in place in both India and China to attract investment from firms from Western countries. For India and China, these will provide benefits in terms of employment, skills and supply-chain development but will also provide stimulation for innovation and technological development in these markets themselves.

Although IP protection and enforcement regimes are in place in India and China the level of protection and enforcement still does not match Western regimes. Although both markets have signed up to the minimum standards of the TRIPs agreement, the weakness in both regimes is with the ability to provide adequate enforcement and remedial action. This paper explores the differences and similarities in the weaknesses in the enforcement regimes in both markets.

Both India and China, for certain products, are already major exporters of counterfeit goods, particularly consumable items, where there is an available market due to low levels of income, demand for necessities and low cost luxury items. This paper explores the extent to which the levels of counterfeiting impact the location and FDI decisions of firms.

Both India and China are members of WIPO, are signatories to the TRIPs agreement, the Paris and Berne conventions on Industrial Property and Literary and Artistic Works, respectively. Both India and China have national legislative frameworks and regulatory bodies relating to Patent, Trademark, Copyright laws and anticompetitive practices. However, although both India and China have similar national laws for IP, and have signed up to similar international conventions and treaties, there are differences in the primary political, social and economic drivers underpinning their IP regimes. This paper explores the extent to which these influence the IPI frameworks, through the experience of UK investing firms.

India and China are very different markets, from a social, economic and political perspective. For example, India is a democratic republic; China is a communist led socialist state. India's social structure is based on a hierarchical caste structure and a number of religious influences; China is predominantly and officially atheist. Political and legal systems in India have developed on a democratic basis, significantly influenced by British governance. However, Chinese systems have developed more latterly to include a constitution, legislative frameworks and human rights regulations. Similarities in these markets include, natural resources and industry sectors; predominant rural population; major trading partners with the US and EU; high investment in skills and education and emerging capabilities in technological development.

North (1990) recognised that the consequences of institutional frameworks on economic performance can vary widely (North, 1990). IPIs in individual countries have evolved and developed as a consequence of political, economic and social influences. The intricacies and complex infrastructures of economies and societies contribute towards the characteristics and unique features of IPIs within each nation. However, supranational institutions (WTO, WIPO) and Western governments seek to protect their IP interests by imposing their IP regimes and frameworks on developing markets. Maskus (2000) questions the 'one size fits all' approach to harmonizing IPIs, citing the different characteristics of markets, products and social institutions. This paper identifies the internal political and social factors influencing the development of IPIs in China and India, on a comparative basis, proposing that the IPIs of both nations are not the same.

3. Literature Review

Much empirical research has been done to develop a comprehensive and standard IP index, which has usually focused on a particular type of IP or a particular sector. There have been a number of IPI indices that have been developed to measure the average levels of IP protection in different countries. IP indices focus primarily on the legislative framework of nations and some include enforcement criteria.

The first study of IP protection was conducted by Gadbaw & Richards, 1998, which identified the level of protection in 7 countries, including India. At this time, IP protection was found to be lower than minimum standards provided by developed countries.

Ostergard (2000) provides a comprehensive index of IPR measurement, covering seventy-six countries. However, this is obtained primarily from US sources and is weak on enforcement data. Rapp and Rozek (1990) predominantly provide an index for patents and do not cover other types of IP. The Rapp and Rozek index is weak on enforcement and does not provide a comparison between IP systems. Seyoum (1996) offers an index across 27 countries, based on US data and is weak on illustrating comparative country data. Sherwood (1997) provides a subjective index, based on personal experience of the researcher which cannot be objectively verified.

The most widely accepted IPI index is by Ginarte and Park (1997), which predominantly measure patent rights of 110 countries and do not capture the relative differences in IP law. Park and Wagh (2002) update the Ginarte and Park index and consequently the index they devise has similar limitations. Smarzynska (2002) extends the index to include more transitional economies and develops a further index adequate comparative country data but is weak on enforcement data. This index also does not properly account for enforcement issues, nor does it provide a comparison between IP systems. Lee and Mansfield (1996) create an index measuring the relationship between IP protection and outward investment decisions. However, this index is criticised for not providing objective comparative data. More recently, Pugatch (2006) has developed an IP Index specifically to capture issues of concern to the pharmaceutical industry and a patent index which captures issues of relevance to the IT industry.

A critical analysis of existing literature shows that fact-based IP indices are recognised as lacking in experienced-based data, which is identified from the following literature:

Pugatch (2006) reviews the strength and weaknesses of current IP indices and recognises that ‘the overall trend is to look at the ‘text-book’ level ‘though there are other more ‘experience-based’ indices’. Park and Wagh (2002) recognise that IP indices tend to relate to the ‘minimum requirements’ of TRIPS, and that a common criticism of the Park and Wagh (2002) patent rights index is that it does not capture actual experiences. Lesser (2001) states that surveys of the *perception* of corruption “as seen by business people”…have the limitation that they reflect perceptions only, but the subject is ‘inherently subjective’ yet ‘perceptions of the quality of governance may often be as important as objective differences in institutions across countries’

4. Methodology and data

4.1 Selection of firms

Firms selected for this case-study research have been identified across a range of sector categories, including software and media, electronics, pharmaceuticals, engineering and construction. Due to the small sample size, the research is not currently sector specific but focuses on country rather than industry differences. Similarly, firms have been selected across a range of size in terms of number of employees and turnover. Firms selected have specifically been targeted as those having an investment interest in China or India, and ideally have invested in, or considered investing in both countries. Firms have also been selected that have protectable IP subject matter, ideally but not exclusively patents.

4.2 Methodology

Experience-based firm data is obtained from interviews conducted in ten UK based firms which have invested in and/or considered investing in India and China. Experience-based data is extracted from interview transcripts taken from departments across the organisational structure including R&D, production, sales, marketing, finance and human resources.

The research evaluates the extent to which the IPI of India and China, particularly the ability of these countries to protect and enforce IPR, influences decision taking of foreign firms. The research measures the effectiveness of the IPI in India and China using a case study method. Case study businesses have been taken from a cross-section of UK outward investors, joint-venture enterprises and exporters into India and China, including both multinational corporations, small and medium enterprises.

5. Empirical Evidence

The interview questionnaire comprises of a mix of open-ended questions and multi-choice questions, where the interviewer was asked to select one box that matched his / her view most closely.

The experience-based data extracted from the interviews have been based on two approaches to analysing the transcripts:

a) A direct correlation between a specific question and a resulting data criterion
b) Extraction of common themes from open-ended questions

The primary findings from the case-study interviews are outlined below:

1. Perception and knowledge of existence of IP legislation

100% of interviewees stated the importance that IP legislation is in place, as this provides the basis for enforcement action, even if the firm is currently unable or unwilling to take anti-counterfeiting measures or bring an enforcement action in China or India.

21% of interviewees were from a firm's legal or contracts team and were familiar with the legislative framework in China and India. The remaining 79% were aware that IP legislation is in place, but not aware of the specific statutes, national laws, conventions and international treaties.

86% of interviewees stated that they were ‘more at ease’ with the Indian legislative framework than the Chinese. This was expressed to be due to the influence and similarities with the British legal system, as both are based on common law, and written in English. This group perceived the Indian legislative framework to be less bureaucratic than Chinese legislation although when questioned further this seemed to be based more on the ‘familiarity’ with it rather than experience of enforcement. Furthermore, this group felt that Chinese legislation was difficult to understand, particularly because of differences in the language and interpretation, but also because of the unfamiliarity with its basis in civil law.

64% of interviewees have experience in both China and India, and perceived Indian legislation to be less problematic in terms of enforcement and obtaining remedies, than in China. However, this group felt that currently enforcement and remedial action is currently too costly and lengthy to consider taking action in both India and China.

100% interviewees expressed the view that the enforcement and remedial action situation is likely, and should improve in the future as both markets become global players.

2. Access to information

1 interviewee, who was not from a firm’s legal or contracts team, expressed a need to know the specific IP legislation in place in both China and India to assist with investment decisions into these markets based on the IP legislation. This interviewee expressed the view that access to accurate and comprehensive legislation on the IP laws in China and India should be available and easily accessible for firms, and stated that currently it is not.

3. ‘Time-lag’ factor

100% of interviewees recognised that IP legislation is in place but that the legislation is not being adequately enforced by the authorities in either China or India. The ability and commitment to take adequate anti-counterfeiting measures is viewed by this group of interviewees as progressing at a very slow pace, and that action to put the legislative framework in place is not being adequately implemented.

93% of the interviewees stated that their firms will currently not take any action against counterfeiters because of the cost, time and uncertainty of the outcome. 64% of interviewees that have experience in both China and India perceive that implementation of legislation in India is happening more quickly than in China but still not sufficiently for firms to consider taking action. Interviewees stated that the problem is inherently within the markets themselves and that they will not alter their investment decisions until there is clear evidence that IP enforcement practices are strengthening.

40% of firms (43% interviewees) had previously taken enforcement action in either China or India. This group expressed the view that having taken enforcement action, the cost, time and outcome did not justify the outcome. This indicates that the time-lag factor between the legislation being passed and being adequately implemented, is real and not simply that a period of time is required to pass before negative perceptions are dispelled. (Mansfield, 1996)

4. ‘Bad-experience’ factor

10% of firms stated that due to a ‘bad-experience’ it would not consider investing in India at all in the foreseeable future, due to a bad experience with a partnership arrangement in India concerning trade-mark infringement. The experience had occurred some years ago, but had financial consequences. It was so significant it has ruled out any investment into India whilst the current management structure is in place. The experience has clearly tainted the perceptions of doing business in India and embedded a lack of trust with Indian businesses across the firm, from the US owners, to the UK operations.

10% of firms stated that due to the ‘reputation’ of how difficult it is to do business in China, and the high risk of counterfeiting, that the firm would not consider any investment into the China market.

5. Likelihood of investing sensitive technologies

10% of firms carry out R&D activity in both India and China, and 20% of firms carry out R & D activity in India. These firms have been present in China and India for a long time with established networks, partnerships and market share. The remaining 80% of firms expressly stated that they would not undertake R&D activities in India or China. However, in this group firms stated that R&D was retained either in the UK or at the head-office, stating that the decision was not influenced by India or China specifically.

90% of firms stated that the type of product that they invested, sold or marketed into China or India was of a lower grade or specification than that sold in European or US markets.

6. Ability to provide ‘value-added’ products or services

100% of firms interviewed that had invested in India or China had some ‘value-added- product or service which enabled them to retain their market share. Although these firms are aware that counterfeiting takes place in India and China, the interviewees stated that they have invested succeeded in obtaining a sufficient market share by having a distinctly different ‘offer’ to the infringing firms. This value added ranged from service delivery, order size, quality, performance, customer care, valued trade-mark or brand. This value added is seen by businesses as a means of mitigating the counterfeiting activity taking place. This finding supports the views of Rapp and Rozek (1990), who recognise in their study that for all industries, patents were deemed least effective means of protecting the competitive advantage of new or improved processes and products stating that secrecy, superior sales or services were all deemed more effective than patents. Findings from this case study research show that despite IP and patent regimes strengthening in India and China, businesses still believe that providing ‘value-added’ in their specific market is more effective than relying on the IP protection and enforcement regime. However, the firms surveyed are generally still reluctant to provide added-value through conducting R&D in India and China or by transferring sensitive technologies to these countries.

7. Partnership trust and relationship development

100% of firms interviewed expressed the importance of partnership trust and relationship development.

60% of firms interviewed have had a presence in China and India for over 10 years and have long established partnerships with customers, joint-venture partners and enforcement agencies. Trust and relationship development is seen in both markets as a key factor to ensuring maximum protection of IP. This ensured that the partners would not leak trade secrets or break confidentiality agreements and this is viewed as an important factor to mitigate against piracy or counterfeiting. Partners in both China and India who were trustworthy could develop relationships with IP enforcement agencies, effect enforcement action, and assist in ensuring the protection of the Principal's IP.

8. Anti-corruption policies (state and investor)

100% of interviewees stated that a significant barrier in both China and India to enforcing and protecting IP is because of the extent of corruption in both markets. This group recognised that corruption occurs at high levels within the local authorities and administrative agencies of the state. This group also stated that corruption practices often extended to local authorities protecting the pirates and counterfeiters who are often located in rural or economically undeveloped communities. All firms interviewed stated that the practice of corruption within India and China is the single greatest factor that impacts on the ability to protect and enforce IP rights, and that the governments of India and China need to operate a zero-tolerance approach to corruption, to enable their IP frameworks to work.

100% of interviewees recognised that IP legislation is more strictly enforced in the more developed and industrial locations in both China and India, but less effectively enforced in the rural and less industrialised communities.

93% of firms stated that they perceived corruption in China occurring to a greater extent than in India. This group stated that the reasons for this are due to differences in culture, the perception of IP by individuals in society, the existence of corruption at higher levels than in India, and the lack of state control of corrupt practices.

80% of firms stated that they expected the IP frameworks in both India and China to improve within the next 10 years, because of the way the countries are developing themselves, and the need of their own industries to protect IP.

100% of firms interviewed stated that they have a zero-tolerance approach to bribery and corrupt practices in China and India, and that such practices must be eliminated from any IP enforcement or remedial action process.

9. Cultural differences (state, businesses and communities)

90% of firms stated that understanding the legislative framework and being able to take enforcement action, in India is easier than in China. This group recognised that there are marked cultural differences between the UK and China.

10. Inability to measure financial loss due to piracy

90% of firms interviewed stated that they were certain that counterfeiting of their products was taking place, definitely in China and to a lesser extent in India. No firm had quantified this financially in terms of the cost of loss of business or market share. 60% of this group stated that quantifying this loss would be virtually impossible to do and were unsure how this would be quantified. This group stated that the cost of investigating the financial loss would outweigh the benefits. 40% stated that although difficult, this financial loss should be quantified.

11. Inability to measure loss of market share due to piracy

90% of firms stated that they have lost market share due to piracy, but had not quantified this. Reasons stated were similar to 10 above. This group stated that provided the market in China and India remains profitable and lucrative, the cost of assessing the loss of market share would outweigh the benefit.

12. Incentive to Commence Proceedings

90% of businesses investing in India and China stated that they would not even consider enforcement or court action because it is not economically viable. Businesses are aware that infringement is happening, but are not taking action under the current legislative climate. Those businesses who have taken action, have had very limited success and are either not aware of the final outcome after reporting an infringer, or they are aware that an infringer has moved on and set up elsewhere. In some cases businesses were reluctant to take action because it just 'moved the problem on to a competitor'. Businesses generally felt that the IP situation was improving, slowly, more so in India than China. However, they would need to be on a par with regimes in the West to even consider taking action. It also considers the experiences of businesses who have considered enforcement and the barriers and activities that take place that make taking action appear to be impossible.

13. Cost and speed of enforcement

100% of interviewees stated that confirmed that the cost and speed of enforcement was completely prohibitive to taking action. The length of time, and the uncertain outcome in most cases, ruled out taking enforcement action. This is the case for both China and India, although India is perceived as being slightly better than China.

14. Understanding the process

Interviewees felt that the process for enforcement in India was clearer and that judges had a legal training similar to the British legal system. The laws and legal processes in India are constructed similarly. The process in China is very unclear, partly because of the levels of corruption, which could make the process much quicker, but all firms had strict corporate policies concerning anti-corruption practices.

15. Transparency and communication of decisions

100% of firms stated that in both India and China the process for IP enforcement is not clear and the outcomes are often unsupported in terms of the reason behind the decision. Decisions are made without stated reasons and decisions can be changed or overturned without a clear and stated reason. The basis for decisions is not clearly stated, but given as broad, general statements which do not assist with lodging an objection or appeal.

6. Conclusions

This paper proposes that firms are taking strategic decisions to enter both China and India, despite their perceptions that their IP is effectively unenforceable due to cost, time and unsatisfactory outcomes. Firms are using alternative location and sales strategies to mitigate against the occurrence of counterfeiting activity, or the inability to take enforcement action. Findings from this case study research show that despite IP and patent regimes strengthening in India and China, businesses are using 'value-added' market entry strategies to protect market share as a more effective mechanism than relying on the country's IPI. Indications show that businesses are still reluctant to provide added-value through investing R&D or sensitive technologies. This is the case for both markets.

Findings show from this small sample, that if a firm finds the right business partner, they are more likely to invest in either China or India. China is perceived as a more risky and difficult market, but this depends partly on the industry, and the market structure. Firms that do invest in China and India seem to do so irrespective of the IP framework. Their decisions to invest are based on other factors and economic motivators which are measured against the IP risk factor. Firm's who do invest in China and India, do so in a more considered and measured way, by finding the right market entry model that minimises loss of market share, through 'value-added' sales and marketing.

Table 1 (experience-based indicators)

Legislative Framework	**Fact-based Indicators ***	**Experience-Based Indicators**	
National Laws	Term of Patent protection	1	Knowledge of existence of IP Laws
TRIPS	Use of compulsory licences in Patented products	2	Access to Comprehensive & Reliable Information
PCT	Levels of Piracy	3	'Time-lag' factor
Membership of International Conventions	Effective Remedies	4	'Bad-Experience' Factor
	Effective Enforcement	5	Likelihood of investing sensitive technologies
	Strength of Exclusivity	6	Ability to provide 'value-added' product or service
	Ban on Parallel Imports	7	Partnership trust & relationship development
	Policing Actions	8	Anti-corruption policies (state and investor)
	Imprisonment	9	Cultural differences (state, businesses and communities)
	Free use of Brands in Packaging	10	Inability to measure financial loss due to piracy
	Loss of Protection	11	Inability to measure loss of market share due to piracy
	Revocation of Conditions	12	Incentive to commence proceedings
	Enforcement Mechanisms	13	Cost & speed of enforcement
	Duration of Protection	14	Understanding the process
	Adequacy of Court Systems	15	Transparency & communication of decisions
	Administration Procedures		
	Appeal Process		
	Public Commitment		

Sources: Pugatch 2006, IT and Pharmaceutical Indices; Ginarte & Park (1997); Lesser (2001); Ostergard (2000)

Table 2 (company matrix)

Company ID	Number of Employees)	Turnover Band	Industry Sector	Department Interviewed	IP Protected	IP Market I = India C= China	Type of Investment *	Investment Market I = India C= China	
A	**0-100**	**0-5m**	**Software**	**Management**	**Business Methods Trade Marks**	**I I I**	**Production Distributor License Agreement**	**I I I**	
B	**5000+**	**5b+**	**Pharmaceuticals**	**R&D, Legal (Patents and Trade Marks**	**Patents Trade Secrets Business Methods Trade Marks**	**CI CI CI CI**	**Manufacturing R&D Facilities**	**CI CI**	
C	**1000-5000**	**500-1b**	**Engineering**	**Management**	**Patents Trade Secrets Business Methods Trade Marks**	**CI CI CI CI**	**Exporting Branch Office Processing Manufacturing Equity JV W/o Subsidiary Distributor License R&D**	**CI CI CI CI C I CI CI CI**	
D	**500-1000**	**5m-500m**	**Engineering; Environmental**	**Management, Legal**	**Patents Trade Secrets Trade Marks Registered Designs**	**CI CI CI CI CI**	**Exporting Branch Office Processing Manufacturing Distributor License R&D**	**CI CI CI CI CI CI I**	
E	**0-50**	**0-5m**	**Software**	**Management**	**Trade Marks**	**I**	**Exporting Distributor License**	**I I I**	
F	**1000-5000**	**500m-1b**	**Electronics**	**Sales**	**Patents Trade Secrets Business Methods Trade Marks**	**CI CI CI CI**	**Exporting Branch Office Equity Joint Venture Wholly Owned Subsidiary Distributor**	**I I I I I I I**	
G	**100-500**	**5m-500m**	**Chemicals**	**Management**	**Patents Trade Mark**	**CI CI**	**Exporting Branch Office Assembly Manufacturing Subsidiary Distributor**	**CI C C C C I**	
H	**100-500**	**5m-500m**	**Engineering**	**Production, Purchasing**	**Patents Trade Secrets Trade Marks**	**CI CI CI**	**Exporting Branch Office Processing Manufacturing W/o subsidiary Distributor License**	**C C C CI C C CI**	
J	**100-500**	**5m-500m**	**Construction**	**R&D**	**Patents Trade Marks**	**C CI**	**Branch Office Manufacturing W/o subsidiary**	**C I CI**	
K	**100-500**	**5m-500m**	**Construction**	**Legal**	**Patent Trade Secrets Trade Marks**	**CI CI CI**	**Exporting Assembly Manufacturing Joint Venture Distributor License**	**CI CI CI C CI C**	

Note: Types of Investment are either investments that firms are currently making, or would consider making in the markets specified

Appendix 1

India and China Economic Data:

	China	**India**
Population	**1,321,851,888**	**1,129,866**
Population Growth Rate	**0.606%**	**1.606%**
Government Type	**Communist State**	**Federal Republic**
Religions	**Atheist (Daoist, Buddhist)**	**Hindu, Muslim, Christian, Sikh**
Literacy	**90.9%**	**61%**
Legal System	**Civil Law**	**English Common Law**
GDP (PPP)	**$10.17 trillion**	**$4.156 trillion**
GDP growth rate	**10.7%**	**9.2%**
GDP by sector	**11.9% agriculture** **48.1% industry** **40% services**	**19.9% agriculture** **19.3% industry** **60.7% services**
Labour force	**798 million**	**509.3m**
***FDI Inflows 2005**	**US$72,406million**	**US$6598million**

Sources: CIA World Factbook
*** UNCTAD (2006) World Investment Report**

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How good are VCs at valuing technology? An analysis of patenting and VC investments in nanotechnology

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Abstract

This paper analyzes how VC firms evaluate the patent portfolios of startup companies in their financing decisions. On one hand, we determine whether the amount of VCs' financing is associated with the size, technological composition and scope of patent portfolios of startup companies. On the other hand, we examine whether the valuation of patents varies across different types of VC firms, depending on their degree of industry specialization and affiliation. We provide empirical evidence from a sample of 332 VC-backed companies in the nanotechnology sector.

Key-words: venture capital, patents, specialization, nanotechnology

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How good are VCs at valuing technology?
An analysis of patenting and VC investments in nanotechnology

1. Introduction

The economic literature points to a superior ability of Venture Capital firms (VCs) in accurately assessing the value of early-stage companies' technological capabilities and patent portfolios. For instance, previous studies has shown a positive association between patenting rates and total amount of VC financing (Baum and Silverman, 2004; Mann et al., 2007) and between the breadth of patent protection and VCs' valuation of new companies (Lerner, 1994). Moreover, previous work has examined the effects of venture capital on patented innovations at the industry level (Kortum and Lerner, 2000; Lerner, 2002) or at the company level (Bertoni et al., 2006), showing a positive association between venture capital and patent productivity.

In general, however, there is only a limited understanding of the determinants of patent value that are more directly taken into consideration by VC firms in their investment decisions. On the contrary, it is likely that such decisions are influenced by other factors in addition to simple patent counts and patent scope. In particular, no attempt has been made in the literature to assess whether VCs value the *technological composition* of patent portfolios in their investment decisions.

In addition to that, it should be noted that there exists a high heterogeneity in the characteristics of VC firms as well, in terms of age, affiliation, managerial style, reputation, previous experience, stage and industry focus. It is thus likely that VCs differ in their ability to effectively value the size, composition and scope of patent portfolios. In particular, several scholars have acknowledged the importance of maintaining a high degree of specialization for controlling risk and gaining access to networks and information, or possessing a deeper knowledge of the ventures' environment (Gupta and Sapienza, 1992; Norton and Tanenbaum, 1992). Specialization might confer competitive advantages in terms of reduced information asymmetries and uncertainty in the valuation and selection process (Cressy et al., 2007). Moreover, the affiliation of the VC firms, separating Independent Venture Capitalists from Corporate Venture Capitalists, is likely to assess their selection criteria and valuation skills as well, due to differences in objectives and capabilities (Bertoni et al., 2006; Gompers, 2002). All these studies suggest that the ability to evaluate technology and intellectual property might not be the same for all VCs, but it might be a function of their degree of specialization in the industry and type of affiliation.

However, to our knowledge no attempt has been made in the literature to assess whether and how VCs consider the technological composition of patent portfolios in their financing decisions, or whether they differ in their valuation ability. In this paper, we address such issues by investigating how different characteristics of startups' patents influence the VC financing process. More specifically, the purpose of the paper is twofold: on one hand, we determine whether the amount of VCs' financing obtained by the company is associated not only with the size and scope of start-ups' patent portfolios, but also with its technological composition, in particular for what concerns the share of patents belonging to core technological areas for the company. On the other hand, we examine whether the valuation of patent portfolios varies across VCs, depending on their affiliation and degree of industry specialization. We argue that the VC's ability to assess the patent portfolios of the investee company should be better-off if the VC is specialized in the same industry of the investee company and if the VC is affiliated to a corporation.

We analyze such topics in the emerging field of nanotechnology, defined as the study and use of the unique characteristics of materials at the nanometer scale. Although nanotechnology is still at an early stage of development and its full market potential will disclose in the next years, there has been a real "boom" in the number of nanotechnology patents registered all over the world, as well as in the number of nanotech ventures financed by VCs. This field thus represents an ideal setting to test our predictions.

Our sample includes all VC-backed companies in the nanotechnology sector identified by the commercial database Venture Expert over the period 1985-2006, corresponding to 332 companies. For each VC-backed company, we collected information about the total amount of VC financing obtained in the initial investment round and on the size and composition of the patent portfolios at that date. In particular, we were able to identify those patent applications more directly related to nanotechnology, by using the code Y01N, recently introduced by the European Patent Office in order to facilitate interdisciplinary searches and monitor trends in nanotechnology. We complemented such information by gathering data on the affiliation (Independent vs. Corporate) and the number of investments (both in the nanotechnology sector and in all sectors) of all the VC firms investing in nanotechnology. For each VC firm, these data were used to construct measures of type of affiliation and degree of investment specialization in nanotechnology (Cressy et al., 2007).

Results from our regression analyses show that the simple number of patents applied by the company before the first investment round does not have a significant impact on the amount of financing received, controlling for the age, the stage of development, the degree of market diversification, the location of the company. On the contrary, the stock of patents belonging to the nanotechnology class has a positive and significant effect on VC financing. Moreover, VCs specialized in nanotechnology tend to place more value on nanotech patents in their financing decisions than unspecialized VCs.

The rest of the paper is organized as follows. We first briefly summarize previous literature which have addressed the relationship between patenting and VC investments. Moreover, we discuss the association between the degree of specialization of the VC firm and its type of affiliation and its ability to evaluate patent portfolios of the investee company. We then describe the nanotech sector, the sample and the variables used in the empirical analysis. We turn to present the results of different regression analyses. In the final section we outline the main conclusions to be drawn from the theoretical and empirical analysis, and discuss the implications for future research.

2. Background

Venture Capitalists (VCs), i.e. financial intermediaries investing equity in young companies, are a distinct type of investors for entrepreneurial companies operating in dynamic and uncertain industries. The activities of VCs can be generally represented as a process involving five major steps: deal origination, deal screening, deal evaluation, deal structuring and post investment activities (Tyebjee and Bruno, 1984).

We focus on the second and third step, in which the venture capitalist applies a set of criteria to conduct preliminary and detailed analyses of the ventures and decide which ventures will be funded. VCs attempt to assess the probability of success or failure by evaluating information surrounding the particular venture. To receive funding, new ventures must pass an initial screening (typically a review of the business plan) followed by a complex process of due diligence.

The importance of understanding in more depth the selection criteria adopted by VCs is linked to the fact that early-stage companies have a very little performance history to adopt conventional financial methods. Thus, one of the major peculiarities of VC investments is the difficult and uncertain valuation on which the selection process is based. The venture capitalist has to rely on a subjective assessment procedure driven not only by the start-ups' business plans, but also by a multidimensional list of characteristics.

A deeper understanding of the criteria employed by successful VCs in evaluating new ventures, in particular for what concerns the role played by patent portfolios, is important for two main reasons: from the VCs' point of view, it would provide a useful framework for evaluating entrepreneurial ventures and reduce the failure rates of the new ventures they finance. From the entrepreneurs' point of view, it could clarify the factors leading to a higher likelihood in obtaining VC financing.

2.1 Criteria adopted by VC firms in the evaluation of startups

Several studies have tried to highlight the most important features considered by VCs in the selection of new ventures to fund. Zopounidis (1994) provides a useful summary of these works, dividing them according to the different methodologies applied: descriptive methods, evaluation using linear statistical methods and multi-criteria evaluation. Looking through such categorization, these works yield almost the same set of investment evaluation criteria. In particular, three major studies provide some generally useful ranking of the relative importance of various decision factors.

Tyebjee and Bruno (1984) conduct a factor analysis, finding that VCs evaluate potential deals in terms of five basic characteristics: market attractiveness, product differentiation, managerial capabilities, environmental threat resistance and cash-out potential. Also, Muzyka, Birley and Leleux (1996) provide a comprehensive list of the evaluation criteria considered important by venture capitalists, obtaining similar key characteristics: financial, product-market, strategic-competitive, fund, management team, management competence, and deal criteria. Finally, the study by

MacMillan, Siegel and Narasimha (1985) identified 27 criteria categorized into six groups: entrepreneurial personality, entrepreneurial experience, characteristics of product or service, characteristics of market, financial characteristics and venture team. They also refer these clusters to six different types of risk, depending on the source stemming them, internal (management and leadership) or external (industry, markets and competitors) to the firm: risk of losing the entire investment, risk of being unable to bail out if necessary, risk of failure to implement the venture idea, competitive risk, risk of management failure and risk of leadership failure.

A further attempt to refine the criteria into a broader classification tries to split the studies into two macro-categories, depending on the criteria on which the studies focus their analyses. The first group includes studies interested in the characteristics of the entrepreneurial team as a potential driver of the investment decision by VCs. The second group, instead, explores the importance of the technological capabilities developed by the new venture and investigates their relationship with the likelihood of VC financing. We will briefly summarize the findings of the former group of studies, and then focus in more depth on the latter group in the following section, given its relevance for the purpose of our paper.

Concerning with the importance of the entrepreneurial team, there is a strand of literature relating educational and management experience to the amount of financial resources obtained by the venture. MacMillan, Siegel and Narasimha (1985), administering a questionnaire to a group of 14 VCs in U.S., highlight that the most important criteria determining whether or not a VC will finance a start-up is the quality of the entrepreneur in terms of his/her experience and personality. Drawing on human capital-based studies, Bates (1990) finds that educational skills are positively correlated with the received financial resources in entrepreneurial ventures. A study by Kaplan and Stromberg (2004) suggests that the experience of start-up management teams is important in guiding the investment decisions by VCs. Fried and Hisrich (1994) advise that social ties are an important reason for investing, because they help in the screening of activities with a high potential growth. Also in a recent study by Hsu (2007), the importance of social capital in the VC's valuation process is investigated. The results suggest that prior founding experience, founders' social network (considered as a tool to recruit executives) and founding teams with a doctoral degree holder are positively related to the likelihood to be funded with higher valuations.

2.2 The relationship between patenting and VC investments

In addition to the abovementioned factors, the economic literature points to a superior ability of VCs in accurately assessing the value of new ventures' technologies and patent portfolios. The majority of the studies confirms that patents are an important signal of a startup's innovative capabilities and ability to obtain complementary resources, increasing the likelihood that it will obtain VC financing.

Kortum and Lerner (2000) examine the patterns that can be discerned at the aggregate industry level rather than at the company level. The authors examine the relationship between the total number of patents issued at the USPTO and the amount of VC financing across 20 manufacturing industries between 1965 and 1992 in the United States. They observe that increases in VC activities in an industry are associated with higher patenting rates. Furthermore, this causality disappears when the impact of VC is measured in terms of patent-R&D ratio, rather than number of patents.

In a study of 204 biotech startups that were founded in Canada between 1991 and 2000, Baum and Silverman found that startups with more patent applications and grants obtained significantly more VC financing. A recent study by Mann and Sager (2007) in the software and biotechnology industries investigates the relationship between number of patents, receipt of venture financing and progression trough the VC cycle. Its findings suggest that patenting increases the likelihood of start-up firms to receive VC financing, even though the relationship seems to be present in later financing rounds, but weak, if not absent, in initial ones. It shows also that the relationship between patenting rates and VC financing depends less on the size of the patent portfolio than on the firm's receipt of at least one patent. However, the study does not address the causation issue, related to the possibility that funding might facilitate patenting.

Besides presenting some controversial results, the literature on this topic provides a limited understanding of the determinants of patent value that are more directly taken into consideration by VC firms in their investment decisions. On the contrary, it is likely that such decisions are influenced by other factors in addition to simple patent counts. An exception is represented by work by Lerner (1994), predicting that the breadth of patent protection is significantly associated with higher valuations by VCs. His regression analyses based on a sample of 535 financing rounds at 173 VC-backed biotechnology companies show that patent scope (as proxied by the count of different IPC classes to which the patent is assigned) positively affects the valuation of new biotech companies by VCs.

However, all the abovementioned studies have made no attempt to assess whether and how VCs consider the technological content of the patent portfolios in their financing decisions, or whether they differ in their valuation ability. In this paper, we first address the former issue, by investigating how the technological composition of the startup's patent portfolio influence the VC financing process. Not only in fact patents differ in their potential economic value, but they also differ in terms of fit with the core technological capabilities of the company. When deciding to invest, for instance, in a biotech or a nanotech startup, it is likely that VCs put more emphasis and importance in the assessment of those patents that are more directly related to the core business of the company. As a first contribution of the paper, we therefore intend to assess whether VCs value the technological contents of the investee company's patent portfolio, in addition to its size and scope, during the selection and financing process.

We then turn to examine whether the selection skills (i.e. the ability to appropriately value a technology) vary across different types of VCs, depending on their degree of industry specialization and on their affiliation, as discussed in the next section.

2.3 The heterogeneity of VC firms and its impact on the valuation of patent portfolios

The role of specialization: specialist vs. generalist VC firms

Most of the financial and strategic literature on venture capital tends to consider VC firms as an homogeneous group, ignoring their significant differences in objectives, investment decisions and managerial styles. On the contrary, more recent work has showed that VC characteristics – and in particular their degree of specialization in a particular industry - can make a difference with respect to the outcome of their investments (Cressy et al., 2007; Gompers et al., 2005).

VCs adopt different strategies as to the composition of their portfolios of investments (Gupta and Sapienza, 1992; Norton and Tenenbaum, 1993). Some VC firms tend to specialize in specific industries and development stages, so to acquire expertise and gain greater value, whereas others follow a more generalist approach, diversifying their investments across a wide variety of industries and technologies. For instance, the empirical study by Gupta and Sapienza (1992) shows that VCs focusing in early stage ventures prefer less industry diversity and narrower geographic scope when compared to other VCs. Furthermore, larger VCs prefer greater industry diversity and broader geographic scope than smaller VCs.

Following the predictions of the resource-based theories of the firm (Barney, 1991), previous experience cumulated in a given industry thanks to specialization might allow VC managers to gain a better understanding and deeper knowledge of the technological, market and competitive specificities of the investee companies' context. This, in turn, might facilitate not only the correct assessment of new investment opportunities, but also allow them to effectively add value to the investee companies, through more competent monitoring and advice. Busenitz et al. (2004) point out that VCs' learning should result in long-term positive performance implications, given that a VC investor with a significant experience of both successes and failures in a industry could have gained a deeper insight into how to select potential "winners" and improve their performance over time.

Norton and Tanenbaum (2002) acknowledge the importance of maintaining a high degree of specialization for controlling risk and gaining access to networks and information. Similar results are found also by Cressy et al. (2007) who argue that possessing a deeper knowledge of the ventures' environment confers competitive advantages in terms of reduced information asymmetries and uncertainty in the valuation and selection process.

The critical role played by the specialization has been also highlighted by Gompers et al. (2005) who point out that, when there are complementarities and a direct relationship among the investments embedded within the portfolio, the VC firm more quickly liquidates its investments through IPOs and with higher valuations. Building on such results, the Authors thus recognize "[…] the importance of industry-specific human capital and the network of industry contacts to identify good investment opportunities, as well as the know-how to manage these investments" (Gompers et al., 2005, p.5).

These studies suggest that the ability to evaluate technology and intellectual property might not be the same for all the VCs, but it might be a function of their degree of specialization in the industry. Thus, we expect that the VC's performance in the assessment of patent portfolios should be better-off if the VC is specialized in the same industry of the investee company.

The role of affiliation: Independent vs. Corporate Venture Capitalists

Concerning the heterogeneity of VC firms, a further distinction can be drawn between Independent Venture Capitalists (VCs), where the capital is provided by professional financial intermediaries, and Corporate Venture Capitalists (CVCs), where the investor is a non-financial entity. The two types widely differ in terms of incentives, monitoring behavior, time horizon, scale of capital invested and the set of objectives pursued (Chesbrough, 2000). As far as the last dimension is concerned, VCs have the dominant financial aim to liquidate their investments through IPO or selling out the company to a larger firm in the shortest possible time. Differently, CVC is generally considered as a way to capture the value from strategic assets, open up a window on new promising technologies or businesses, respond more competitively in dynamic industries and support demand for core products (Brody and Ehrlich, 1998). CVC can be useful to accelerate market entry, monitor technological changes that could affect further strategic investments, provide access to highly qualified human capital, create new opportunities, develop an entrepreneurial culture and increase internal efficiency of R&D (Dushnitsky and Lenox, 2006). The existence of these critical differences explains the need to analyze VC and CVC as autonomous forms of new ventures financing.

In the previous literature, such evidence led to the analysis of the distinct contributions of VC and CVC to innovation, and broadly to ventures' growth. More precisely, the economic literature frequently points out the active role of VC in the businesses they finance, not only through monitoring, but also by providing valuable support and governance. For instance, previous studies have shown the significant role played in terms of professionalization of start-up firms (Hellmann and Puri, 2002), the improvement of ventures' performance at the IPO (Brav and Gompers, 1997) and the positive association between VC and patenting rate (Kortum and Lerner, 2000). About CVC, several studies point out its role as an important source of technological innovation for corporations, by providing a window on emerging technologies, market opportunities and new business models (Markham et ali, 2005). Jain and Kini (1995) compare the growth of VC and CVC-backed firms with non-VC counterparts, finding that the former outperforms the latter. In a recent study by Bertoni, Colombo and Grilli (2007), the results suggest that, even though both VC and CVC positively affect ventures growth, the benefits of the former considerably exceed those of the latter.

Nevertheless, in these studies no attempt has been made to compare the decision-making process and the criteria used by VC and CVC in their ventures selection. This distinction could be important to assess whether and how VCs and CVCs differently consider some dimensions in their financing decisions, i.e. the quality of patent portfolios, or whether they differ in their valuation ability. If the abovementioned differences do not matter, a basic measure of technology based on the total number of patents owned by the ventures could be adequate to screen entrepreneurial activities. On the other hand, CVCs are affiliated to corporations with well-defined core-businesses and competences, possessing internal expertise and knowledge that can be leveraged in the course of the due diligence process. As a consequence, it is likely that CVCs develop more expertise (when compared to VCs) in the evaluation of specific technological capabilities. We could therefore expect that their investment decisions are influenced by other factors in addition to simple patent numbers, for instance by measures which capture the technological content and the quality of patents.

3. Methods

3.1 The context

Nanotechnology can be defined as the study and use of the unique characteristics of materials at the nanometer scale, between the classical large-molecule level to which traditional physics and chemistry apply and the atomic level in which the rules of quantum mechanics take effect (Lemeley, 2005). Although the scientific interest in the “nano” world can be traced backed at least to the 1950s, a key-date for the industrial development of nanotechnology is 1981, with the design of the Scanning Tunnelling Microscope by IBM scientists. The STM allowed researchers to “see” atoms and molecules at the nanometre scale, a precondition to find novel proprieties at the nanoscale and make use of this knowledge to develop new materials and products. Indeed, the wide interest in nanotechnology stems from the fact that the ability to operate with atomic precision allow scientists to produce materials with improved or new optical, magnetic, thermal or electric proprieties, opening up a broad range of commercial applications.

An important characteristic of patents in nanotechnology is their inter-disciplinarity: nanotechnology is sometimes referred to as a general-purpose technology, because in its advanced form it will have significant impact on almost all industries and all areas of society. It attracts scientists from many areas of science (i.e., physics, chemistry, biology, computer science, etc.), and in the wide spectrum of potential market applications, which can involve very different businesses (such as computers, flat-panel displays, diagnostic products sensors, lighting devices and many others).

The field of nanotechnology is an optimal setting to study how VC firms evaluate patent portfolios in their investment decisions for various reasons. First, several new ventures have been created in nanotechnology in the United States and other countries in the world, mainly spun out of universities and government laboratories. The creation and growth of new companies has been favoured by the wide availability of funding by governments, established companies and venture capitalists. In particular, VC investments in the nanotech field has steadily increased over the last decade, reminiscing the earlier development of the biotech industry. Second, patents represent an important and effective mechanism to protect the returns stemming from nanotech investments, as witnessed by a real "boom" in the number of nanotechnology patents registered all over the world during the last 10 years. According to the Wall Street Journal, "[P]atents awarded annually for nanotechnology inventions have tripled since 1996, with 10-fold or greater increases in some areas during the past years". For many nanotech startups, the intellectual-property portfolio represent the main asset, to be exploited through business models based on the commercialization of new products (vertical integration) or on licensing revenues.

In addition to that, the definition of what is a nanotechnology patent is not an easy task, given the newness of the field and the many different scientific and technical areas involved. Such characteristics make it extremely difficult to adopt conventional IPC classes to tag nanotech patents, inducing high levels of uncertainty for patent examiners, inventors and prospective investors, including VCs.

In order to facilitate interdisciplinary searches and monitor trends in nanotechnology, the EPO has recently developed a new code (the Y01N) in order to tag all nanotech patents[2]. All European patent applications have been classified ex-post by a group of

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[2] In the Y01N subclass the term 'nanotechnology' "[…] covers all things with a controlled geometrical size of at least one functional component below 100 nanometers (nm) in one or more dimensions

patent experts in order to tag them, if the case, with the new code. The new classification has been publicly disclosed by the EPO since January 2006. From that date, with a simple query on the search engines of the EPO website, it is possible to collect information on all the patents granted in the nanotech field.

3.2 The sample

We created a sample of companies operating in nanotechnology and financed by VC funds over the period 1985-2006. Our data on VC investments in nanotechnology are taken from Thomson Venture Economics (*Venture Expert*), which can be considered as the most comprehensive commercial data source on the global VC industry. All VC-backed companies taking place worldwide in the field of nanotechnology over the period 1985-2006 were identified[6], amounting to 361 companies. For each company, we collected from Venture Expert the following information: country, main industries (according to the 4-digit Venture Expert Industry Classification), VC firms investing in the company (including the lead investor in syndicated deals), founding year, year of the first and subsequent stages of investment, amount raised (in US $) in each financing round. Information on the initial amount of funding received by VC was available for only 332 companies, which therefore represent our final sample.

For each VC-backed company, we identified the lead investor as either (a) the PE firm that at the moment of the buyout was explicitly mentioned as lead investor or (b) the firm that held the largest equity stake the buyout. We then complemented such information by gathering the following data on all the VC firms investing in nanotechnology: firm name, affiliation (i.e. independent, corporate, financial, public), number of companies in the current portfolio, breakdown of portfolio companies by industry.

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susceptible to make physical, chemical or biological effects available which cannot be achieved above that size without a loss of performance (Scheu, 2005)".

[6] Venture Economics classifies all venture capital and private equity deals in 6 main categories (and several other sub-categories), according to the stage of development of the investee company: seed, early-stage, expansion, later-stage, buyout/acquisition, and other. Since our interest resides in new ventures, we focused exclusively on deals belonging to the first 4 categories, and excluded from the analysis "buyout/acquisition" deals. In order to identify companies operating in nanotechnology, we adopted the classification of Venture Expert, which assigns each company to specific technological areas, including nanotechnology.

In order to construct the patent portfolios of our sample companies, we referred to patent applications at the European Patent Office. We first identified all patents applications at the European Patent Office in the field of nanotechnology over the period 1980-2006. Nanotech patents were identified as showing the code Y01N in the ECLA classification scheme. As of June 2007, the date of data extraction, the European Patent Office register contained 9813 nanotech patent applications.

3.3 Variables

Dependent variable.

VC Financing Amount measures the log transformation of the total amount of VC financing (in million US dollars) obtained by the company at the first investment round[4]. Limiting the study to the initial financing round eliminates the problems related to the causality link between patenting and VC financing. Indeed, previous work has shown that the receipt of VC funding might significantly enhance patent productivity (Kortum and Lerner, 2001; Bertoni et al., 2006). By considering only the initial financing rounds, we could directly assess the impact of the characteristics of patent portfolios on VC investment decisions, our research question, and rule out the "chicken-egg" problem related to the positive impact of VC investments on patenting activity.

Independent variable.

Patents measures, for each company, the stock of patent applications at the European Patent Office at the date of the first financing round. The searches were conducted in June 2007 using the April 2007 version of the Patstat database, realized by the European Patent Office.

For each company, *Nanotech Patents* measures the stock of patent applications at the EPO in the nanotechnology class. Nanotech patents were identified through the "Y01N" code of the ECLA classification, specifically introduced by the EPO to tag this kind of patents.

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[4] While Venture Economics identifies for each financing round the date and number of investors, and in most of the cases the amount invested by each investor, it does not track in a systematic way the price paid per share. Given that data on the so called pre-money valuation - the product of the price paid per share in the financing round and the shares outstanding before the financing round - were largely unavailable, we couldn't assess the impact of patent portfolio size, composition and scope on firm value, as in Lerner (1994).

Patent scope captures the average breadth of patents included in the portfolio of the VC-backed company at the year of the first financing round. Ideally patent scope should be measured, for each patent, through the subjective assessment of experts in the nanotechnology field (i.e. researchers, patent attorneys) in order to value the breadth of the claims. However, this is practically impossible for large groups of patents. We thus decided to apply the measure identified and validated by Lerner (1994) in his study of the biotechnology industry. Therefore, for each patent, we measured patent scope by counting the number of IPC classes to which patent examiners assigned each nanotech patent, using the first four IPC digits only. We then computed the average value of this measure for all the patent application included in the company's portfolio at the year of the first financing round. If the company had no patents, we code the average patent scope as zero, as in Lerner (1994).

In order to identify different types of VC firms investing in nanotechnology we used the following dummy variables, which were used to perform "split-sample" regression analyses.

Specialized VC is a dummy taking the value 1 if the company was financed by a lead VC firm specialized in nanotechnology, and 0 in all other cases[5].

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[5] The measure of specialization of the lead VC firm in nanotechnology is adapted from Cressy et al. (2007). For each VC firm included in Venture Expert, we first defined an index, *RIA*, or Revealed Industrial Advantage in nanotechnology, computed as:

$$RIA_{iN} = (C_{iN} / C_{.N})/(C_{i.} / C_{..})$$

where:
C_{iN} is the number of portfolio companies of VC firm *i* in the field of nanotechnology,
$C_{.N}$ is the total number of companies invested in the nanotechnology field by all VC firms
$C_{i.}$ is the total number of portfolio companies of VC firm *i* and
$C_{..}$ is the total number of companies invested by all VC firms (i.e. across all sectors).

The numerator in this measure ($C_{iN}/C_{.N}$) represents the VC firm *i*'s share of all investments in the field of nanotechnology and the denominator ($C_{i.}/C_{..}$) the VC firm *i*'s share in all investments (i.e. across all sectors). RIA_{ij} therefore measures the VC firm *i*'s *investment focus* in nanotechnology *relative to that of its VC competitors.*

Note that:

$$RIA_{iN}\begin{cases} = 0 \Leftrightarrow C_{iN} = 0 \\ < 1 \Leftrightarrow C_{iN} / C_{.N} < C_{i.} / C_{..} \\ \geq 1 \Leftrightarrow C_{iN} / C_{.N} \geq C_{i.} / C_{..} \end{cases}$$

so that a value of RIA_{iN} less (greater) than one indicates that the VC firm *i* is relatively unspecialised (specialised) in nanotechnology.

We used Venture Economics in order to identify, for each VC firm, the share of its portfolio companies in nanotechnology, as well as the total number of portfolio companies included in each

Corporate VC is a dummy taking the value 1 if the company was financed by a Corporate VC firm, and 0 otherwise, based on the classification provided by Venture Expert.

Control variables.

We included in our analyses also a set of control variables which might affect the total amount of financing obtained by the investee company in the initial round.

Company Age measures the age of the company at the date of the initial financing round, computed as the difference between the investment year and the foundation year of the company[6].

Market scope captures the degree of market diversification of the investee company. Previous research has shown that the size and attractiveness of the product markets in which the target companies operate represent important determinants of the investment decision by VC firms (Tyebee and Bruno, 1984; MacMillan et al, 1985). It is thus likely that companies operating in different markets are characterize by a higher growth potential, thus obtaining higher valuations and financing by VC firms. We proxied the market scope of the investee company with the count of different industries to which the company is assigned by Venture Economics.

Dummy US. is a dummy taking the value 1 for companies located in the United States, and 0 in all other cases. Since the VC industry in the U.S. is by far the most developed in the world in terms of overall amount of funds available, number and experience of VC firms, it is possible that U.S. nanotech ventures benefit from higher investment opportunities than their foreign counterparts.

Dummy Early VC takes the value 1 for investment in the "seed" or "startup" stages of development. Indeed, Gompers (1995) has shown that the amount of financing

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industrial sector over the period 1990-2006. We computed the *RIA* index over the period 1990-2006, consistently with the time period under study.

We then used the *RIA* index to create the dummy variable *Specialized VC*. For each company in the sample, *Specialized VC* takes the value 1 when the company was acquired by a lead VC firm specialized in nanotechnology (i.e. with a *RIA* greater than 1), and 0 in all other cases.

[6] The information on the foundation year of the companies included in the sample was obtained by Venture Expert. In cases were such information was missing, we performed searches on the Internet to gather the relevant data. However, we were not able to find this kind of information for 19 companies out of 332 included in our sample. For such companies, we computed Company Age as the average age at the first financing round of the nanotech companies backed by VC firms in the same stage of development.

received from VC firms tend to be higher, on average, in later rounds as compared to earlier rounds, as a consequence of reduced uncertainty and information asymmetries.

4. Analyses and results

4.1 Descriptive statistics and correlation analysis

Table 1 presents descriptive statistics from the sample of VC-backed companies. On average, the companies included in our sample received 5.01 million US $ in the first financing round by VC firms. At time of first VC investment, they had a mean of 0.84 patents and 0.28 nanotech patents in their portfolio, with a maximum of 15 and 7 patents respectively. Such low figures are due to the fact that only a limited number of companies had obtained a patent before their first financing. More precisely, only 28% (95/332) of the companies had a patent at initial VC financing, whereas this number lowers to 10% (35/332) for nanotech patents. However, it should be noted that such figures are higher than those reported by Mann and Sager (2007) in their study of the software and biotechnology industries. They found that the number of firms with at least one patent before the first financing was just 9% (75/877) in their sample of VC-backed software companies, and 23% (49/212) in their sample of VC-backed biotech companies. Therefore, such results confirm the strategic importance of patenting in the nanotech business. Concerning the breadth of patent protection, the average number of four-digit IPC classes into which a sample patent is classified is 0.46. On average, sample companies operate in 1.7 different industrial sectors, according to the classification of Venture Economics, with a maximum number of 4 different sectors. The mean age of the company at date of the initial VC investment is around 2 years. The large majority of our sample companies is located in the United States (around 86%), followed by Europe (7%), Canada (3%) and Israel.

--- Insert Table 1 around here ---

Table 2 reports the correlation matrix for our variables. We note that whilst most correlations are moderate there is a rather high correlation (0.54) that between *Patents* and *Patent scope,* which might pose problems of multicollinearity. As a robustness check, we therefore replicated our regression analyses including and excluding *Patent Scope* in the specification model. The results substantially remain the same in all the models estimated concerning the effects of patent portofolios' characteristics on VC financing, with the sole exception of the slit-sample analysis regarding the specialization of VC firms, as discussed in more detail below. For the sake of simplicity, in this paper we report only the tables of the full models with both independent variables.

--- Insert Table 2 around here ---

4.2 Regression analyses and results

We analyzed the relationship between patent portfolios' characteristics of start-up companies and total amount of VC financing in a regression framework, in order to control for the potential influence of other factors. We first adopted an OLS estimator on the full sample including all 332 VC-backed companies. Table 3 (Column 1) shows the results of this first model. The coefficient of the variable *Patents* is positive (0.013), although not statistically significant. The simple number of patents, thus, does not have a significant impact on the amount of funding obtained by VC firms. This evidence is in line with results by Mann and Whitney (2007) in the software industry, showing a little significance of having a patent before the first round of financing on the progress of companies through the VC cycle. It is also consistent with the results of Hsu (2004), who finds no relation between pre-funding patents and various measures of firm performance in his study of a dataset of VC-backed and SBIC startups.

--- Insert Table 3 around here ---

A possible explanation for this evidence resides in the fact that VCs do not simply consider the existence of patents in the process of screening and due diligence of prospective investments, but evaluate in more depth the very nature of the underlying inventions being patented. Indeed, our regression shows that the coefficient of the variable *Nanotech Patents* is positive (0.154) and statistically significant at the 1%

level. This suggests that VCs are sophisticated investors able to evaluate the technological composition of patent portfolios, by placing more relevance on those patents more directly related to the core technological competences of the company, in this specific case related to nanotechnology. This evidence is even more significant if we consider that the EPO publicly reported in its databases the new Y01N code for nanotech patents only in January 2006. Before that date the identification of nanotech patents was an ambiguous and uncertain task, given the inter-disciplinarity and the newness of the field.

On the other hand, we do not find a support in our data for the positive impact of patent breadth on VC financing. Although positive in sign in fact, the variable *Patent Scope* is not statistically significant in our estimates. This evidence, in conflict with the results by Lerner (2004) showing a positive effects of patent scope, might be due to the newness and uncertainty of patenting in the nanotechnology sector, still characterized by a real rush towards strategic patenting. On the one hand, first inventors have strong incentives to stake broad claims in the early days of a technology, in order to safeguard their inventions from infringements and thus increase their innovation's rents (Merges and Nelson, 1990). Early in the history of a technology, there is a higher possibility of obtaining broad patents, due to the absence of competing inventions, the high uncertainty about the market applications, the limited understanding of the prior art landscape by patent examiners. At the same time, however, in the specific case of nanotechnology "[…] the intensifying race to file patent applications has sparked concern that a proliferation of patents, especially broadly defined ones, could hobble innovation and produce a thicket of conflicting legal claims that could eventually drive up costs for consumers" (WSJ, 18/6/04). Therefore, it is not immediate to ascertain the value of large patent scope in this uncertain environment.

Turning to the control variables, only the dummy *Early VC* is statistically significant at the 1% level, and negative in sign. As expected, companies in earlier stages of development (i.e. seed, start-up) tend to receive a lower amount of financing in the initial rounds, also as a way to reduce uncertainty and opportunistic behaviour by entrepreneurs (Gompers, 1995).

We then turn to analyze whether the relation between the patent portfolios of startup firms and the amount of VC financing depends of the characteristics of the VC investor. We first look at the effects of the degree of specialization in nanotechnology of the lead VC firm investing in the company. In order to do that, we split our observations into two sub-samples depending on whether the lead VC firm is specialized (*Dummy Specialized VC* =1) or not (*Dummy Specialized VC* =0) in nanotechnology. In particular, we have a first sub-sample including all the companies financed by lead VC firms specialized in nanotechnology (253 observations), and a second sub-sample including all the observations by lead VC firms which are not specialized in this field (77 observations)[7].

Table 3 reports in columns 2 and 3 the results of the split sample analysis, showing interesting differences. In fact, the coefficient of *Patents* is positive (0.035) and not significant in the sub-sample of companies backed by VCs specialized in nanotech, whereas it is negative (-0.450) and significant at 1% level in the sub-sample of unspecialized VC firms. On the contrary, the coefficient of *Nanotech Patents* is positive (0.149) and statistically significant at the 1% level in the former sub-sample, whereas it becomes not significant at conventional levels in the latter sub-sample. In addition, in the sub-sample of companies backed by unspecialized VC firms, the coefficient of Patent Scope is positive (1.347) and statistically significant[8].

Such results confirm that VCs having a stronger focus in the nanotech sector tend to accumulate a specific knowledge allowing them to evaluate more effectively those patents tightly related to nanotechnology. On the contrary, not specialized VC firms do not consider the technological composition of patent portfolios in their financing decisions.

Finally, Columns 4 and 5 of Table 3 report the findings of the split sample analysis related to the type of affiliation of VC firms. Column 4 refers to the sub-sample including all the companies financed by Corporate Venture Capitalists (142 observations), whereas Column 5 refers to companies backed only by Independent VC firms (190 observations). In both cases, the coefficients of *Nano Patents* is positive and statistically significant at the 5% level, whereas simple *Patent* counts and *Patent Scope* are not statistically significant. Our analysis therefore does not provide

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[7] We were not able to compute the index of specialization in nanotechnology for two companies in our sample, due to missing data.

[8] However, the analysis of the correlation matrix for the subsample of companies financed by VC firms which are *not* specialized in nanotechnology shows the presence of a high correlation (0.81) between *Patents* and *Patent Scope*. We therefore ran further estimates dropping the latter variable from the model. In this case, the coefficient of *Patents* results positive but not statistically significant, whereas *Nano Patents* remains positive and not statistically significant. This analysis provides a more robust confirmation than VC firm specialized in nanotechnology tend to value more nanotech patents in their investment decisions than unspecialized VC firms.

evidence of significant differences in the evaluation of patent portfolios by CVCs and Independent VCs in the course of the selection and financing process.

5. Conclusions

This paper analyzed the impact of the characteristics of patent portfolios by startups - in terms of size, scope and technological composition - on the amount of financing obtained by VC firms. It provides two main contributions to the existing literature on the relationship between patenting and VC investments. First, it moves beyond the simple analysis of patent counts, by claming that VC firms consider the technological relevance of the IPRs possessed by target companies in their selection process. Second, it recognizes that VC firms are not all alike as to the capabilities required to effectively assess the value of startups' technology and intellectual property. In particular, we argued that their degree of specialization in the specific industry of the company under scrutiny and their type of affiliation might influence their evaluation criteria and skills.

We tested our expectations on a sample of 332 VC-backed companies in the nanotechnology sector. Our results show that the simple number of patents applied by the company before the first investment round does not have a significant impact on the amount of financing obtained, controlling for the age, the stage of development, the degree of market diversification, the location of the startup. On the contrary, the startup's stock of patents belonging to the nanotechnology class has a positive and significant effect on VC financing. Such findings help to interpret previous evidence by Mann and Sager (2007) showing no impact patents obtained pre financing and the amount invested by VCs. We show that it is the *type* of patents owned by the startup that matters in the financing decision, in particular for what concerns their technological content, not just their simple number. Overall, our results support the view of VCs as competent investors, able to identify and evaluate the technological capabilities of target companies.

Moreover, it also suggests that this kind of selection skills are not evenly distributed across VC firms. In fact, we showed that VCs relatively more specialized in nanotechnology in their investment strategies tend to value more nanotech patents in their financing decisions than unspecialized VCs. Specialization seems therefore provide a better understanding and deeper knowledge of the technological specificities of the investee companies' context. This, in turn, might facilitate the correct assessment of new investment opportunities.

On the contrary, we did not find significant differences between Corporate and Independent VCs in the assessment of patent portfolios in the financing decisions. It might be that CVCs retain an evaluation advantage with respect to their independent counterparts only if they possess a sufficient absorptive capacity, in terms of previous technological knowledge stock. Dushnistsky and Lenox (2005) have demonstrated that the marginal contribution of CVC investments on patenting is higher for incumbent firms with higher absorptive capacity. This suggests that the ability of an investing incumbent firm to appropriately identify and transfer knowledge through interaction with a new venture requires that the former has sufficient technical understanding. In this paper we were not able to discriminate CVCs in terms of levels of absorptive capacity, in particular for what concerns the nanotechnology field, an issue which could be directly addressed by future research.

Finally, some qualifications and suggestions for future research.

To begin with, our analysis relied on data from a single sector, nanotechnology, characterized by high degree of newness, uncertainty and inter-disciplinarity. As we have already mentioned, such specificities raise concerns about the generalizability of our results to other contexts, in particular to more mature and established businesses.

Second, it is likely that investment decisions by VCs are influenced also by other characteristics of patent portfolios that we did not consider in our analysis, for instance patent lifetime (as a proxy of the remaining economic usefulness of the patent), family size (as a proxy of the market size of the underlying invention) or patent legal status (i.e. existence of renewal or opposition). There are therefore opportunities to analyze other determinants of patent value that are more directly taken into consideration by VC firms in their investment choices.

Finally, we limited our analysis to the initial financing rounds of the VC cycle, as a way to circumvent the causality problems which limit previous research on patenting and VC investments. Mann and Sager (2007) suggest that patents have their greatest value for companies at the later stage of the investment cycle, whereas in earlier stages other determinants, such as the characteristics of the entrepreneurial team, play a dominant role. However, they do not provide a direct empirical test for such claims. Further research should investigate in more depth the relative importance of the different criteria adopted by VC firms in the evaluation of startups companies and how they change over the VC cycle.

Tables

Table 1
Descriptive statistics for VC-backed companies

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Log VC financing (mil US $)	332	0.750189	1.47175	-3.21888	4.714562
Patents	332	0.843374	1.975572	0	15
Nanotech Patents	332	0.207831	0.801546	0	7
Patent Scope	332	0.459759	1.083547	0	7.66
Company Age	332	2.03012	2.708217	0	18
Dummy US	332	0.861446	0.346002	0	1
Market Scope	332	1.64759	0.707679	1	4
Dummy Early VC	332	0.331325	0.4714	0	1

Table 2
Correlation Matrix

		1	2	3	4	5	6	7
1	VC financing (mil US $)	1						
2	Patents	0.1046	1					
3	Nanotech Patents	0.0981	0.1179	1				
4	Patent Scope	0.1244	0.5495	0.0157	1			
5	Company Age	0.1467	0.3261	-0.0307	0.2909	1		
6	Dummy US	0.034	-0.0628	0.0061	-0.0874	-0.0439	1	
7	Market Scope	0.0086	0.0857	-0.0729	0.0281	-0.0339	0.0221	1

Table 3
Regressions for patent portfolio characteristics and VC financing: full and split samples

	(1) Full sample	(2) Specialized VC firms	(3) Unspecialized VC firms	(4) Corporate VC firms	(5) Independent VC firms
Variable	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*
Patents	.012	.035	-.450***	-.041	.031
	(.044)	(.048)	(.145)	(.064)	(.068)
Nanotech Patents	.153***	.149***	.096	.180**	.139**
	(.046)	(.044)	(.223)	(.084)	(.062)
Patent Scope	.071	.047	1.347***	.067	.070
	(.064)	(.065)	(.373)	(.110)	(.080)
Company Age	.029	.003	.119**	.099**	.003
	(.032)	(.034)	(.054)	(.039)	(.036)
Dummy US	.061	-.012	.037	.399	-.169
	(.185)	(.185)	(.547)	(.311)	(.238)
Market Scope	.054	.079	-.162	.036	.055
	(.115)	(.135)	(.258)	(.185)	(.144)
Dummy Early VC	-1.189***	-1.475***	.372	-1.244***	-1.134***
	(.170)	(.189)	(.350)	(.255)	(.227)
Constant	.866***	.966***	1.010	.736*	.921**
	(.280)	(.304)	(.661)	(.436)	(.359)
R^2	.178	.239	.178	.223	.161
F ratio for regression	11.63***	11.98***	4.91***	7.46***	5.98***
N. obs in regression	332	253	77	142	190

Robust standard errors are in parentheses.
Level of significance reported: ***; **; * significant at the 1%,5% and 10% levels respectively.

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A Compromise Proposal for the Computer-Implemented Inventions / Software Patent Controversy by Means of Substantive Patent Law

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Abstract: The present proposal argues for a novel solution of the Computer-implemented inventions / software patent controversy by defining several new classes of patentable subject matter. Based on general legal definitions of computer operations, it introduces a novel patentable entity: the composition of computer and program, applicable for uses of computers where no actual programming takes place, thereby fulfilling a perceived patentability need of the industry. Furthermore, the exclusion of computer programs by the European Patent Convention is completely re-defined in terms of basic unpatentable building blocks. The regulations' details are highly adjustable and are intended to serve as a basis for further debate.

Keywords: Computer-implemented inventions, software patents, substantive patent law, European Patent Convention, sui generis rights, legal definition of computing, patent claims

Acknowledgements: Stimulating discussions with Stefan Walz (German Federal Ministry of Justice), Markus Rau (Max Planck Institute for Comparative Public Law and International Law), and André Rebentisch are gratefully acknowledged.

1. Introduction

Although the rejection of the proposal for a EU directive on the patentability of computer-implemented inventions (CII directive) by the European Parliament in 2005 did calm down the respective political debate for some time, the underlying controversy as regards substantive patent law remains essentially unresolved to this day. For, the status quo of patentability in the realm of computing in Europe was deemed unsatisfactory by both the directive's proponents and the opposition to it, as both camps pushed for quite involved changes to statutory regulations of substantive patent law (European Commission, 2002; Wikipedia, 2007).

However, it seemed at the time that compromise options within substantive patent law were virtually unfeasible inasmuch a common terminology for the subject matter in question did not exist. The opponents spoke of the directive's subject matter in terms of software patents, a term common in the United States and elsewhere, while the proponents maintained the term computer-implemented inventions, to be understood as something quite different from software patents.

Thus, for the time being, patentability questions in computing will continue to be the domain of case law. In view of the present enormous relevance of computers to industrial value creation, it seems however doubtful that the evolution of case law will easily contribute to the stability of law. A few recent rulings of courts in the United Kingdom are indicative of the latter (Pearce, 2007).

2. The problem of defining patentability limits for computer programs

When the European Patent Convention (EPC) was negotiated and signed in 1973, it would have been hard to image the ubiquity of computers in 2007, having microprocessors embedded in basically every electronic gadget on the market. A 1973 vintage computer would be usually be contained a big box too heavy to lift for a single person, while a 2007 vintage computer may comfortably fit, in form of a digital hearing aid, into a human auditory canal. And yet both examples have at their heart technically much of the same kind of device: a machine capable of performing arithmetic and logical computations very quickly.

The EPC excludes, amongst other subject matter, 'programs for computers' from patentability, while narrowing the exclusions with the notorious 'as such' clause, leading to evolving interpretations that made Hilty and Geiger (2005) claim that today "the letter of the law is nothing but hollow words". Thus the lack of a common terminology during the debate about the CII directive may also hint at inherent difficulties in finding an appropriate terminology.

Coming back to the digital hearing aid, one may want to have all functionality of such an object be patentable, as formerly hearing aids did not contain computers at all and were clearly patentable. By this example we observe the almost complete convergence of (patentable) hardware and (as wished by some, non-patentable) software, prevalent in many fields of technology. Presently, elaborate hardware contraptions are often more economically replaced, retaining the very same function, by programs running on small computers embedded in specific products — why, one might argue, should this change patentability?

On the other hand, one may still want to exclude programs installed on desktop computers or bigger hardware from patentability, as voiced by the opposition to the CII directive, for economic and other reasons, thereby continuing the regulatory effect the EPC may have had in its early years (Winischhofer 2000).

3. A compromise proposal detailed in terms of substantive patent law

In view of the above, the present work proposes a twofold solution: Firstly, a new entity within substantive patent law, called *composition of computer and program*, addresses the patentability needs arising from the ever growing convergence of "classical" engineering disciplines and computer science. The term *composition of computer and program* is defined in such a way that hardware and software which is reasonably inseparable, such as the above digital hearing aid, as well as the proverbial computer-controlled washing machine and ABS breaking system, fall under this notion.

Secondly, the exclusion of programs for computers following the European Patent Convention is defined anew in detail for all cases that do not fall under the preceding paragraph. In a nutshell, only programs that are not pre-installed on a given computer and do no more than internal calculation and interactions with humans will thus be non-patentable, for example programs for everyday use on personal computers. On the other hand, any means going beyond that, such as to for example the control of industrial production equipment by software, will be clearly patentable.

The proposal sketched above has been put into statutory language; and, for reasons of simplicity, it has been detailed in terms of a seven–page amendment to the European Patent Convention. The following sections summarise its essential content.

3.1 Legal definitions for computing terminology

As a prerequisite, it is necessary to delineate an as appropriate as possible terminology comprising the basic modes of computer hardware and program operation that are to be excluded from or included in patentable subject matter.

Firstly, a computer is to be understood as a *digital* computer, namely a machine operating exclusively with information in terms of discrete values. Thereby we rule out other types of devices that are also called 'computer', usually with a distinctive adjective. Next, information processing on computers means only digital computations that are orchestrated by discrete time steps that transform one information state into the next one.

There are also input and output devices — generally of an unspecified kind — communicating digital information in and out of a computer, important special cases of which are other computers and data storage media. A set of computers connected in this way (a network) is to be considered a computer in its own right if all of them are confined into a small physical space with lengths of the order of one metre.

Programs are defined as arbitrary subsets of all of the digital information within a computer. (Note: Because of this, entities colloquially called 'data', such as word processing documents, are programs as well.) Digital information is usually and in principle, but not always and concretely, changeable by computations. Program installation equates to entering it via input devices, except in cases of mere archiving. Usage of a program is the usage of the respective computer and its associated input/output devices in dependence of said program.

Complete sources of programs are all digital information required to construct a program in the form they are edited by the program's author; external contributions to a program are those informations not edited by the program's author. This is important for the definition of *non-public programs*, these are constructed by relying on non-public, i.e., secret, technical documentation of either computer hardware or external contributions — if there is an unbroken chain of relying on non-public documentation from the hardware to the program in question.

A non-public program in terms of the above paragraph will lose this quality if all its complete sources and external contributions are available at competitive prices and are thus not considered secret.

One should note that these definitions are somehow but purposefully more general than everyday or even information technology specialists' engineering definitions of some of the same words. By this generality we hope to gain reasonable independence of the fast-changing state of the art. Here and in the following sections, it turned out to be convenient to define technical entities in a style reminding of patent claims.

3.2 Novel patentable entities: compositions of computer and program

The new term *composition of computer and program* serves to differentiate between programs for computers as a means to a specific end — such as the software within a digital video recorder — and programs that are a result of the programmability of a computer. This construction hinges on the facts that a) the playing software is installed on the digital video recorder at the time of purchase and, alternatively, that b) the construction of said software is essentially impossible without detailed technical information that is usually closely guarded as a trade secret. Conversely, programming of the video recorder by the home user (the definitions of Section 3.1 cover this colloquial term nicely) falls under neither of points a) nor b) and will thus be patent-free. A composition of computer and program is thus meant to indicate the effective absence of programmability, either because of lack of accessible documentation or because of the fact that the software was already there at point of sale.

Concerning point a), if one the following facts hold true *at the time of physical exchange* related to a purchase, a composition of computer and program is construed:
— the program is installed on the computer
— program and computer are inseparably boxed
— program and computer are transferred for a combined, single price (subsidies in either direction do not equal a single price)
— the joint purchase of program and computer enacts a discounted price.
Note that this would include the vast majority of operating systems presently sold for personal computers.

Concerning point b), any non-public program as defined in Section 3.1, with respect to the computer concerned, constitutes a composition of computer and program. However, digital information in the style of usage passwords, cryptographic locks, copyright licensing schemes, digital rights management (DRM) schemes or other artificial secrets restricting the usage of program never suffice to constitute a composition of computer and program.

It is very important to note that, in order to precisely capture the patentability only for software that acts after a fashion as a hardware replacement, all rights and prohibitions from a patent of a composition of computer and program are linked to the computer as a physical object. A patent violation may only happen after the installation of the program in question.

Thereby, a separate sale of software will not fall under possible patent restrictions. The respective liabilities should be further limited to manufacturers of hardware (these include of course subjects that pre-install software), as opposed to mere resellers. Naturally, a manufacturer disseminating non-public information leading to non-public programs, implying compositions of computer and program, will want to carefully word contracts with external software creators receiving non-public information. Otherwise, there would be no eventual compensations for patent violations depending on decisions made by the external software creator.

The complications of the last paragraph are somewhat unfortunate but indispensable for this proposal to act as a compromise. For, without this patent indemnity for software distribution regarding compositions of computer and program, it would be still feasible to sue and thereby economically threaten software vendors for the sake of legal uncertainty, even if the existence of a composition of computer and program will be easily ruled out in court.

3.3 Narrowing the limits of non-patentable computer programs

If a program is not subject to a composition of computer and program of Section 3.2, it may be called a *non-composite program*. Rather than trying to define software-controlled processes, such as blast furnaces to produce metal, that one wishes to include in patentable subject matter, we proceed by detailing patentability exclusions. They are meant to comprise all conceivable interactions of humans with computers, and of inter-computer interaction in digital networks.

All aspects of the operation of non-composite programs are exempt from patentability, inasmuch they are composed from the following building blocks:
— digital computations as by Section 3.1
— structure of digital information
— computations with information gained from patentable processes; if done outside of said processes, for which a time delay of five seconds is sufficient
— digital information representing non-patentable subject matter as per EPC, or renditions of human language
— using output devices that produce results directly perceptible by human senses
— using input devices that substitute human perception
— using input devices controlled by humans
— unsteady processes using above devices on human-perceptible time scales

— input of physical time that is accurate to the computer's time step(s)
— input of the computer's localisation up to metres
— input of true random numbers
— digital communication and protocols on networks and data storage media
Note that there is a deliberate shortage of output devices operating as actors: e.g., while the action of a force-feedback joystick is directly perceptible by human senses, the actions of the arms of an industrial robot are clearly not.

Also, any kind of simulation or digital modelling of patentable subject matter with programs meeting the above criteria is expressly excluded from patentability. Otherwise, the important functionality of computers as a support for the human brain would be seriously hampered. And, for instance, it seems relatively unreasonable to require licensing of ABS braking systems simulated within car racing video games.

Since this regulatory proposal is designed as an replacement for the 'as such' clause number 3 of article 52 EPC that allows patenting of programs for computers only in a highly contested way, desired additional patentable subject matter has to be expressly defined. Consequently, functional combinations of most of the unpatentable subject matter of this section and other patentable subject matter are to be defined as patentable, in order to enable patents for the distinctive use of computers in general technical applications.

3.4 Miscellanea

Pre-existing patents of any kind will not be invalidated by this proposal. Rather, their applicability may be re-interpreted in terms of Sections 3.2 and 3.3. In this way, any computer-related subject matter stays patentable as long as related hardware and software are sold at the same time; and it seems plausible that these are by far the most abundant cases.

An amendment to the European Patent Convention appears to be the technically most appropriate means to put this proposal into law. A version in statutory language (in German, available from the author on request) has been written mainly as an additional chapter to the EPC. However, other options, such as a renewed European directive, remain in possible principle. Political aspects of either procedure are out of the scope of the present work.

4. Related work

It has been argued (Hilty and Geiger, 2005) that a *sui generis* right for computer programs replacing possible patent protection might be created. Hollar (2005) proposed such a new protection system that combines aspects of patent and copyright. Winischhofer (2000) proposed to delete clause number 3 from article 52 EPC, without any substitution, in order to remove most computer programs from patentability.

5. Conclusions

It has been shown that detailed regulations fulfilling diverse requirements for the patentability of computer operations can be formulated, while catering for the needs of different kinds of stakeholders. The present wording aims at a consistent solution, but the detailed regulations of Section 3 will allow for a substantial amount of adjustability. Hence it is to be hoped that the present work will help further discussions in this area or even be a step in the direction of a common language for patentability and computing.

While the present proposal has been formulated in terms of substantive patent law, it comes close to amount to a sui generis solution in its own right. But it also accounts for inclusion into and exclusion from patentable subject matter — an issue that would not automatically vanish in case of the establishment of an additional type of intellectual property protection coined specifically for the usage of computers.

In the future, the regulations of Section 3 should be put to the scrutiny of test of cases, such as those of the UK Intellectual Property Office (2005), or existing patents that are considered relevant, in addition to input from stakeholders.

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Proximity of Inventors and Knowledge Flows

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DRAFT, March 2007

This paper contributes to understanding the role of geographical proximity in knowledge interactions. By using survey data on 6,945 patents of European inventors, we study the geographical breadth of knowledge exchange in the form of meetings, discussions and, more generally, circulation of ideas that inventors develop during the inventive process. We start by showing that interactions with geographically close individuals are fewer and less important than interactions across regions. We then explore two issues concerning the geographical extent of knowledge interactions. First, is there a "Silicon Valley effect", i.e. do local interactions develop in technological active and richer regions (the technological clusters) more than elsewhere? Second, is the spatial dimension of interactions shaped by the characteristics of the inventors who set them up? Our results show that, after controlling for many factors, the importance of local interactions is not correlated with being located in the technological clusters. Differently, inventors' personal background is key in explaining the geographical extent of knowledge ties. Specifically, interactions tend to be local when the research project has a low scientific content and the inventors are young and have a low level of education. By contrast, the higher the experience and the educational background of the inventors, the wider and more dispersed geographically are the research networks. This suggests that local links are established because of the individual inadequacy to enter into broader research networks. Implications for the design and effectiveness of regional policies to stimulate technological development arise compared to actions directed to individual "openness".

1. Introduction

Since Marshall (1920) a large amount of research has been devoted to theorize and prove the existence, extent and merits of geographically localized knowledge spillovers as one of the advantages of regional agglomeration economies. The basic idea is that there are geographic boundaries to knowledge flows and that physical proximity among individuals foster communication and makes it easier to access information produced by others, therefore reducing the complexity and uncertainty of production and research activities (for a survey, see Doring and Schnellenbach, 2006; Feldman, 1999). Moreover, compared to manufacturing, inventive activities benefit the most from co-location, particularly in skilled and R&D-intensive industries (Audretsch and Feldman, 1996) and in sectors that rely more on new economic knowledge, practice and learning-by-doing (Pavitt, 1987; Maskell, 2001).

Knowledge spillovers have important economic implications. On the one hand, the fact that knowledge spills over from the source that generates it to other parties might lower the incentive to produce it in the first place, and encourages free-riding on others' research efforts. On the other hand, by generating increasing returns, spillovers foster economic growth (e.g. Romer, 1990; Grossman and Helpman, 1991). Moreover, as the ability to exchange knowledge is geographically constrained, innovative and economic activities tend to be geographically concentrated. This contributes to shape the geographical distribution of innovative and economic activities and, at the same time, it increases inequality among regions and countries (Saxenian, 1994; Verspagen, 1997; Swann *et al.* 1998).

The importance of knowledge spillovers has encouraged scholars in economic and managerial disciplines to document them and to study their boundaries (see, for example, Jaffe, 1989; Acs et al. 1994 among others; Jaffe, Trajtenberg and Fogarty, 2000; Funke and Niebuhr, 2005). A seminal paper in this direction, on which a large number of later contributions are based, is by Jaffe et al. (1993). They use US patent citations and a matching method that controls for the pre-existing distribution of production activities, and show that knowledge spillovers are geographically concentrated between and within countries (for Europe see Verspagen, 1997; Verspagen and De Loo, 1999).[1]

In spite of this research that provides evidence about the existence and benefits of locally bounded knowledge spillovers, some recent contributions are more skeptical. There is concern, for example,

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[1] For a discussion on the use of patent citations as measures of knowledge flows: Jaffe et al. (1993), Ameida and Kogut (1999), Hall et al. (2001), Jaffe and Trajtenberg (2002).

about the use of patent citations to measure spillovers, as Alcacer and Gittelman (2006) show that an important fraction of patent citations are included by the examiners rather than inventors (see also Jaffe *et al.*,1998, Harhoff et al., 2005). Precisely, this share is about 41% for USPTO patents. This problem is especially relevant for patents issued by the EPO, because 93% of patent citations are generated by the examiner or search officer. This makes patent citations a noisy measure of the extent and direction of the knowledge flows.

Moreover, even if one trusts citations as a measure of knowledge flows, in a 2005 paper, Thompson and Fox Kean revisit the Jaffe et al. (1993) work and, by using patent citations, find no evidence of regional spillovers. To check the robustness of the Jaffe et al. analysis they use finer criteria to select the control sample of patents – which is critical in order to control for the pre-existing patterns of industrial activities – and find that this eliminates the intra-national location of knowledge spillovers (at the level of the State and Consolidated Metropolitan Statistical Areas). Only international location effects remain. By using a different identification methodology that compares the geographic matching of a sample of US cited and citing patents in the two alternative settings in which citations are added by inventors and by examiners, Thompson (2004) finds evidence of a modest location effect, with inventors' citations being more likely to match the intra-national location of the cited patents compared to examiners' citations.[2]

Not only has the measurement of knowledge spillovers been discussed, but also the traditional notion of spillovers as merely being "in the air" is now debated against other mechanisms whereby individuals and their personal networks shape the direction and geographical breadth of knowledge flows. For example, Zucker et al. (1998 and 1999) show that what might appear to be localized knowledge spillovers in the US biotechnology industry is in fact a pure market mechanism through which star scientists are either employees or collaborators of biotechnology companies in the regions. Almeida and Kogut (1999) use US patent citations of important semiconductor inventions and find that the location of knowledge spillovers varies across regions and they tend to be located in only three out of the thirteen regions that they analyzed. In addition, they suggest that an important mechanism by which knowledge is transferred in semiconductors is inter-firm mobility of

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[2] More generally on agglomeration economies Klepper (2002) studied the US automobile industry and argues that firm competencies rather than regional agglomeration economies are the drivers of the evolution and location of the industry. Buenstorf and Klepper (2005) examine the geographical distribution of firm entry in the U.S. tire industry and find little evidence of agglomeration economies shaping the regional patterns of firm origination. Rather, the regional distribution of firm birth reflects the distribution of potential founders with adequate competencies.

Cassiman and Veugelers (2002) show that when knowledge spillovers are important inputs for the invention process, firms in the Belgian manufacturing industry are also likely to engage in cooperative R&D agreements.

human capital that embodies knowledge. Likewise, others take the inventor as the unit of analysis and show that knowledge flows and regional co-location is in fact driven by the underlying social networks among researchers (e.g. Breschi and Lissoni, 2004; Singh, 2005; Fleming et al. 2007).

This paper provides new evidence on the extent to which knowledge flows are geographically localized, and the factors that affect the probability that they are bounded within specific regions. To do so it exploits new data collected from a survey of 9,550 European patents (i.e. the PatVal-EU survey) and, by using information drawn directly from the inventors solves the problems highlighted above about the measurement and mechanisms through which knowledge spillovers take place. First, by introducing a novel indicator of knowledge exchange as provided by the inventors, it limits the problem of using indirect indicators like patent citations.

Second, it focuses on a form of knowledge exchange that mimics closely the idea of "marshallian" knowledge spillovers. As a matter of fact, the output of a research project is a positive function of the inputs that it employs. They consist of the firm/inventor own knowledge and, to the extent in which it/he can appropriate it, knowledge produced by others. External knowledge, in turn, can be either acquired through contractual agreements (i.e. market transactions) or by means of informal interactions that are not explicitly regulated by any market transaction. In the latter case, there are increasing returns in the production of new knowledge, as the input is acquired at no cost. By asking the inventors to report on interactions such as meetings, discussions, and more generally, circulation of ideas that were important for the research leading to the patent, and by excluding interactions that end up in co-inventorship, we try to capture these informal types of knowledge exchange. Moreover, by asking them about interactions that were important for the development of a patent, we focused on knowledge that was actually used as an input in the research project.

Third, our study employs indicators for the individual characteristics of the inventors who set up the interactions. This is an important novelty of the paper as we can understand the relative importance of location factors vis-à-vis inventors' individual characteristics on the probability to enter into local/broader networks of research during the inventive process.

The empirical analysis consists of two stages. It first analyses the importance of geographical proximity among individuals to establish interactions during the inventive process. The data indicate that interactions with individuals external to the inventor's organization are not common, and that local interactions are much less important than interactions that involve distant ties. This is true across European regions and types of organizations, suggesting that local knowledge flows are not a major factor in this process. Second, by means of multiple correlation analysis, the paper explores the idea that local interactions take place in technological active regions ("vibrant regions" by using Almeida and Kogut, 1999) to a greater extent than elsewhere. We call this the “Silicon Valley effect”. In addition, it investigates to what extent the spatial dimension of such links is shaped by the characteristics of the individual inventors. After controlling for the distribution of inventive activities and for inventor, patent, firm and technology characteristics, the results show that the technological features of the location do not affect the importance of local interactions during the inventive process. There is a mild evidence of local interactions to be more important than distant ties only when regions develop a marked comparative advantage in the specific technological sector in which the inventor performs research. This is however extremely rare in Europe, as it concerns less than 10% of the regions in our sample. We find, however, that key factors in explaining the geographical breadth of knowledge interactions are the nature of the research and the characteristics of the inventors. Specifically, the higher the scientific content of the research conducted, the greater the importance of distant interactions. Likewise, the higher the level of education and the age of the inventors are, the higher the propensity to engage in geographically wide interactions, suggesting that local ties are likely to be the output of the individual inadequacy to set up larger networks.

The remainder of the paper is organized as follows. Section 2 discusses our measure of knowledge spillovers and provides descriptive statistics about their geographical extension and importance for the inventors. Section 3 introduces the hypotheses and the variables used in the ordered probit regressions. Section 4 discusses the results. Section 5 concludes. Appendix 1 shows the ISI-INPI-OST list of technological classes used in the paper. Appendix 2 describes the robustness checks.

2. Our measure and the geographical extent of knowledge interactions

As discussed above, an important novelty of this paper is that it tries to document the importance of “marshallian” knowledge spillovers without resorting to indirect indicators like patent citations. Since knowledge flows are invisible and they leave “[…] no paper trial” (Krugman 1991), we collected direct information from patent inventors, and we asked them about the importance of geographical proximity for setting up knowledge interactions with other people during the inventive process. This was done by means of the PatVal-EU survey that interviewed the inventors of 9,550 patents granted by the European Patent Office (EPO) between 1993 and 1998, and located in Denmark, France, Germany, Hungary, Italy, the Netherlands, Spain, the United Kingdom. The survey provides information on the individual inventors, the invention process and the resulting patents. Giuri et al. (2006) report the details of the survey and key descriptive statistics.

This paper uses information on a sub-sample of 6,945 patents that we obtained by excluding data with missing answers in the survey and French patents. This is because the PatVal-EU survey in France was conducted by asking some questions to the inventors while others to the managers of the applicant organisations. In order to avoid potential biases in our analysis we decided not to use the French sample. In any case, when we perform the empirical analysis by including it, our results do not change significantly.

For the purpose of studying the importance of geographically localized knowledge spillovers we asked the inventors to rate the importance of interactions with other people during the invention process. More specifically, by using a scale from 0 (not used) to 5 (very important), they indicated the importance of meetings, discussions and, more generally, circulation of ideas for the research leading to the patent. They also specified the geographical extent of the interactions and whether they took place among people affiliated to the inventor's organization or with individuals affiliated to different organizations. In the end, the answer to this question provided information about the importance of four types of interactions: (1) interactions with people *External* to the organization and geographically *Close*; (2) interactions with people *External* to the organization and geographically *Distant*; (3) interactions with people *Internal* to the organization and geographically *Close*; (4) interactions *Internal* to the organization and geographically *Distant*. In this paper we focus on interactions with individuals external to the inventor's organization, and we leave (3) and (4) above for future research.[3] We therefore record the importance of:

- *Close* interactions: interactions with people not in the inventor's organization and geographically close, i.e. it takes less than an hour to reach their office or location.

- *Distant* interactions: interactions with people not in the inventor's organization and geographically distant, i.e. it takes more than an hour to reach their office or location.

Close and *Distant* interactions differ only for their geographical extent. The former implies geographical proximity between the inventor and the interacting people, while the latter does not. We use the answer to this question to understand the frequency with which inventors interact on informal basis with people external to their own organization, and we investigate whether the probability to interact is influenced by geographical proximity.[4]

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[3] This is like excluding self-citations in studies that use patent citations.

[4] We explicitly asked the inventors to exclude interactions with co-inventors. We did not ask explicitly to exclude other forms of collaborations. By using information from the survey we controlled for the extent to which inventors use external interactions (*Close* or *Distant*) and inter-firm collaborations ("collaborative" patents) together to develop a patent. The share of "non collaborative" patents invented with external interactions (*Close* or *Distant* >0) is 40.5%. The average importance of external interactions is 2.6 for

We deliberately defined geographical proximity in terms of the time that it takes to reach the location of the interacting person: interactions with geographically close people are those that typically take less than an hour to reach; interactions with geographically distant people are those that take more than an hour. This is a particularly useful feature of our data that, by measuring distance in terms of the effort required to reach the other party, limits problems associated with other measures of geographical distance. For example, if distance is measured in kilometers, locations might be similar in terms of kilometric distance, but extremely different in terms of effort/time required to be reached. To simplify, suppose that a researcher is employed in a company located in the periphery of a large town, and that he interacts with two individuals who are both in a ray of 50 kilometers from his office. However, one of them is 50 kilometers towards the countryside, where roads are in good conditions and there is no traffic. The other one is 50 kilometers downtown with tremendous traffic jam. Same distance, but big difference in the effort required to reach the interacting party: in the former case it takes 15 minutes to meet; in the latter case it takes more than an hour to reach. Therefore, while traditional measures based on kilometric distance would consider them as similar locations for the researcher, our measure considers them as being different, i.e. *Close* and *Distant* respectively. Compared to measures of geographical proximity based on administrative boundaries, our definition solves cases in which locations are practically contiguous, but are considered distant because they belong to different administrative regions, or cases in which locations are considered to be close because they are in the same administrative region, but that, actually, are located far away.

How often are knowledge interactions with people external to the inventor's organization used in developing inventions? Figure 1 shows the share of patents invented by using *Close* and *Distant* interactions (y-axis) in each score class (x-axis: 0, not used; 5, very important). Up-right in the graph we also report the average importance and standard deviations of *Close* and *Distant* interactions across all inventors.

[FIGURE 1]

We compute the maximum score assigned by the inventors to either *Close* or *Distant* interactions, and report it in the dashed line in Figure 1. Over half of the patents in our sample (54.4%) are developed without any form of interaction with people external to the inventor's organization (i.e.

"collaborative" patents, while it is 1.1 for "non-collaborative" patents and the difference is statistically significant. The idea that we make from the data is that there are patents that are developed with an "open" approach: the inventors use extensively sources of knowledge external to their own organization (co-inventorship, collaborations and informal interactions). There are other patents, instead, for which the role of external knowledge is limited.

the scores of *Close* and *Distant* are both 0). When external interactions (either *Close* or *Distant*) occur during the inventive process, in 16.5% of the patents their importance is small (score 1 or 2). Their role is higher in 29.1% of the patents (score 3 and higher). This suggests that external interactions, being them with geographically close or distant people, are not a major input in the inventive process. If we take our knowledge interactions as an indicator of knowledge spillovers, this suggests that the latter are not as diffused as one might think according to the numerous contributions that emphasize them, as only one third of the inventions benefited significantly during the inventive process from informal interactions with people affiliated to other organizations.[5]

The second issue that we investigate is whether geographical proximity matters for establishing external interactions. The continuous lines in Figure 1 report the share of patents invented either with *Close* or *Distant* interactions. The two distributions in Figure 1 overlap to a great extent, even though for low values of the score (0-1-2) the *Close* distribution dominates the *Distant* distribution; for high values (3-5) the *Distant* distribution dominates the *Close* distribution. This indicates that patents that benefited from *Close* interactions are fewer than those invented with *Distant* interactions: in 69.2% of the patents the inventors indicated that they were not exposed to any interactions with *Close* individuals, compared to 59.3% of patents with no *Distant* links. This is confirmed by the average importance of *Close* across all patents (conditional on the score being higher than 0): this is 2.30 compared to 2.88 of *Distant*.

All this casts doubts about the importance of external knowledge interactions in general and, more specifically, about the importance of geographical proximity in fostering communication and informal contacts among people in the invention process. Rather, local ties are less frequent and less important than interactions across regions and countries. Figure 2 confirms these results. We compute for each patent the difference between the scores of *Close* and *Distant*. Figure 2 shows that *Close* and *Distant* interactions are equally important in 71.30% of the patents (in 54.4% of the patents they are both 0). *Distant* interactions are more important than *Close* interactions in 20.65% of the patents, while *Close* interactions benefited the invention process more than *Distant* interactions only in 8.05% of the cases.

[FIGURE 2]

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[5] We compared these data with the importance of interactions *Internal* to the inventor's organization. Only 19.5% of the patents are invented with no *Internal* interactions (excluding co-inventors), and the share of patents for which *Internal* interactions (*Close* or *Distant*) are important (score 3 to 5) is 68.3%. This suggests that knowledge spillovers in the form of discussions, meetings, etc. are more likely to occur with individuals affiliated to the same organization, i.e. spillovers are internalized within the firm/institution of the inventor.

The next Section provides an explanation for these results that, although unexpected given the many contributions on the role of geographically localized knowledge spillovers for producing innovations, are consistent with other work. For example, Audretsch and Stephan (1996) find that local links between scientists and private biotechnology companies in the USA are anything, but overwhelming. By means of case studies, Davenport (2005) shows that, for a sample of SMEs located in New Zealand, non local interactions are relevant for innovation more than local links. Hendry et al. (2000) describes how, in the opto-electronic sector, national and international networks of firms are more important than local ones for the growth of firms (see also Staber, 1996).

We also checked whether there are differences across technological classes, countries and type of applicant organization in the relative importance of *Close* vs. *Distant* interactions. For each applicant organization, the histograms in Figure 3 reports the difference between the shares of patents invented with *Close* and *Distant* interactions in each score category. Positive (negative) differences, i.e. those in the upper (lower) part of the graph, indicate that the share of patents invented with *Close* interactions is higher (lower) than the share of patents invented with *Distant* interactions in the selected category.

[FIGURE 3]

Consistently with Figure 1, the graph shows that the share of patents that do not use *Close* interactions is higher than the share of patents with no *Distant* interactions (score = 0). The same applies when the importance of external interactions is small (score = 1 or 2). When the score is 3 and higher, *Close* interactions are less frequent than *Distant* interactions. These results suggest that, independently of the type of employer organization, geographical localized knowledge interactions are less frequent and less important than those with distant people.[6] This pattern is confirmed across countries and technologies (Results available from the authors).

3. Is there a Silicon Valley effect?

Up to now we know that the majority of patents are developed with no interactions with people external to the inventor's organization. Moreover, both the frequency and the average importance of

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[6] The share of patents invented by Large Firms that do not use any *Close* interaction is 70.1%, similar to Medium and Small firms (68.9% and 68.8%) and higher than Universities (60.2%). The share of patents developed by no means of *Distant* interactions is 59.2%, 62.5%, 63.0%, and 47.1% respectively for the four types of organizations. For high scores (3 to 5) of *Close* interactions, the share of patents developed by Large Firms is 11.4%. It is 13.2% for Medium Firms, 15.1% for Small Firms and 16.2% for Universities.

Close interactions are lower than those of *Distant* interactions, suggesting that geographical proximity does not play a major role in fostering such links.

This is true unconditionally. There might be, however, variation across regions in the extent to which geographical proximity matters for establishing local ties. In other words, knowledge spillovers, if they exist, are not uniformly distributed across regions and the exchange of knowledge is stimulated in some regions more than in others according to their local technological endowment. This is also suggested by studies like Almeida and Kogut (1999) who show that the localization of knowledge varies across US regions with Silicon Valley, New York and Southern California at the top of the list for semiconductors. Thompson (2006) shows that knowledge spillovers are stronger in California, Texas and Massachusetts than elsewhere (see also Audretsch and Feldman, 1996).

This part of our research will therefore shed some light on two questions concerning the geographical extent of knowledge interactions that inventors set up during the inventive process:

1. Is there a “Silicon Valley effect”? We test the hypothesis that local interactions are more likely to take place in technological active and richer regions (i.e. the technological clusters) to a greater extent than elsewhere. In other words, we expect that the inter-regional variation is reflected in the extent to which people take advantage of localized knowledge spillovers. Therefore, after controlling for other factors, we expect *Close* interactions to be more important than *Distant* interactions in the cluster regions.

2. Is the spatial dimension of interactions shaped by the characteristics of the inventors who set them up? Studies like Audretsch and Stephan (1996) on the role of scientists on the geographical dimension of research links between universities and private companies in biotechnology suggest that these might be key factors also in our analysis. This would be also consistent with other contributions like Almeida and Kogut (1999), Breschi and Lissoni (2001), Singh (2005), Sorenson and Singh (2007), and Fleming et al. (2007) on the role played by the individual (“social”) networks in explaining knowledge flows and regional co-location.

To explore these issues we perform a multiple correlation analysis followed by a number of robustness checks. We discuss in the following sub sections the reduced form model that we test.

3.1. Construction and interpretation of the dependent variables: levels and pairwise differences

The importance of *Close* interactions (score 0 to 5) and the importance of *Distant* interactions (score 0 to 5) are the two dependent variables of our Ordered Probit regressions. Each of these two dependent variables, however, measures two simultaneous decisions by the inventor: the institutional setting in which interaction takes place (*Internal* vs. *External*) and its geographical breadth (*Close* vs. *Distant*). By reading the estimated coefficients of the two equations it is not possible to isolate the effect of the regressors on each decision separately. Therefore, for example, the results to the *Close* equation would speak about the factors that affect the importance of interactions that are geographically close and institutionally external to the inventor's organization. Similarly, the estimated coefficients of the *Distant* equation would show the correlates with the importance of interactions that are both geographically distant and external to the inventor's organization.

As a possible solution to separate the two effects we propose to perform a third regression whereby the dependent variable is the pairwise difference between the score assigned by the inventor to *Close* and *Distant* interactions to develop the specific patent. This is because, for the single patent, *Close* and *Distant* interactions share the same institutional setting (i.e. *External*) while they differ in the geographical extent of the links. The estimated coefficient of this regression would show the net effect of each variable on the relative importance of *Close* vs. *Distant* interactions, given that they take place with individuals external to the inventor's organization. Moreover, by running a third equation on the difference between *Close* and *Distant* scores, we limit a potential problem that we would have with other statistical tests when there is correlation between the error terms of the two equations (because, for example, of common omitted variables).

This variable ranges from -5 to +5. A negative difference indicates that *Distant* interactions are more important than *Close* interactions to develop the patent, while a positive difference indicates that *Close* interactions are more important than *Distant* interactions. A difference of 0 implies that *Close* and *Distant* interactions are equally important during the inventive process.

3.2. Discussion of explanatory variables

Let us assume that the importance of an interaction depends on the probability to find a "matching" individual with complementary competencies needed in the inventive process. The pool of potential matching people, in turn, is located in the inventor's region (*Close*) and in other regions (*Distant*).

The data shown in Section 2, where, on average, *Distant* interactions are more important than *Close* interactions, are consistent with the following view. Suppose that there are r regions that an inventor can reach, and that the pool of potential matching individuals is evenly distributed across them. The inventor is located in one region where he can set up *Close* interactions; he can develop *Distant* interactions with individuals located in all the other $r-1$ regions. As r increases, the probability to find a perfect match in the *r-1* regions increases as well. The higher *r* is, the higher the probability to find the perfect match in one of the *r-1* regions compared to find it at home. In our study, the own region is the one in one-hour reach of the inventor, while the number of outside regions is very large, suggesting that, on average, the probability to find a good *Distant* match is high compared to have it *Close*.

Given a fixed number of *Distant* regions (as it is in our study and in general), two additional regional factors contribute to explain the relative importance of *Close* and *Distant* interactions: one is the geographical distribution of the pool of potential matching individuals; the other one is the existence of geographically bounded knowledge spillovers. Specifically, suppose that knowledge spillovers are not geographically bounded. Then, the probability to develop *Close* and *Distant* interactions simply mirrors the geographical distribution of the matching individuals: knowledge interactions are more likely to take place in regions where the potential pool of interacting individuals concentrates.[7] Differently, if knowledge spillovers arise in the technological clusters, the expectation is that the positive impact on *Close* interactions is higher than the negative effect on *Distant* interactions due to some increasing returns process. In other words, the propensity to engage in local relationships does not simply follow the local pool of potential matching individuals: when we move to the technological clusters, local knowledge flows increase more than proportionally compared to the local availability of intellectual resources.[8]

In order to take these forces into account, we include a set of variables that describe the technological environment in which the inventor works. We first measure the importance of the general technological setting outside the inventor's organization in all technological disciplines. Since we do not have an indicator of the number of individuals with whom the inventor might match, we consider, as a proxy for it, the 1994-1996 average number of patents applied in all sectors in the NUTS3 region where the inventor was located at the time of the invention (REGPATS) (source: Regio Eurostat).[9] Moreover, in order to distinguish between private and public sources of knowledge, we downloaded from the *European R&D database* (1996) a stock of

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[7] To simplify suppose that 100% of the research is performed in the region of the inventor. In this case he will develop no *Distant* interactions. If this is the case, however, rather than the effect of localized knowledge spillovers, *Close* and *Distant* interactions would result from the uneven geographical distribution of inventive activities (Jaffe et al., 1993), which we need to control for if the aim of the study is to understand the additional role played by geographical proximity.

[8] Other factors may affect the probability to set up *Close* and *Distant* interactions like the different cost to reach nearby people compared to distant individuals. We capture these factors by controlling for firm and inventor's characteristics. As a further check we also run separate regressions for the two sub-samples of arge and small firms, for which, typically, resource constrains are different.

[9] The list of European regions used in this paper is available from the authors and from the website http://ec.europa.eu/comm/eurostat/ramon/nuts/codelist_en.cfm?list=nuts

about 20,000 R&D laboratories located in Europe as for December 1995, and classified them as private laboratories, universities and government laboratories. In place of REGPATS we then included the 1995 stock of private research laboratories (LABS_PRIVATE), public research laboratories (LABS_PUBLIC) and higher education laboratories (LABS_UNI) located in the NUTS3 region.[10]

Second, since knowledge interactions might be more likely to occur between people sharing common research interests and complementary competencies within a technological field, we include a set of variables that proxy for the technological endowment of the region that is specific to the technology of the surveyed patent. To do this we collected from the Regio Eurostat database the 1994-1996 number of regional patents applied at the EPO in each of the 30 ISI-INPI-OST technological classes in which the patents in our sample are also classified (see Appendix 1 for the list). The breadth of the 30 technological classes is such that each of them includes inter-connected micro fields, without being too narrow to capture only research in the very micro-specialty. For each patent in our sample we computed the share of patents invented in the region in the specific technology over the number of patents invented in all regions in the same technology (SHARE_TECH). The larger the share is, the higher the potential for setting up interactions. Moreover, to control for the fact that knowledge spillovers arise only after a "critical mass" of research located in the region, we construct a variable that indicates whether a region is top in the discipline of the patent. We ranked the regions according to SHARE_TECH and produce a dummy variable (TOP5_TECH) that is 1 for regions in the top 5% of the distribution in each technology; 0 otherwise. Similarly, the variable TOP1_TECH is for regions in the top 1% of the distribution. Regions in the top percentile have between 4% up to 15% of the patents in the technology. In order to check for higher level top regions, we introduce the variable THRESH5_TECH that takes the value 1 if more than 5% of the European patents in a specific technology is located in the region; 0 otherwise. This is intended to capture regions that develop the bulk of innovations in each technology.[11] The inclusion of these variables will also tell us whether interactions (and possibly knowledge spillovers) are not "generic" but, rather, they occur because of the research effort undertaken by others in the particular technological discipline of the inventor (see, among others, the results reported by Jaffe 1989 and Furman et al. 2006).

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[10] Jaffe (1989) provide evidence that corporate patent activity is positively affected by university research. Zucker et al. (1998) show the importance of proximity to university research for developing inventions in biotechnology. Similarly, Furman et al. (2006) find that spillovers to pharmaceutical research come from public knowledge, while private research is negatively correlated with research productivity.

[11] SHARE_TECH and TOP1_TECH are calculated at the NUTS2 regional level of aggregation because NUTS3 level data by micro technological class are not available from Regio-Eurostat.

To the technological features of the regions we add exogenous controls for their size (AREA), population (POP) and economic development (GDPPC).

Apart from the technological endowment of the external environment, other factors affect the extent to which inventors develop *Close* vs. *Distant* ties during the inventive process. For example, the attributes of the inventor and the invention that he produces, and the characteristics of the applicant organization may affect the cost and benefits of *Close* vs. *Distant* interactions.

We therefore include a set of variables that describe the applicant organization. They can affect both the decision to develop *Internal* vs. *External* interactions, and the decision to go *Close* vs. *Distant*.[12] We control for the type of organization: large (LARGE), medium (MEDIUM) and small firms (SMALL), private research organisations (PRIVATE), Universities and other public research institutions (UNIV), and independent inventors (INV). Moreover, for private firms, we have information about the size and R&D intensity of the parent company drawn from Compustat (1998) and Amadeus (2005). We use the number of employees (EMPLOYEES) to proxy for the scale of the firms, and the ratio between R&D expenditure and sales (R&DINT) for R&D intensity. By controlling for both the size and the R&D intensity of the organisation, we separate the effect of the scale of the organisation from its capacity/effort devoted to innovation, which otherwise would both be reflected by the same variable.[13] R&D intensity measures the importance of research and invention for the organization, which, in turn, might affect the extent to which inventors need to set up interactions during the invention process. Moreover, the development of inventions requires extensive resources in terms of technical equipment, research laboratories, instruments, research assistants and complementary expertise. The size and R&D intensity of the organisation also proxy for the availability of internal resources, and therefore for the extent to which inventors might want to resort to external interactions. Compared to smaller companies and to other private and public research institutions, large firms might have enough internal resources to engage in complex research projects and to ask for patent protection on a larger number of inventions. We therefore expect that, on average, they will tend to internalize spillovers and to use less external interactions compared to the other private and public types of organizations.[14] Moreover, given that one uses

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[12] This is worth keeping in mind. It will be true also for other variables like inventor and invention characteristics, and this is the driver of our decision to run the third regressions where the dependent variable is the difference *Close-Distant*.

[13] The dummy variable for the type of organization is also used to cover missing data for EMPLOYEES and R&DINT. Information on EMPLOYEES are available for 77.78% patents; data on R&DINT iare available for 41.92% patents. The sample of missing EMPLOYEES is a subsample of missing R&DINT. The share of missings for R&DINT is 45.21% for large firms; it is 99.6% for small and medium firms.

[14] See, for example, Acs, Audretsch and Feldman (1994) and Feldman (1999).

external resources, if *Distant* interactions are more expensive than *Close* interactions in terms of organizational capabilities and financial resources, small firms might suffer from this constrain more than large corporations.

A challenging opportunity provided by the PatVal-EU survey is the possibility to control for the individual characteristics of the inventor who established the interaction. This is quite useful in our analysis, as the establishment of local vs. global networks of researchers may rest, to a great extent, in the ability and experience of the individuals. For example, young researchers might tend to invest in the organization in which they work. Only later on in their career they might want to exploit the output of this investment outside the firm (Cole, 1979; Audretsch and Stephan, 1996). We therefore expect them to focus more on interactions with people internal to the firm than with external parties. However, conditionally upon the fact that they establish links outside the employer organization, we expect younger and less experienced researchers to be more likely to engage in local networks of researchers more than older and more experienced inventors (Audretsch and Stephan, 1996). Once controlling for age (AGE), the educational background of the inventors is another key factor that might influence the geographical extent of the interactions. Inventors with a long and high level curriculum of education might have had better opportunities to enter into geographically extensive networks of people who share common scientific interests. The level of education might then be a signal of the inventor's ability to rely on personal research connections to establish interactions in their working career: the higher the educational background, the larger and geographically broader is expected to be, on average, the network of individuals to interact with. We employ a dummy variable for the highest degree of education among the following: Secondary and High School (HIGH_DEGREE), University BSc or Master (UNI_DEGREE), PhD (PhD_DEGREE). Moreover, to control for the effort that, on average, male inventors can spend in doing research and in setting up interactions compared to women, we also use a dummy for their gender (MALE).

We also include a set of invention-level indicators. We first control for co-inventorship (N_INVENTORS). This variable indicates whether more formal types of interactions that end up in co-inventorship are complement or substitutes to more informal knowledge interactions. The number of inventors involved in developing a patent is also a proxy for the scale of the research project leading to the invention. If there is complementarity (substitutability) between more formal types of collaborations and our informal knowledge interactions, there will be a positive (negative) sign in both *Close* and *Distant* regressions, while the coefficient will not be statistically significant in the *Close-Distant* regression. We then control for the extent to which a patent is related to basic research. This is done by SCIENCE that measures the importance of the scientific literature as a source of knowledge for the research that led to the invention. As Gittelman (2005) suggests, the benefits of geographical proximity are expected to be less important for science-based research compared to more technological work. More scientific research would benefit less from geographically localized spillovers due to more open and spatially dispersed communities of individuals and to the communication mechanisms that are not linked to location externalities. Finally, we control for the reasons that led the inventor to patent the invention. Specifically, we control whether the inventor was moved by the desire to commercially exploit the invention (COMM_EXPLOIT), license it (LICENSING) or prevent others from imitation (IMITATION). For example, we expect inventors to be more inward-looking when they work on patents that are exploited commercially or that are produced to prevent others from imitation. Differently, interactions with external parties are expected to be more important for patents that are produced to be licensed, which would determine a positive sign of LICENSING in both regressions. We do not have priors on the effect of these variables on the importance of *Close* compared to *Distant*.

Finally, all regressions are performed with dummies for the application year and dummies for the country of the inventors to capture the effect of regional characteristics that are independent of the variation across countries. We also include dummies for the 30 micro ISI-INIPI-OST technological classes of the patents. This is because the mechanism by which knowledge is transferred might be different in different technological fields (Audretsch and Feldman, 1996; Jaffe et al. 993). Table 1 provides the definition of the variables. Table 2 shows their descriptive statistics.

[TABLES 1 and 2]

4. Results

We performed three reduced-form model regressions. The dependent variable of the first one is the importance of *Close* interactions; the second one is for the importance of *Distant* interactions; and the third regression is performed on the difference between importance of *Close* and *Distant* interactions. This set of three regressions is performed with six specifications that differ for the regional technological variables included. All the other variables are the same across all specifications. As we will discuss in Section 5, a number of robustness checks are also performed with no significant changes in the results.

Tables 3 and 4 show the results of the econometric estimates. Since the survey over-sampled “important” patents, we corrected for the stratification by computed sampling weights for the hypothetical unbiased sample. Sampling weights also control for the representativeness of the sample of patents for which we received a response with respect to the selected sample of patents/questionnaires that have been sent to inventors (for details, see Giuri and Mariani, 2006).

Cluster robust estimators on firms are included in order to take into account any unobserved correlation among the errors of the patents belonging to the same parent company.

All the variables are in logs. All regressions include dummies for missing value for EMPLOYEES and R&DINT, inventor country, year of application and technological field of the patent (30 ISI-INIPI-OST classes).

[TABLES 3 and 4]

The goal of the econometric exercise is to understand if, after controlling for other possible factors, there is a Silicon Valley effect, i.e. if knowledge interactions with close-by people are more likely to take place in technological active and rich regions compared to elsewhere. Additionally, we test the hypothesis that the inventors' personal characteristics influence the geographical breadth of their research network.

The first specification uses the variable on the general technological environment external to inventor as measured by REGPATS. Let's go through the results. Firm characteristics do not affect the geographical extent of interactions set up with individuals outside the employer organization. EMPLOYEES is not statistically significant on both *Close* and *Distant* interactions, while R&D intensity matters only for the decision to set up knowledge interactions *External* to the employer organization. The higher the R&D intensity of a firm, the higher the probability to internalize knowledge interactions: the importance of both *Close* and *Distant* interactions decreases as R&DINT gets higher, and the effect is statistically significant at 5% level. However, R&DINT is not statistically significance on the difference *Close-Distant*, suggesting that, given that the inventor interacts with people external to the organization, R&D intensity does not affect the geographical breadth of the relationship.

As expected, inventors' characteristics are correlated with the decision/ability to enter into local vs. broader networks of research. First of all, the age of the inventor (AGE) has a negative and statistically significant effect on *Close*, although it is not correlated with *Distant*. Therefore, interactions with people *Close* and *External* to the firm are less important for older inventors. However, we know that this measures the effect of AGE on the importance of both *Close* and *External* interactions, i.e. with both the geographical extent and the institutional setting in which interactions take place. To isolate the net effect of AGE on the geographical dimension of the interactions, the third regression shows that the estimated coefficient of AGE is negative and statistically significant at 5% level. This suggests that, once conditioning on *External* interactions, the older the inventor is, the more likely it is that he engages in *Distant* compared to *Close* interactions.

Second, the educational background explains a lot of the geographical dimension of knowledge interactions. Our baseline category is High School degree or lower. The estimated coefficient of both University/Master and PhD degree is statistically not significant on the importance of *Close* interactions. They are, however, both positive and statistically significant on *Distant* interactions and, as expected, they are positive and statistically significant at 5% and 1% level respectively, on the difference *Close-Distant*. This is very important as it shows that inventors with a high level of education have better opportunities to enter into broader networks of research. As we discussed earlier, this might be because prior experience gave the inventors the opportunity to set up personal relationships with people who share common interests. These relationships are then used later to get knowledge from people that they know might have the needed expertise.

From the PatVal-EU survey we also know the inventors' mobility across organizations before and after the development of the surveyed patent. We constructed a dummy variable equal to 1 if the inventor changed employer at least once in the ten years before the patent application in order to explore whether knowledge interactions are explained by human capital mobility.[15] The estimated coefficient of the mobility variable is positive and statistically significant on both *Close* and *Distant*. It is, however, statistically not significant on the difference *Close-Distant*. This holds both when the mobility variable is included in place of the educational background and when it is included in addition to it (results available from the authors), suggesting that, once we control for exogenous inventors' characteristics, the extent to which they move across organizations does not affect the geographical breadth of knowledge interactions. It says, however, that more mobile inventors have a higher probability to set up knowledge interactions with people external to their current employer organization independently of the fact that they are geographical close.

As far as the characteristics of the invention are concerned, the variable SCIENCE is positively correlated with both the importance of *Close* and *Distant* interactions. The estimated coefficient is significant at 1% level. However, this could be due to the fact that, by its own nature, more scientific work is performed by a more "open" network of researchers, and that therefore, the positive correlation is due to the tendency to link to people *External* to the employer organization. The third regression should isolate the net effect of SCIENCE on the relative importance of *Close* vs. *Distant*, given that interactions are *External* to the organization. The estimated coefficient of

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[15] We do not show the results here because mobility may be endogenous to other inventor's characteristics like the level of education that, in turn, proxies for the unobservable individual talent. Multiple correlation analysis (negative binomial regressions) with the number of moves as the dependent variable shows that mobility is highly correlated with the educational background of the inventors, though, unexpectedly, it is not correlated with the technological characteristics of the European regions.

SCIENCE is negative and statistically significant at 1% level, suggesting that more scientific work is more likely to be undertaken by a geographically broad network of people.

The other patent controls are either not correlated with any of our types of interactions, or, like LICENSING, is positively correlated with *Close* and *Distant* (significant at 1% level), but it is not correlated with *Close-Distant* in the third regression. This suggests, again, that if an invention is patented to be licensed out, the inventor will be more likely to engage in interactions with *External* parties, independently of their geographical location.

Therefore, as we expected, the nature of the invention and the individual characteristics of the inventors are important in shaping the geographical extension of knowledge interactions. We did not expect, however, that these are the only factors that matter in our regressions. In particular, we did not expect that the estimated coefficient of REGPATS, which proxies for the richness of the external technological environment, is not correlated with the importance of local ties.

However, the variable REGPATS may not capture technological aspects of the regions that are more specific to the rise of local knowledge spillovers. We therefore replaced it with the number of public, private and University research laboratories located in the NUTS3 region (columns 4-6 in Table 3). The results show that, while the scientific content of the invention and inventor characteristics are still significantly correlated with the geographical dimension of knowledge interactions, the number of research laboratories of any type does not affect it. The estimated coefficients of LABS_UNI, LABS_PUBLIC and LABS_PRIVATE are not statistically significant in any of the three regressions.[16]

Still, however, spillovers may occur because of the regional co-location of research activities specific to the technological field of the patent/inventor. Moreover, inventors may link to *Close* more than to *Distant* people if, compared to other regions, the area has a sort of technological "advantage" in the specific discipline. Patents and research laboratories in all technologies may not capture this aspect. We therefore include a set of variables that proxy for the relative importance of

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[16] An issue arises here about the potential endogeneity of firm location: the decision to locate in a region might be a function of the desire to access knowledge generated by others, or, by contrast, to avoid that knowledge produced by the own firm spills over to others. Or, still, the firm might determine to a large extent the technological characteristics of the region. This problem is limited in our case for various reasons. First, since we use data at the level of the inventor, it is unlikely that the strategic behavior of the firm with respect to competitors applies also to individuals. It is also unlikely that the specific inventor/interaction determines the technological characteristics of a region. Second, we showed in Section 2 that the importance of Close interactions is low, suggesting that they are not a major factor in shaping the technological advantage of the regions. Finally, in order to use pre-determined (and therefore more exogenous) regional variables, we employed the stock of University and public research laboratories in 1995 and patents invented in 1994-1996, which are the output of research conducted earlier.

the region in the technology of the patent. The first one is SHARE_TECH calculated as the share of patents invented in the region in the specific technology over the number of patents invented in all regions in the same technology. The third specification (columns 7-9 in Table 3) shows the results for the inclusion SHARE_TECH in addition to REGPATS. The estimated coefficient of SHARE_TECH is negative and statistically significant at 1% level on *Distant* interactions. It is positive, although not statistically significant on *Close*. It is negative and statistically significant at 1% level on *Close-Distant*. This suggests that, when the region is comparatively good at doing research in a specific technological field, than inventors will look link less to people in other regions. Or, to say it differently, when a large pool of potential matching individuals is located at home, the need to go outside it decreases. This does not produce, however, an increase in the importance of *Close* interactions. This might be because more than 90% of the regions in our sample perform a modest share (less than 4%) of the total European research in the technology of interest. Hence, in most cases, the cross-regional change in SHARE_TECH is very small and does not give rise to the "critical mass" of research activities that is probably needed to stimulate knowledge exchange locally, i.e. to let spillovers arise. Again, all the other inventor, patent and firm variables behave as in previous specifications.

The next step is to find out whether there is a threshold in the local availability of technological resources in order to give rise to local knowledge exchange. We therefore replace SHARE_TECH with a dummy variable for the top 5% and 1% regions in the discipline of the patents. Specifications 4 (columns 1-3 in Table 4) and 5 (columns 4-6 in Table 4) show the results for the inclusion of TOP5_TECH and TOP1_TECH respectively. The effect of both variables is negative and statistically significant on *Distant*. It is, as expected, positive on *Close*, even though it is not highly significant (it is almost at 10% level for TOP1_TECH).

We also go one step further, and given that the regions in the top percentile develop between 2.6% up to 15.1% of the patents in the specific technology, we restrict the sample of top regions to those that develop the bulk of innovations in each technology. The variable THRESH5_TECH serves this purpose. It takes the value 1 if more than 5% of the European patents in a specific technology are located in the region. The results (columns 7-9 in Table 4) show that the effect of this variable is negative and statistically significant at 5% level on *Distant*; it is positive and statistically significant at 10% level on *Close*. It is positive and statistically significant at 1% level on the difference *Close-Distant*. This gradual increase in the importance of *Close* interactions as we restrict the analysis to the very top regions might suggest that the importance of local knowledge interactions increases only in the very few technological clusters in the specific discipline. However, in order to control whether this is the effect of an increasing returns process or if this is the result of the geographical distribution of inventive activities (i.e. the potential pool is located at home), we computed the marginal effects of these variables (at their means) for *Close* and *Distant* interactions.[17] The elasticity for the top region variables (TOP5_TECH, TOP1_TECH and THRESH5_TECH) are almost the same on *Close* and *Distant*, though with opposite signs. This suggests that, more than increasing returns associated to local spillovers and a critical mass of research in a region, the relative increase in *Close* might follow the distribution of inventive activities: when the pool of potentially interacting people is at home, the probability to link with it increases independently of any effect of localized knowledge spillovers.

We achieved the same results as those shown in Tables 3 and 4 when we used the number of research laboratories in the three categories in place of AVGPATS, and when we define the top regions according to the total number of patents rather than patents in the specific technology: the top variables are never statistically significant (both at the NUTS3 and NUTS2 regional level). The estimated results do not change also when we run the regressions for the two sub-samples of large and medium-small firms, guided by the consideration that large firms might have a different cost to go Distant compared to small, and that this difference is not fully captured by the firm level variables included in the regressions (results are available from the authors).[18]

All in all, we can conclude as follows. First, in general, local knowledge interactions do not seem to be more important in cluster-like regions. Moreover, if a slight positive effect of being in a technological cluster exists on local knowledge interactions, it applies only to a very restrict club of top regions in Europe. Second, the most important actors that explain the geographical breadth of inter-personal knowledge interactions are the scientific content of the research and the individual characteristics of the inventors that allow them to take part in local vs. more international research networks. This holds across different specifications.

5. Conclusions

This paper provides new evidence about the role of geographical proximity in fostering knowledge interactions. To do so it uses new data collected from a large survey of European inventors (i.e. the PatVal-EU survey) and other data from complementary databases on the characteristics of the organizations in which the inventors were employed at the time of the invention, and the

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[17] We computed the marginal effects in a probit regression for *Close* and *Distant* with: 0=no interactions and 1=yes interactions, independently of their importance.

[18] We also used the number of patents in the technology invented in the region in place of the SHARE_TECH. Technological fields were measured both by using the ISI classification and the IPC3-digit. Alternatively, we computed the share and number of patents by IPC1-digit at the more disaggregated NUTS3 regions. The estimated results are similar to those shown in Table 3.

characteristics of the regions in which they were located. An important novelty of the paper is that, instead of using indirect indicators, it employs a measure of knowledge exchange as provided directly by the inventors: this is given by the importance of meetings, discussions and, more generally, circulation of ideas that inventors developed during the inventive process.

The empirical analysis consisted of two stages. First, we analyzed the importance of geographical proximity among individuals to establish knowledge interactions. The data indicated that interactions with individuals external to the inventor's organization are not common during the inventive process. On average, interactions with geographically close individuals are fewer and less important than interactions that cut across regions, suggesting that geography boundaries do not represent a real barrier to knowledge spillovers.

In the second part of the paper we tried to answer two questions on the geographical extent of knowledge interactions. The first one is whether a "Silicon Valley effect" exists, i.e. if local interactions are more likely to take place in technological active and richer regions (i.e. the technological clusters) to a greater extent than elsewhere. Second, we explore the role of inventors' personal characteristics in shaping the spatial dimension of knowledge interactions. We used ordered probit regressions to show that, once controlling for many factors, a positive environment for research does not affect significantly the importance of local interactions during the inventive process. Interestingly, however, key factors are the inventors' educational background and the scientific content of the research performed. Specifically, knowledge interactions are set up with geographically close individuals when: 1) the research project has a low scientific content; 2) the inventors are young and have a low level of education. By contrast, the higher the experience and the educational background of the inventors, the wider and more geographically dispersed are inter-personal connections.

What are the implications of all this? If spillovers are important for economic growth, we showed that inter-regional spillovers (assuming that our indicator is a proxy for them) are more important than local spillovers. Moreover, our analysis shows that, being located in a technological cluster does not increase the importance of *Close* compared to *Distant* interactions. This raises concerns about the design and effectiveness of regional policies aimed at fostering them. Moreover, we found that the real barrier to knowledge spillovers is the inventor. Inventors with a lower level of education and little experience tend to enter in local networks of research, while older and better educated inventors take part in broader networks. This suggests that, more than an opportunity, the setting up of local interactions is the result of an inventor constrain: local networks seem to be an option that the inventors play when they do not have the possibility to take part in broader networks.

This suggests that it might be beneficial to think about policies aimed at stimulating "openness" at the micro individual level.

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Appendix 1. List of ISI-INPI-OST technological classes used in the paper and descriptive statistics.

	Mean	Std. Dev.
Electrical devices, engineering, energy	0.074	0.262
Audio-visual technology	0.020	0.139
Telecommunications	0.032	0.176
Information technology	0.022	0.146
Semiconductors	0.010	0.101
Optics	0.019	0.138
Analysis, measurement, control technology	0.060	0.237
Medical technology	0.024	0.153
Organic fine chemistry	0.066	0.249
Macromolecular chemistry, polymers	0.056	0.230
Pharmaceuticals, cosmetics	0.017	0.131
Biotechnology	0.009	0.093
Materials, metallurgy	0.032	0.176
Agriculture, food chemistry	0.015	0.121
Chemical&petrol, basic materials chem.	0.037	0.188
Chemical engineering	0.031	0.174
Surface technology, coating	0.015	0.121
Materials processing, textiles, paper	0.054	0.225
Thermal processes and apparatus	0.022	0.148
Environmental technology	0.018	0.135
Machine tools	0.035	0.183
Engines, pumps, turbines	0.032	0.176
Mechanical Elements	0.043	0.203
Handling, printing	0.076	0.264
Agricultural&food proc-machin-apparatus	0.021	0.144
Transport	0.066	0.248
Nuclear engineering	0.003	0.057
Space technology weapons	0.004	0.062
Consumer goods and equipment	0.047	0.212
Civil engineering, building, mining	0.039	0.195

Appendix 2. Robustness checks

This Appendix describes a part of the robustness checks that we performed in order to control the robustness of our estimated results. Other robustness checks are reported in various parts of the text.

We started by using a different formulation of the dependent variables used in the three equations. In place of the 0-5 scale for *Close* and *Distant* we employed a dichotomous variable that takes the value 0 when no interactions take place (score 0), and the value 1 when interactions occur independently of their importance (score 1 to 5). We used these variables in two probit regressions. The third regression was performed on the difference between the dichotomous *Close* and *Distant* variables. This is a new variable that ranges between -1 and 1.

Also, in order to take into account that a difference between small scores of *Close* and *Distant* [e.g. 2-1] might mean something different compared to the same distance between higher scores (e.g. 5-4), we build a third "standardized" variable for *Close-Distant*. This is: [(*Close*+1)-(*Distant*+1)] / [(*Close*+1)+(*Disant*+1)]. The correlation coefficient between the resulting variable and the -5 to +5 variable is 0.98 and it is statistically significant. We employed this as the dependent variable in an OLS regressions. The signs and statistical significance of the estimated coefficients in the regressions with each of these new formulations of the dependent variables are similar to the ones obtained by using the 0-5 dependent variables.

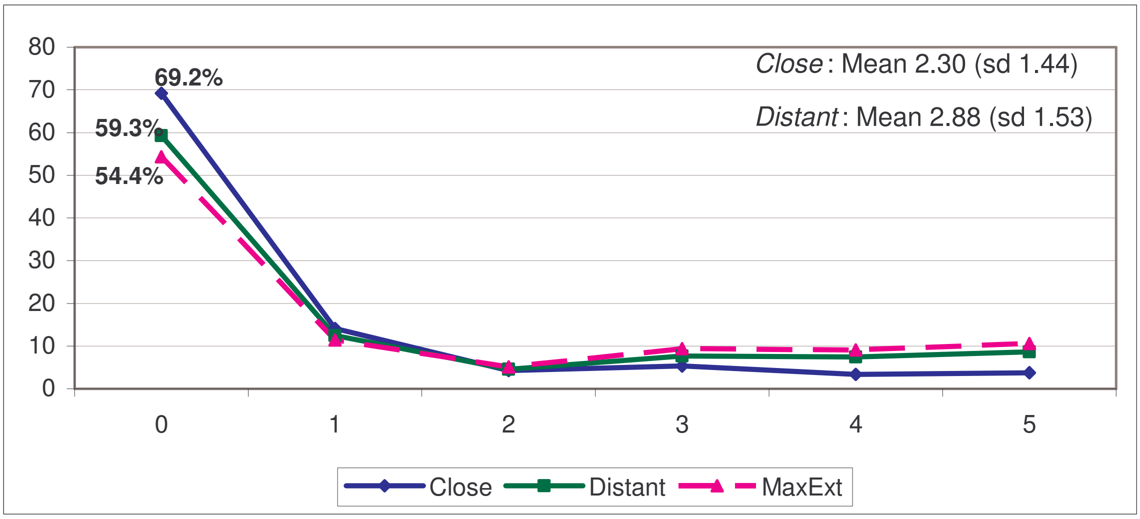
The results obtained by means of pairwise difference regressions do not change significantly also when we perform Wald tests for statistically significant differences between the estimated coefficients of the *Close* and *Distant* equations (since we estimated them separately, no correlation between the error terms of the two equations is assumed).

A concern with our estimates is multicollinearity between different regional variables like GDP, population and number of patents invented in the areas. For example, the simple correlation coefficient between the log of GDPPC and AVGPATS is 0.40. We performed our regressions by omitting alternatively GDPPC, POP and AREA, and all three together. We also run alternative specifications with TOP5_TECH, TOP1_TECH and THRESH5_TECH without controlling for the general technological environment of the region (REGPATS and LABS). In all these checks the sign and statistical significance of the variables included in the regressions do not change significantly compared to those in Tables 3 and 4.

Another possible concern with our estimates is the correlation between firm variables, i.e. R&DINT and EMPLOYEES. We perform our regressions by omitting R&DINT. The estimated coefficient of EMPLOYEES turned out to be negative and statistically significant in the *Close-Distant* regression. We also tried with different specifications for firm dummies: we omitted EMPLOYEES and used a dummy for the size of the companies while employing a dichotomous variables for missing R&DINT; we included both EMPLOYEES and R&DINT and a dichotomous variable for missing R&DINT. All the estimated coefficients are consistent with those described in Section 4. In particular, while it holds that inventors in R&D intensive firms do less *External* interactions, being them *Close* or *Distant*, when we use EMPLOYEES and R&DINT and only a dichotomous variable for missing R&DINT, inventors in smaller organizations tend to engage in *Close* interactions more than in *Distant* ones.

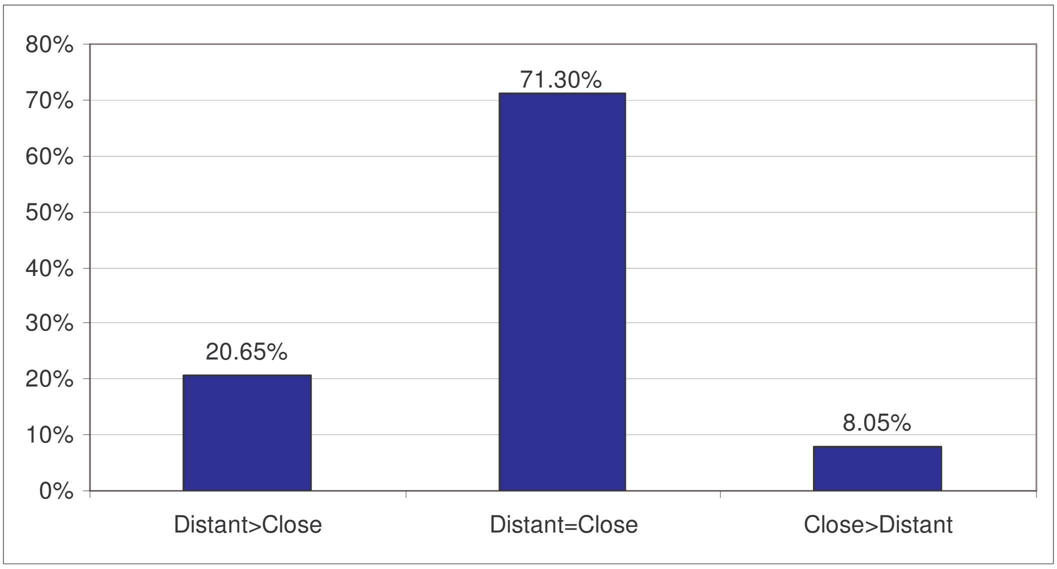
Tables and Figures

Figure 1: *Close* and *Distant* interactions: mean value and frequency distribution



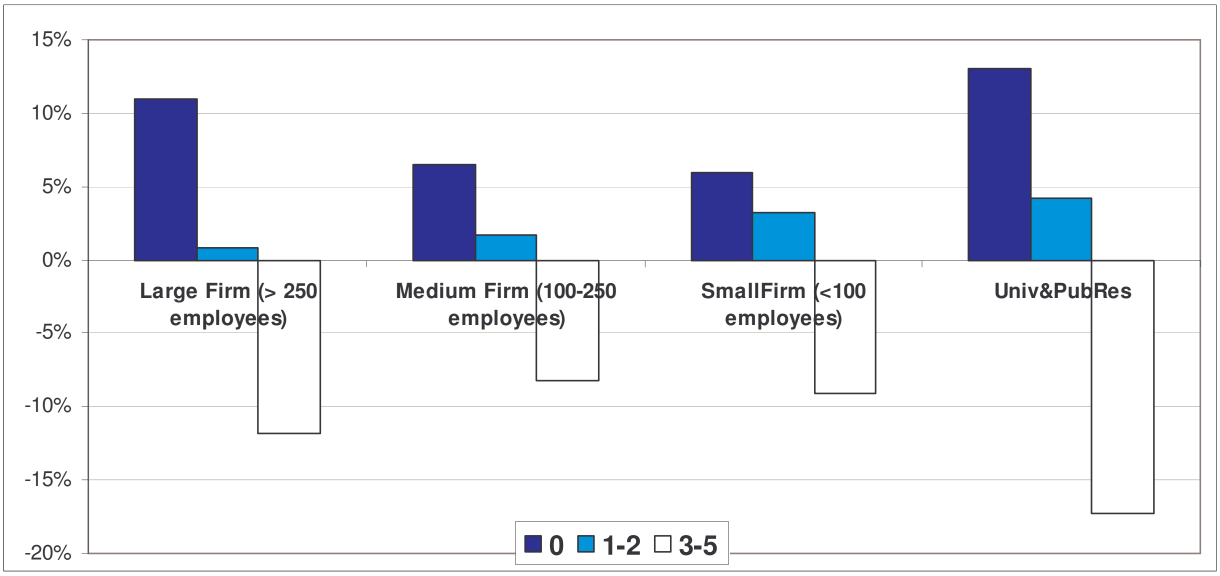
Source: PatVal-EU dataset

Figure 2: Relative importance of *Close* vs. *Distant* interactions



Source: PatVal-EU dataset

Figure 3: *Close* and *Distant* interactions by type of Applicant (Parent) Organization. Differences between shares of *Close* and *Distant* interactions by categories of importance: 0; 1-2; 3 to 5.



Source: PatVal-EU dataset

Table 1. Variables

	Dependent Variables	Source of data
Close	Importance of interactions with people belonging to unaffiliated organizations and geographically close. Scale 0 (not used) to 5 (very important)	PatVal-EU
Distant	Importance of interactions with people belonging to unaffiliated organizations and geographically distant. Scale 0 (not used) to 5 (very important)	PatVal-EU
Close-Distant	Relative importance of close vs. distant external interactions. Scale: -5 to +5 (-5 to -1: Distant more important than Close; 1-5 = Close more important than Distant).	PatVal-EU
	Employer and Inventor characteristics	
EMPLOYEES	Number of employees of the applicant parent company	Amadeus, Compustat
MISS_EMPLOYEES	SMALL, MEDIUM, LARGE applicant parent company	PatVal
R&DINT	R&D/sales ratio of the applicant parent company	Compustat
MISS_R&D	Small and Medium company: <250 empl; Medium and Large company: 251-500 empl; Large company: >500 empl; PRI: University or public research institution; Independent Inventor.	PatVal
AGE	Age of inventors: year of patent application-year of birth	PatVal
MALE	0 = Female inventor (baseline case); 1 = Male inventor	PatVal
HIGH_DEGREE	Dummy for the level of education: equal to 1 if highest Academic degree at the time of the invention is High School Degree or lower. This is the baseline case in our regressions.	PatVal
UNI_DEGREE	Dummy for the level of education: equal to 1 if highest Academic degree at the time of the invention is UNIV_MASTER.	PatVal
PhD_DEGREE	Dummy for the level of education: equal to 1 if highest Academic degree at the time of the invention is PhD.	PatVal
	Patent characteristics	
N_INVENTORS	Number of co-inventors listed in the patent	EPO
SCIENCE	Importance of scientific literature as a source of knowledge for the research that led to the invention (0 not important; 5 = very important)	PatVal
COMM_EXPLOIT	Importance of commercial exploitation as a reason to patent the invention (0 not important; 5 = very important)	PatVal
LICENSING	Importance of licensing as a reason to patent the invention (0 not important; 5 = very important)	PatVal
IMITATION	Importance of prevention from imitation as a reason to patent the invention (0 not important; 5 = very important)	PatVal
	Regional characteristics	
GDPPC	NUTS3 regional per capita Gross Domestic Product in 000 of purchasing power parity corrected for inflation (average 1994-1996)	Eurostat-Regio
POP	NUTS3 Population of the region (thousands - average 1994-1996)	Eurostat-Regio
AREA	NUTS3 Area of the region (Km2)	Eurostat-Regio
REGPATS	NUTS3 Number of patent applications in all sectors invented in the region (units - average 1994-1996)	Eurostat-Regio
LABS_UNI	NUTS3 Number of universities laboratories located in the region (stock in 1995)	European R&D database
LABS_PUBLIC	NUTS3 Number of public laboratories located in the region (stock in 1995)	European R&D database
LABS_PRIVATE	NUTS3 Number of private laboratories located in the region (stock in	European R&D

	1995)	database
SHARE_TECH	NUTS 2 Number of patent applications in the same micro technological field of the patent (ISI-INPI-OST classification in 30 technogical fields).	Eurostat-Regio
TOP5_TECH	Dummy variable: 1 for regions in the top 5% of the distribution in each technology; 0 otherwise	Eurostat-Regio
TOP1_TECH	Dummy variable: 1 for regions in the top 1% of the distribution in each technology; 0 otherwise	Eurostat-Regio
THRESH5_TECH	Dummy variable: 1 if more than 5% of the European patents in a specific technology is located in the region; 0 otherwise.	Eurostat-Regio
	Other Controls	
COUNTRY	Seven dummies for the country of inventor (IT, DE, ES, UK, DK, HU, NL). Baseline = UK.	EPO
YEAR	Dummies for the patent application year (from 1993 to 1998)	EPO
TECH_FIELD	Dummies for 30 micro technological fields in which the patent is classified (ISI-INIPI-OST classification)	EPO

Source: PatVal-EU dataset, EPO, Eurostat-Regio, *European R&D database*

Table 2. Descriptive statistics

	Mean	Std. Dev.	Min	Max
Dependent Variables				
Close	0.710	1.331	0	5
Distant	1.175	1.722	0	5
Close-Distant	-0.465	1.772	-5	5
Employer and Inventor characteristics				
EMPLOYEES	84260.45	114751	1	723328.6
MISS_EMPLOYEES	0.222	0.416	0	1
R&DINT	0.055	0.032	0	0.412
MISS_R&D	0.581	0.493	0	1
AGE	44.946	9.736	20	84
MALE	0.973	0.162	0	1
HIGH_DEGREE	0.195	0.396	0	1
UNI_DEGREE	0.547	0.498	0	1
PhD_DEGREE	0.258	0.438	0	1
Patent characteristics				
N_INVENTORS	2.266	1.527	1	22
SCIENCE	2.593	1.873	0	5
COMM_EXPLOIT	3.808	1.554	0	5
LICENSING	2.059	1.543	0	5
IMITATION	3.798	1.578	0	5
Regional characteristics				
GDPPC	22941.680	8915.593	5479.200	76910.800
POP	727.197	873.060	19.900	4634.400
AREA	1583.436	1997.538	35.600	18275.300
REGPATS	120.412	132.559	0.830	543.213
LABS_UNI	45.635	84.048	0	429
LABS_PUBLIC	12.438	36.351	0	461
LABS_PRIVATE	7.165	14.192	0	118
SHARE_TECH	0.024	0.026	0	0.151
TOP5_TECH	0.436	0.496	0	1
TOP1_TECH	0.142	0.349	0	1
THRESH5_TECH	0.146	0.353	0	1
Other Controls				
UK	0.182	0.386	0	1
DE	0.410	0.492	0	1
IT	0.158	0.365	0	1
ES	0.027	0.161	0	1
NL	0.158	0.364	0	1
DK	0.062	0.241	0	1
HU	0.004	0.067	0	1
AppYear1993	0.027	0.162	0	1
AppYear1994	0.278	0.448	0	1
AppYear1995	0.263	0.440	0	1
AppYear1996	0.225	0.418	0	1
AppYear1997	0.157	0.363	0	1
AppYear1998	0.050	0.217	0	1

Source: PatVal-EU dataset, EPO, Eurostat-Regio, *European R&D database. # obs:* 6945.

Table 3: Ordered probit estimations. Specifications 1-3

Variable	*Close*	*Distant*	*Close-Distant*	*Close*	*Distant*	*Close-Distant*	*Close*	*Distant*	*Close-Distant*
	Specification 1			*Specification 2*			*Specification 3*		
Employer and Inventor characteristics									
EMPLOYEES	0 (0.01)	0.01 (0.01)	-0.01 (0.01)	0 (0.01)	0.01 (0.01)	-0.01 (0.01)	0 (0.01)	0.01 (0.01)	-0.01 (0.01)
R&DINT	-2.82** (1.21)	-1.77** (0.96)	-0.35 (0.6)	-2.84** (1.21)	-1.82** (0.96)	-0.33 (0.6)	-2.83** (1.22)	-1.73** (0.94)	-0.38 (0.6)
AGE	-0.39*** (0.08)	-0.12 (0.08)	-0.19** (0.08)	-0.39*** (0.08)	-0.12 (0.08)	-0.19** (0.08)	-0.39*** (0.08)	-0.12 (0.08)	-0.2** (0.08)
MALE	0.05 (0.12)	-0.13 (0.09)	0.19** (0.09)	0.05 (0.12)	-0.13 (0.09)	0.19** (0.09)	0.04 (0.12)	-0.12 (0.09)	0.19** (0.09)
UNI_DEGREE	-0.03 (0.05)	0.12** (0.05)	-0.12** (0.05)	-0.03 (0.05)	0.11** (0.05)	-0.12** (0.05)	-0.03 (0.05)	0.11** (0.05)	-0.11** (0.05)
PhD_DEGREE	0.02 (0.06)	0.23*** (0.06)	-0.21*** (0.06)	0.02 (0.06)	0.23*** (0.06)	-0.21*** (0.06)	0.02 (0.06)	0.24*** (0.06)	-0.21*** (0.06)
Patent characteristics									
N_INVENTORS	0.02 (0.04)	0.02 (0.03)	0 (0.03)	0.02 (0.04)	0.02 (0.03)	0 (0.03)	0.02 (0.04)	0.03 (0.03)	0 (0.03)
SCIENCE	0.3*** (0.03)	0.29*** (0.03)	-0.07*** (0.02)	0.3*** (0.03)	0.29*** (0.03)	-0.07*** (0.02)	0.3*** (0.03)	0.29*** (0.03)	-0.06*** (0.02)
COMM_EXPLOIT	0.03 (0.04)	0.04 (0.04)	-0.03 (0.04)	0.03 (0.04)	0.04 (0.04)	-0.03 (0.04)	0.03 (0.04)	0.04 (0.04)	-0.03 (0.04)
LICENSING	0.17*** (0.03)	0.16*** (0.03)	-0.02 (0.03)	0.17*** (0.03)	0.16*** (0.03)	-0.02 (0.03)	0.17*** (0.03)	0.16*** (0.03)	-0.02 (0.03)
IMITATION	0.08* (0.04)	0.05 (0.05)	0.01 (0.04)	0.08* (0.04)	0.05 (0.05)	0.01 (0.04)	0.08* (0.04)	0.05 (0.05)	0.01 (0.04)
Regional characteristics									
GDPPC	-0.06 (0.08)	-0.17* (0.09)	0.12* (0.07)	-0.07 (0.07)	-0.2** (0.09)	0.13* (0.07)	-0.06 (0.08)	-0.15* (0.09)	0.1 (0.06)
POP	0.06* (0.04)	0.03 (0.04)	0.03 (0.04)	0.05 (0.04)	-0.02 (0.04)	0.05 (0.04)	0.06* (0.04)	0.02 (0.04)	0.04 (0.03)
AREA	-0.05*** (0.02)	0 (0.02)	-0.03* (0.02)	-0.05*** (0.02)	0 (0.02)	-0.04* (0.02)	-0.05*** (0.02)	-0.01 (0.02)	-0.03 (0.02)
REGPATS	0 (0.03)	-0.02 (0.03)	0.01 (0.03)				-0.01 (0.03)	0.01 (0.03)	-0.02 (0.03)
LABS_UNI				-0.01 (0.02)	0.02 (0.02)	-0.01 (0.02)			
LABS_PUBLIC				0.01 (0.03)	-0.02 (0.02)	0.01 (0.02)			
LABS_PRIVATE				0 (0.02)	0.02 (0.02)	-0.01 (0.02)			
SHARE_TECH							0.54 (0.96)	-2.83*** (0.83)	3.08*** (1.01)
N	6945	6945	6945	6945	6945	6945	6945	6945	6945
Ll	-7022.52	-8897.15	-8390.63	-7022.35	-8896.35	-8390.17	-7022.31	-8890.82	-8382.87
chi2	497.6	513.72	170.66	508.78	517.87	173.57	496.91	553.68	197.63

Note: Cluster-Robust standard errors are in parentheses. All regressions include dummies for *Missing value for EMPLOYEES and R&DINT*, *Inventor country,Year of application and Technological field (30* ISI-INIPI-OST classes). Coefficient significant at *0.1 level, ** 0.05, ***0.01

Table 4: Ordered probit estimations. Specifications 4-6

Variable	*Close*	*Distant*	*Close-Distant*	*Close*	*Distant*	*Close-Distant*	*Close*	*Distant*	*Close-Distant*
	Specification 4			*Specification 5*			*Specification 6*		
Employer and Inventor characteristics									
EMPLOYEES	0	0.01	-0.01	0	0.01	-0.01	0	0.01	-0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
R&DINT	-2.82**	-1.74*	-0.37	-2.83**	-1.77*	-0.33	-2.87**	-1.74*	-0.38
	(1.22)	(0.94)	(0.6)	(1.21)	(0.96)	(0.6)	(1.21)	(0.96)	(0.6)
AGE	-0.39***	-0.12	-0.19**	-0.4***	-0.12	-0.2***	-0.4***	-0.11	-0.21***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
MALE	0.05	-0.12	0.19**	0.05	-0.13	0.19**	0.04	-0.12	0.19**
	(0.12)	(0.09)	(0.09)	(0.12)	(0.09)	(0.09)	(0.12)	(0.09)	(0.09)
UNI_DEGREE	-0.03	0.12**	-0.12**	-0.03	0.11**	-0.11**	-0.03	0.11**	-0.11**
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
PhD_DEGREE	0.02	0.24***	-0.21***	0.02	0.24***	-0.21***	0.02	0.24***	-0.22***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Patent characteristics									
N_INVENTORS	0.02	0.02	0	0.02	0.02	0	0.02	0.02	0
	(0.04)	(0.03)	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)	(0.03)	(0.03)
SCIENCE	0.3***	0.29***	-0.07***	0.3***	0.29***	-0.06***	0.3***	0.29***	-0.06***
	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)
COMM_EXPLOIT	0.03	0.04	-0.03	0.03	0.04	-0.03	0.03	0.04	-0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
LICENSING	0.17***	0.16***	-0.02	0.17***	0.16***	-0.03	0.17***	0.16***	-0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
IMITATION	0.08*	0.05	0.02	0.07*	0.05	0.01	0.07*	0.05	0.01
	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)
Regional characteristics									
GDPPC	-0.06	-0.16*	0.12*	-0.07	-0.15*	0.1	-0.07	-0.16*	0.1
	(0.08)	(0.09)	(0.07)	(0.08)	(0.09)	(0.06)	(0.08)	(0.09)	(0.06)
POP	0.06	0.02	0.03	0.07*	0.02	0.04	0.06*	0.03	0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)
AREA	-0.05***	-0.01	-0.03	-0.05**	-0.01	-0.03	-0.05**	-0.01	-0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
REGPATS	-0.01	0	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
TOP5_TECH	0.01	-0.09**	0.08**						
	(0.05)	(0.04)	(0.04)						
TOP1_TECH				0.09	-0.14***	0.2***			
				(0.05)	(0.05)	(0.05)			
THRESH5_TECH							0.11*	-0.13**	0.22***
							(0.06)	(0.05)	(0.06)
N	6945	6945	6945	6945	6945	6945	6945	6945	6945
ll	-7022.5	-8894.62	-8388.53	-7021.03	-8892.93	-8381.32	-7020.38	-8893.72	-8381.08
chi2	497.59	517.56	177.77	494.36	542.25	213.53	494.13	535.92	197.90

Note: Cluster-Robust standard errors are in parentheses. All regressions include dummies for *Missing value for EMPLOYEES and R&DINT*, *Inventor country,Year of application and Technological field (30* ISI-INIPI-OST classes). Coefficient significant at *0.1 level, ** 0.05, ***0.01

PAPERS IN THE DRAWER. ESTIMATING THE DETERMINANTS OF THE PATENT-PUBLICATION LAGS IN EUROPE AND USA.

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[preliminary draft to be presented at the 2nd EPIP Conference, Lund, SE
please do not quote or cite without author explicit permission]

September 2007

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Keywords: academic patenting, grace period, patent system, technology transfer, open science, knowledge dissemination, university patent office.

JEL classification: O34; O31; K33

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[1] *Acknowledgements*. The authors wish to thank Marco Ricolfi and Massimiliano Granieri for helpful suggestions. Federico Caviggioli and Marco Riva have provided excellent research assistantship in the collection and storage of data. All errors are those of the authors.

1. Introduction

In accordance to the traditional objective of spurring dynamic efficiency in the economic system, the aim of patent law is that of offering a legally-enforceable competitive advantage to the inventors, in exchange of a complete and detailed disclosure of the invention to the general public. While a large and long-lasting theoretical debate has focussed on the definition of optimal patent scope, length and height (Gilbert and Shapiro, 1990; Scotchmer, 1991; Green and Scotchmer, 1995; Denicolò, 1996) fewer contribution have addressed the issue of the non prejudicial disclosure and the so called "grace period", which are also likely to have a non-negligible impact on the pace of knowledge diffusion[2].

Briefly stated, in a system which allows for a grace period, the disclosures made by an inventor does not bar the possibility for him to subsequently apply for a valid patent within a certain period of time. This is presently allowed in some countries, including the US and Japan patent systems, while is banned in the European patent system.

In Europe, any information made public before the filing of the application in whatever form (conferences, articles, etc..) rules-out the possibility for the inventor to be granted a valid patent[3]. This rule holds invariably against the author-inventor, who can be opposed her own article as a prior art destroying the novelty of any subsequent patent application. In the USA, under the first-to-invent regime, inventor's own publications made up to one-year before filing, do not bar the patent (Scotchmer and Green, 1990)[4]. Japan allows for a similar exception for a shorter period (six months). However, even in the American or Japanese systems, problems might arise when an extension of the patent applied under the grace period is desired in countries where the grace period does not exist. In fact, patent examiners of such countries would turn down the patent application for lack of novelty. The discrepancy of regulations being in place, a cautious policy of IPR protection should avoid any communication of results before the filing of a patent, in all national systems. This is especially the case for the wealthiest inventions like drugs or ICTs, for which a global market is expected. As discussed in deeper detail below, the opportunity of allowing or non-allowing inventors for a grace period is the subject of an intense debate within the more general context of the harmonization of national patent systems and international and patent cooperation treaty reforms[5]. Nevertheless, at

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[2] For a general critical analysis of the impact of patent systems' features on the nature and intensity of R&D see Jaffe and Lerner (2004) and Barton (2000) for the US and Kingston (2001). On the specific topic of optimal design of patent granting procedures, see Graham et al. (2003) and Hall et al. (2003).

[3] European Patent Convention, Part II, Chapter I:54. The requirement of *absolute novelty* accepts very few exceptions: in case of 1) evident abuses (the circulation was made contrary to the intentions or interest of the inventor) or 2) for a very limited number of officially recognised international exhibitions, for the six months proceeding the filing (Art.55).

[4] USA Patent Act, Title 35, Part II, Chapter 10:102. European Patent Convention, Part II, Chapter I:54.

[5] The debate has grown around the opportunity to come to an harmonization of international patent law, which, at present are based on the so-called first-to-file system in Europe (IPRs are granted to the first person

present, the debate is being complicated by the overall lack of empirical sound data on the actual use, effectiveness, and impact of either systems on the patenting behaviour.

In this paper we will try to shed light on this specific theme, by collecting an original set of data, which can offer insights on such issues as how extensively the grace period is being used in those systems that allow for it, how long is the average time lag between the patent application and the diffusion of knowledge, and what is the effect of the grace period on this lag. We do so by looking at a sample of patents which includes patents applied to USPTO, EPO and patents extended from the former to the latter.

Our database is made of 567 academic patents, i.e. patents applied for in year 2000 and assigned to an academic institution, of which 230 were matched to a scientific paper. The choice of focussing on academic patents only is motivated by two main reasons. First, for academic patents, the majority of non-patent disclosures take the form of scientific publications, searchable in international databases, while for non-academic patents it is generally impossible to know if and when an invention is communicated, for instance in a catalogue, exhibition or advertised, unless the patent undergoes a trial. Second, the recent increase in the number of university patents, has raised a new wave of petitions in favour of extending the general grace period to the international patent law, as a way to minimize the hang on to scientific publications when the scientists decides to apply for a patent. In recent years, a growing literature has addressed the issue of the patent and publication behaviour of scientists working in academia (Azoulay et al., 2006; Calderini and Scellato, 2005; Calderini et al., 2007; Stephan et al., 2007). The number of academic scientists seeking patent protection for their inventions in increasing on both sides of the Atlantic, encouraged by a large number of national government policies in favour of technology transfer. One of the many concerns raised by this literature is that delays in publication might arise if those scientists comply to the duties of secrecy imposed either by the requirements of patent procedures, or by contractual duties related to IPRs, with negative consequences for the pace of new knowledge diffusion (Dasgupta and David, 1994; Heller and Eisenberg, 1998). Academics -it is argued- face a high opportunity cost of holding a publication in their desk drawer to cope with the timing of patent applications, because their career depends crucially on their publication productivity. In this light, the debate upon a general international introduction of a grace period has acquired new supporters, as a way to enable a prompt disclosure of scientific works, and protect from inadvertently disclosures (Bagley, 2006). Those who advocate in favour of an extension of the grace period maintain that this would increase the rate of disclosure and reduce the lag trespassing from the discovery to the dissemination of results in open science, which would benefits both the progress of science and technology and the adoption rate of

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to file), vs. a first-to-invent system (IPRs are granted to the one who can prove to be first in inventing) in the USA.

innovations by firms. On the contrary, those who oppose this view claim that a grace period would increase the uncertainty of Intellectual Property Rights at the systemic level, because it would extend the time span during which third parties would be unsure whether or not a patent is underway, with a detrimental effect on the incentives to innovate and to adopt new technological solutions.

To cope with this issues, some European countries, such as France, have proposed an amended form of the grace period in the EPO and WIPO which would only cover academic patents. On this respect, it is unclear whether or not a grace period should be limited to scientific communications or perhaps associated only to the academic status of the inventor, and concerns have been raised that this would give an unjustifiable comparative advantage to academic institutions in the race for commercial inventions.

At present, empirical evidence available to support either views and enlighten the debate is hardly available. We have scarcely more than anecdotic reports of delays (or fear of) of publication related to patenting activity. A full discussion of the (legal and strategic) determinants underlying such delays is also missing.

In order to contribute to this debate and offer preliminary empirical evidence, in this paper we make a specific effort to develop a robust and replicable methodology that allows to single out non-patent disclosures and to identify patent and publication pairs (Murray and Stern, 2007; Lissoni and Montobbio 2006), using an algorithm of content-analysis. Content and text analyses are increasingly been used to extract information from large text documents and transform them in mathematical format (Franzoni et al., 2007).

After having estimated patent-publication time lags in our sample of USPTO and EPO patents, we made a set of comparative descriptive statistics aiming at answering the following questions: i) how often is the grace period being used by patents having a US priority; ii) when the grace period is not used, how long does it take to the scientist to publish the content on a scientific article; iii) do time lags differ for US vs. EPO-priority patents; iv) do US patents extended to EPO show a longer (shorter) patent-publication lag; v) is the time lag sector-specific and/or affected by the presence of a firm among the patents assignees.

Results bring relevant implications to clarify the actual effectiveness of the grace period exception in the US, with special focus on patents being extended to the EPO. Implications for a mindful policy of scientific knowledge diffusion are discussed with specific reference to the perspective reforms of the European and the US patent systems.

The paper is organized as follows: in the following section, we offer a review of non-prejudicial disclosures in European and US patent laws, discuss the expected effect of such rules on the patent-publication lags and describe them in the light of the current practices of technology transfer. In section three we present the dataset construction procedure and the original methodology developed to identify the patent-publication pairs and related lags. In section four we show the results of comparative statistics and multivariate analysis. Conclusions and implications are drawn in section five.

2. Disclosure of knowledge and the effect of the "Grace Period"

2.1 Non-prejudicial disclosures and general grace period

For a patent to be held valid at the examination process, the invention should be non-obvious and novel. The issue of non-prejudicial disclosure comes in jointly knit to that of novelty. In every national patent system, the rights to be granted a patent and thus benefit from a temporary exclusivity are accorded to the inventor strictly for those pieces of invention that where not known at the time of the priority. Inventions that were already patented, published or made available at the time the inventor claims her rights (after filing, in the EPO, or after inventing in the USPTO) are to be considered part of the prior art, i.e. the body of information already available to the general public in whatever form (written or oral description, use and any other way), and cannot consequently be taken away from its disposal. In all patent systems, several exceptions are however allowed to the general rule of novelty, which take the name of *non-prejudicial disclosures*, i.e. actions that, despite being recognized as acts of disclosure, are nonetheless being awarded a special treatment that does not ban the rights of the inventor.

In the European Patent Convention, disclosures that do not bar establishing rights over an invention are very limited and should strictly fall in either of two codified types (E.P.C., art. 55): a) disclosures in consequence of an abuse, i.e. when the subject for which protection is claimed has been unlawfully disclosed, for instance stolen or disclosed without permission of the author, which was holding it in confidence; and b) if the invention was displayed in an international exhibition that was officially recognized under the Convention on International Exhibitions, and only if the applicant explicitly declares, at the time of filing the application, that the invention had been so displayed[6]. In the United States Patent Act, analogous provisions are made under section 2(4) a) and b) of the 1977 Patent Act. In addition to the latter, non-prejudicial disclosures are allowed in a broader sense, which partially comes as a consequence of the *first-to-invent* principle governing the establishment of rights, which grants the right of exclusivity to the person that first invents, even when he or she was not the first to file the application. Under the § 102 of the U.S. Code, "Conditions for patentability; novelty and loss of right to patent", it is stated that a person shall be entitled to a patent unless a) "the invention was known or used by others in this country, or patented or described in a printed publication in this or a

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[6] Last revisions on 1928 and 1972.

foreign country, before the invention thereof by the applicant for patent, or" b) "the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of the application for patent in the United States". While 102 a) states the general requirement of novelty and should be interpreted as applying to everybody, 102 b) applies to everybody besides the inventor, as long as she claims its rights soon enough, by applying for a patent at the competent office. Such statement of novelty and its statutory bars therefore allows that the inventor herself cannot be barred from filing a valid patent even if she published a printed note describing the invention, as long as that happened within the previous 12-months (the so called *general grace period*)[7].

The sense of this broader exception from the general principle of novelty in the US law is that an inventor cannot defeat her own novelty by taking some actions such as publishing an article describing her invention, in accordance to the preference given by the law to the acts of creativity. Therefore, any earlier publication by the same inventor would only proof that she was entitled to her rights of patenting (under a first-to-invent regime) earlier than filing. Even so, the inventor can cause a statutory bar by not taking such action as claiming her rights within the grace period of twelve months. On the contrary, in the European system, any form of disclosure either made by a third party or by the inventor herself before the day of filing will disqualify the invention from patentability.

2.2 Pros and Cons of a General Grace Period for Innovation Incentives

The presence of a grace period is likely to generate relevant effects in terms of incentives and efficiency, which we will try to summarize, both from the point of view of the inventor and from the point of view of society.

From the point of view of the inventor, the first obvious advantage of the grace period is that the inventor is protected against incautious disclosures made before filing that might compromise her rights simply by mistake. Secondly, during the grace period, the inventor can hold up the filing while she acquires useful information for instance on the market value of her invention and later decide whether or not the patent is worth filing. In this sense, the grace period has a clear option value to the inventor, whose disclosure becomes prior art to every third party, including independent inventors, while allows her to wait up to 12 months before applying for a valid patent. Lastly, an additional advantage relates to those inventors, such as researchers and scientists, who earn additional

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[7] For a comprehensive discussion of the US legal patent system, see for instance Halpern et al., 2007 or Merges and Duffy, 2002.

and independent returns from other forms of disclosures, such as, for instance, articles on scientific journals, presentations to conferences, and disclosures to open science at large. Scientists, of course, depend on scientific publications and from the reputation of peers more than on everything else for their own career, and the grace period allows them to earn a reputation from what they know as soon as they know it, and before filing a patent, an action that would compromise (at the cost of a patent option) a patent validity, in the absence of a grace period.

Disclosure under the grace period exception, however, also comes at some cost for the inventor. The major cost relates to the risk that, in the absence of a property right protection, a third party may make use of the invention and further develop and patent some improved version of it. In that case, the latter patent would become prior-art and ban a subsequent patent of the basic invention, even if the initial inventor files an application within the following year. This is because the 102 b) works as an exception to the general rule of novelty, but does not protect against the lawful actions by third parties as in 102 a)[8]. In other words, in case an improved invention was patented before the filing of the basic one, the law would rather protect the reasonable expectation of the second inventor, who, having acquired the information publicly disclosed by the first inventor, relied in good faith on their free use.

From the point of view of the third parties, or the general public, the advantage of allowing for a grace period can be summarized as follows. First, in certain circumstances, a grace period might result in an earlier disclosure. Second, if the inventor comes to know that the invention has no commercial value, she would avoid overloading the patent offices with worthless patents. At the same time, the grace period brings also potential detrimental effects related to the higher uncertainty to third parties. This is due to the fact that a patent application is kept under secrecy by the patent offices for 18-months after filing[9], a period of time during which third parties are uncertain on their rights to use a certain innovation freely. The grace period in practice extends this period of uncertainty up to additional 12 months, at the inventor's will. It is arguable if such extension of the period of time under which inventions might or might not be clear of rights would offset the balance between the right of the inventor and the right of the public too much in favour of the former.

Besides, the longer the period of uncertainty, the more likely it is that two or more inventors come up with some infringing applications[10].

At the level of the economic system, such increased uncertainty has a negative impact on innovation incentives, especially in the light of the constant increase in patent litigations experienced in recent years (Bessen and Meurer, 2005, 2006). The issue becomes more problematic when we consider the

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[8] U.S. Code Title 35, Part II, Chapter 10, §102.

[9] For patents filed after 29 November 2000 in the US.

[10] In the US this would result in interference procedures.

international patent law, because the majority of national patent systems do not recognize the general grace period, as in the European patent law described before and patents applied to could not be extended under the International Patent Treaty.

At present, given the non harmonization of national patent systems such as those of USPTO and JPO from the one side and that of EPO from the other, the following situation might arise. For instance, an inventor who has applied for a patent in the US, using the general grace period, and holds a valid US patent, will be opposed his own early disclosure when he tries to extend the patent outside the US, say to the EPO. This also means that, whenever the potential market for the invention is broader than the US only, such as for drugs and chemicals, and nowadays for the majority of inventions, no general grace period should be used by the US inventor. For this reason, it is reported that even in the US, Property Rights Offices, not least those of universities, have adopted the practice of banning their researchers from publishing patentable material at least until a provisional application is being filed, in case the invention will eventually earn international attention (Bagley, 2006:245). Consequently, whatever the benefit of allowing for a general grace period seems to be conditional to a widespread international application of the rule. In our analysis we will focus extensively on this issue by comparing a set of US patents extended vs non-extended abroad.

The issue is non-trivial, because, even after having filed a patent, there are other reasons to procrastinate a publication. During the patent procedure, in fact, patent consultants and attorneys do extensive refinement of the claims, references and description of the invention offered in the patent document until the application is finally published. A wise refinement of the document is in most of cases extremely valuable to enhance the value of the future patent, by maximising its breadth and its potential to face successfully a litigation (Buzzacchi and Scellato, 2008). In practice, the area of refinement is very delicate and suffers of what has been meanwhile disclosed in other unprotected forms. Hence, despite publications occurred after filing cannot in principle be used against the patent filed, in practice, holding the knowledge base unpublished until the patent application is finally made public holds a number of advantages in terms of degrees of freedom in the process of refinement. As a result, it is not uncommon for universities to adopt a policy of non-disclosure of material undergoing patent application, which extends the lag under which a piece of knowledge will be set free for a scientist to circulate. A survey conducted among American firms and TTOs, for instance, revealed that a high proportion of firm-university agreement for joint research included explicit clauses of delayed disclosure of 4 month on average after a patent was filed, going up to one year of non-disclosure clause in some cases (Jensen et al., 2003). Corporate policies are clearly more strict with regard to publication and dissemination of results to protect their competitive advantage as much as possible.

3. Data and Methodological issues

The objective of the empirical analysis is to see if and when the content of a patent is communicated through a scientific publication and to measure the time lag trespassing from the filing of a patent to the publication of a scientific article. The lag would be negative in case of use of the grace period.

The first task to be accomplished to this aim is to find a match between a patent and a scientific article, having at least one author in common.

We started from extracting all patents granted by the USPTO and the EPO that listed among the assignees at least one academic institution, or Public Research Organization (PRO) and had the first priority date in year 2000. Search was done through Delphion Thompson proprietary database. The query resulted in 3857 granted patents, of which 421 were granted by the EPO and 3436 by the USPTO. After drops of duplicates, we kept all patents assigned by the EPO (which were fewer) and drew a random sample of USPTO patents to obtain a final sample of 632 patents evenly split between EPO and USPTO granted. We then used the list of patent inventors' names to search for articles published in scientific journals in the Institute for Scientific Information (ISI) Science Citation Index database. We extracted all records (74.615 article-patent pair) that listed at least one of the inventors' names among the article authors in the time span that included the year of patent priority and the two years after it for the EP original priorities and for a time span of 5 years [t_{-2}; t_{+2}] for the US original priorities (including EPO patents with US priority). The average number of articles retrieved per patent was 130.67 (st.dev. = 233.97) and for 61 patents no published article was found, which left us with a final sample of 567 patents. Articles were stored as standard reference record, plus the full abstract.

We then proceeded by applying our methodology of patent-paper search of "resonance", i.e. the degree to which two texts describe the same meaning. Resonance search was based on comparing the content of patents and articles titles and abstracts. The content analysis and resonance estimate has been performed by means of a software (Crawdad Text Analysis System 1.2), which works on a natural language processing algorithm, based on both stemmed words co-occurrence and influence measure. The software calculates a measure of influence of each term, depending on the structural position of the word within a text, and captures how people create coherence in their communication[11]. The software outputs a resonance index for each couple of article and patent, standardized for the lengths of compared texts and ranging in the [0; 1] interval.

Unrelated texts, as those for instance resulting from homonyms inventor-author typically have a null resonance value, or a very low one, in case they are on the same scientific field. This is particularly important, since our methodology allows us to cope with potential fake matches, due to homonyms,

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[11] See Crawdad Software description at http://www.crawdadtech.com/html/01_software.html.

otherwise very frequent in ISI database search. In Table 1 we report summary statistics for the resonance index and for the number of publications which have been examined for every patent included in our sample. The correlation between the computed resonance index and the number of publications is rather low (0.20) confirming that the algorithm for the evaluation of the resonance is not affected by the number of publications.

Table 1 – Summary statistics for computed reference index and publications screened for each patent

Variable	Mean	Std.	Min	Max
Resonance Index	0.104	0.080	0.001	0.821
Number of Publications	130.674	233.971	2.000	2540

At this stage we had to make sense of the resonance index output. We firstly dropped from the sample all those patents that gave a null resonance level. We are left with 567 patents, each paired with the article ranked first in the computed values of non-null resonance. The distribution of resonance index in our sample is shown in A manual check of matched patents and articles obtained in such way confirms the reliability of the selected threshold. We also fixed a higher threshold level at 0.1767, equal to the 85th percentile (85 observations) of the distribution of resonance among the sample, to check for the sensitivity of results to the selected threshold of resonance. As shown in deeper detail below, results do not significantly change when the second and more selective threshold is used. For this reason, we herein present descriptive sample statistics related to the 0.1 threshold.

Figure 1. The distribution is truncated in zero, skewed to the left and shows a long right tail. If you consider that the algorithm would give a value of one when the title and abstracts of patents and papers are identical not only in the choice of words, but also in the description syntax, you can appreciate that the right tail is made by those pairs of article and patent made on a cut-and-paste across documents. Because a patent and a scientific publication are aimed at different ends (industrial use vs. communication to a scientific community) and patents are generally subjected to the screening and refinement of a number of people besides the authors, such as liaison office associates, patent attorneys and examiners, you can appreciate that those matches should very rarely occur and possibly come from inexperienced people[12].

To provide the reader with some insights on the output and reliability of matches, in the Annex 1 we report some examples of matched patent and papers and the related resonance index. In order to

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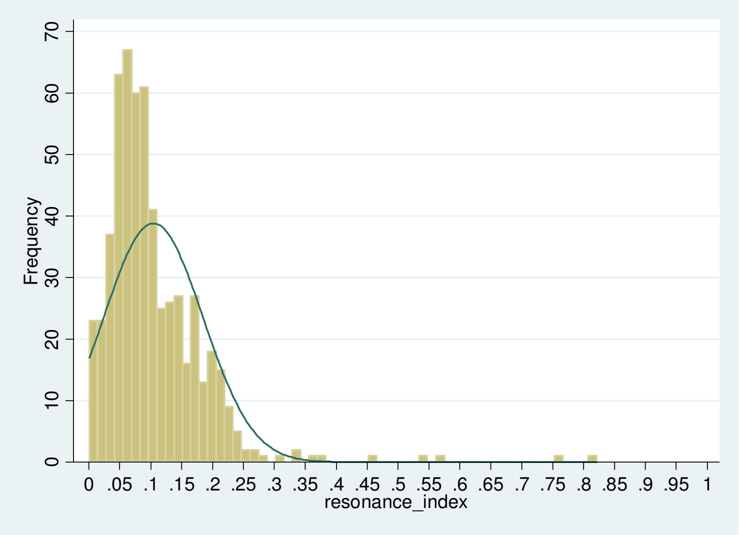
[12] When observing cases with resonance level above 0.5 we found a perfect coincidence of patent and paper abstracts. However, patents' abstract might included just a subset of the contents of the publication and vice-versa. Moreover, the contents of the patent might reasonably derive from a number of different publications, among which we will select the most similar. In this perspective, our matching is more flexible than a strict matched-pair procedure.

identify a threshold of significant resonance, we took the following approach. We assumed that, if the European examination procedure works well, we should observe no highly resonant article published before the priority date. We use this observation as a natural experiment, allowing us to fix a threshold level of minimum resonance equal to 0.1, as the one that gives a negligible incidence of matched articles in the prior art. This resonance level equals the 60th percentile of the distribution of resonance, leading to a sample of 230 patent-paper pares above threshold, out of a sample of 567 potential patent-publication pairs (having a non null resonance).

A manual check of matched patents and articles obtained in such way confirms the reliability of the selected threshold. We also fixed a higher threshold level at 0.1767, equal to the 85th percentile (85 observations) of the distribution of resonance among the sample, to check for the sensitivity of results to the selected threshold of resonance. As shown in deeper detail below, results do not significantly change when the second and more selective threshold is used. For this reason, we herein present descriptive sample statistics related to the 0.1 threshold.

Figure 1 - Distribution of Resonance Index in the Sample



The final dataset comprises 230 relevant patent-paper pairs. Summary statistics showing the incidence of resonant publications per 1-digit International Patent Class (IPC) code, publication and priority country and type of assignee are shown in Table 2.

Patents in the IPC classes are distributed in the usual way, with the majority of academic patents concentrated in the two classes of human necessities (comprising biotechnologies and drugs), and chemistry & metallurgy, which overall account for nearly 60% of the sample. Physics accounts for nearly 20% and the rest is comprised into performing operations and electricity.

The sample was constructed in such a way to be evenly split among USPTO and EPO-granted patents. Even so, nearly the 70% of all patents resulted to have had an original US-priority, i.e. a priority in a country that allows for a general grace period. Approximately the 30% of patents (62) resulted to be originally a US patent extended to the EPO, for which we expect that no general grace period should have been used.

Table 2 Summary statistics of matched patent (above resonance threshold 0.1)

	Variable	observations	% on total
Ipc	human necessities	67	29.13
	performing operations	15	6.52
	chemistry and metallurgy	69	30.00
	textile and papers	3	1.30
	fixed construction	0	
	mechanical engineering	1	0.43
	Physics	43	18.70
	Electricity	32	13.91
patent type	US patent	114	49.57
	EPO patent	116	50.43
	US-priority	159	69.13
	US-extended to EPO	62	26.96
Assignees	University	221	96.09
	firm assignee	28	12.17
	PRO	31	13.48
	single assignee	184	80.00
	university-only assignee	173	75.22

4. Results: Patent-Publication Lags and the Effect of the Grace Period

As explained in the previous section, our analysis is based on patent-paper pairs, i.e. on a one-to-one document match of a patent and an article published on a scientific journal, as identified by similarity of content. Similarity is computed by the resonance index which gives a continuous metrics in the interval [0; 1]. Our threshold value is 0.1 and threshold for the sensitivity check if 0.1767. For sake of clarity, in the following tables we will report our results only for the lower threshold (0.1) while in Annex 2 we show the results for the more restrictive threshold.

4.1. Use of the grace period in the USPTO

Table 3 shows the estimated incidence of patents that have been applied for during the grace-period and have thus been granted thanks to the non-prejudicial disclosure exception. According to our estimation, out of the 159 patents that were applied for in the USPTO, only 37 (23.3%) resulted to have used the grace period, while the great majority of patents (122, equal to 76.7%) were not disclosed before filing, under the 102 b).

The content of patents that used the grace period was published on a scientific article on average 7 months before filing the application[13], while applications that did not use the grace period were disclosed in a scientific article on average 16 months after filing. It is quite notable that, not only the average lag difference is quite striking (23.5 months), but also the average publication delay of non-grace patents is quite big in absolute values. Our results seem to suggest that when the grace period was not used, the content was published into a scientific article nearly 24 months after being discovered. In addition, although in principle on the day after having filed a patent, disclosures in whatever form, including publications on scientific journals, would not add to the prior art, inventors waited more than 16 months before disclosing to open science, i.e. 2 months on average before the patent itself would go into public domain. This would in turn suggests that the inventor is holding (or being asked to hold) her invention secret to preserve the commercial value of her patent.

In Table 3 we also report the breakdown of patents and their related publication lags per 1-digit IPC classes. Although the number are quite small, inventions in the electricity and textile & paper classes result to experience the bigger lag (18 months), while chemistry and human necessities have a mean lag of nearly 16 months.

Table 3 Incidence of the use of grace period and mean patent publication lags

	Freq.	did not use grace	used grace	% that did not use grace	% that did not use grace	did not use grace: mean lag	used grace: mean lag	ttest Ha: mean_diff≠ 0
USPTO priorities patents	159	122	37	76.7%	23.3%	16.488	-7.004	***
IPC human necessities	45	38	7	84.4%	15.6%	15.905	-12.090	***
IPC performing operations	10	7	3	70.0%	30.0%	12.476	-3.111	**
IPC chemistry & metallurgy	55	47	8	85.5%	14.5%	15.690	-3.892	***
IPC mechanical engineering	2	2	0	100.0%	0.0%			
IPC physics	0	0	0					
IPC electricity	23	14	9	60.9%	39.1%	18.379	-4.948	***
IPC textiles & paper	24	14	10	58.3%	41.7%	18.107	-8.950	***
firm	20	14	6	70.0%	30.0%	23.667	-4.211	***
university	150	113	37	75.3%	24.7%	16.264	-7.004	***
PRO	24	21	3	87.5%	12.5%	20.067	-6.011	***
single assignee	126	95	31	75.4%	24.6%	15.401	-7.142	***
university-only assigned	117	88	29	75.2%	24.8%	14.705	-7.721	***

* p≤0.10, ** p≤0.06, *** p≤0.01

Results are also very interesting when comparing the average publication lag of patents according to the typology of assignees, also reported in Table 3[14]. Patents that were co-assigned to at least one

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[13] Tolerance error is of 2 months.

[14] Note that all patents need to be assigned at least to one university or PRO among the assignees, because of the sampling procedure. The variable "firm" is a dummy having value 1 if the patent has at least one firm among the assignees. The variable "PROs" is a dummy having value 1 if the patent has at least one Public Research Organization (PRO) among the assignees. The variable "university" is a dummy having value 1 if the patent has at least one university among the assignees.

firm show an average time to publication of 23.6 months. A similar result (20.1 months) was found for patents co-assigned to at least one Public Research Organization (PRO).

4.2 Comparing the patent-publication lag across different international patent systems

We start by comparing time lags of patents with different priority countries. For each matched couple of patent and scientific article we have computed the time span expressed in months between the patent priority date and the publication date of the scientific article. We then proceeded by comparing the average time lag for sub samples of matched couples with a set of one tailed t-tests. In Table 4 we show the comparison between the average time lag of grace-priority patents (USPTO) and non grace-priority patents[15]. In model I the analysis involves all the 230 patents with a resonance above the threshold value of 0.1. In this case we obtain a positive and significant difference pointing to a longer time lag before the publication of the scientific article for the non-grace priority sub sample of patents. Clearly such result might be driven by the fact that USPTO patents are allowed a grace period, leading in some cases to negative lags which contribute to lower the average. For this reason, in model II of we restrict the analysis to those patents with a positive time lag (hence excluding cases involving the grace period). Even in this case we find a significantly longer delay in the case of non-grace priority patents.

Table 4 Comparing time lags of patent with an original USPTO priority vs. European priorities.

	variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
I	Non grace priority country	71	15.422	1.420	6.400	0.000
	Grace priority country	159	9.022	1.069		
II	Non grace priority country	64	17.940	1.164	3.452	0.010
	Grace priority country	122	14.488	0.864		

The fact that even when dealing with patents with a positive time lag (model II) we obtain a shorter delay for the sub sample including patents with a US priority might suggest that the presence a grace period actually affects the behaviour of patentees also in the post-application period. As we explained in section 2.2, during the post application period the contents of a patent are subject to potential refinement. Hence, the inventors might have an incentive to postpone the publication of a related scientific article even after being assigned a patent priority. In presence of a grace period system such incentives are likely to be lower, because any scientific article would not fall in the prior art of any refined patent application.

While the above reported results seem to indicate an advantage of the US system in terms of shorter average delays between patent application and scientific publication, in the introduction of this paper

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[15] Non grace-priority patents include EPO priorities, EPO-member state priorities and priorities of other countries that do not allow for a general grace period. In our sample, grace priority patents include only US-priority patents.

we stressed how the overall actual impact of the grace period is reasonably affected by the non harmonised international patent rules. In principle, patents originally applied in the US but subsequently extended to EPO cannot benefit from the grace period exception. In order to provide evidence on this point we performed an additional test, reported in Table 5, in which we compare the average time lag for patents with an original USPTO priority date and later extended to the EPO, and the average time lag for patents with an original USPTO priority date and not extended. The group of extended patents shows a significantly higher average time lag. To enlighten this result it is worth considering that the US authors-inventors are reasonably subjected to some degree of uncertainty concerning the probability that a specific publication might be judged as prior art barring the extension abroad of their patent. In this sense the absence of a grace period in Europe might have some impact also on publishing behaviour of US academics. We can expect this effect to be stronger for those people working in technological and scientific fields whose industrial application have a potential international or global market. Beside this issue, the punctual evidence of average delay of approximately 12 months for US extended patents (see Table 5) supports the reliability of our methodology as a way to identify pairs of patents and publications. In common practice, extensions from the US to the EPO are commonly performed at the verge of the 12th month after the original application, as allowed by international treaties, so to exploit the patent right as long as possible. This suggests that US inventors opt for publishing the innovation on scientific journals as early as possible, i.e. right after the extension to the EPO.

Table 5 Comparing time lags of USPTO extended and not extend patents

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
US extended	62	12.217	1.457	5.237	0.008
US non extended	97	6.979	1.452		

Finally, Table 6 shows USPTO patents extended to the EPO showed on average a shorter time to publication than the EPO and EPO-members countries patents.

Table 6 Comparing time lags of USPTO extended vs. EPO-priority patents

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
US priority extended to EPO	62	12.217	1.457	-3.205	0.059
EPO priority	71	15.422	1.420		

4.3 In search of the determinants of patent-publication lags

In the previous analyses we have investigated those determinants of patent publication lags which are essentially related to differences in patent systems. We now turn to considering the potential impact on extending the time lags determining by other factors, relating to the management of the intellectual property rights.

Our database includes 184 (80%) patents with above-threshold resonance which show multiple assignees. Of those 28 (12.2%) patents listed at least one firm among the assignees. Co-assignations to a firm can typically arise from several circumstances: they might derive from firm-sponsored research, they can be patents developed by an academic professor, for which the University Technology Office has found a buyer or partner very early (before filing a patent), or can be patents co-assigned to an academic spin-off.

The test reported in
Table **7** suggest that there is a potential longer delay whenever an academic patent is co-assigned to a private company (90% confidence level). This might be interpreted as depending on the lower incentives to disclose of firms vs. academe alone. This results are confirmed by the data reported in Table 8, where we test the effect of having only universities as assignee vs. firm and/or public research institutions.

Table 7 Comparing time lags of patent with and without at least one firm among assignees.

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
firm	28	14.765	2.788	4.290	0.0554
no firm	202	10.475	0.920		

Table 8 Comparing time lags of patents with only on university as assignee and others.

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
others	57	14.461	1.814	4.605	0.0117
university only	173	9.856	0.992		

The data in the two tables above clearly stress how the process of protection of IP rights is likely to be affected by significant transaction costs and what we observe is actually the outcome of a complex bargaining involving agents (inventors, financers of R&D, patent attorneys and managers of Technology transfer offices) with sometimes contrasting objectives. This is reflected in the higher time lag identified for those patent with multiple assignees, independently of their identity, as shown in the results of Table 9.

Table 9 Comparing time lags of patents with single and multiple assignees

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
multiple assegnees	46	15.128	1.869	5.163	0.0093
single assignee	184	9.965	0.983		

In section 3 we have provided descriptive statistics concerning the technological classification of the patents included in our sample according to the IPC. In the following we introduce a set of simple multivariate analyses in which we specifically control for IPC classification through dummy variables. Multivariate analysis allows us to control that the differentials estimated in the t-tests are not driven by the technological composition of the sub groups, by field-specific timing of publications, co-assignment of the patent to a firm and so on. We apply a standard OLS model using time lags expressed in months as the dependent variable. For the sake of comparability, the models reported in Table 10 and Table 11 are applied only to the sub sample of patents (with either EPO priority or USPTO priority) with a positive time lag, hence ruling out US patents granted under the grace period exception. We regress the time lag against a set of dummy variables. *PRO assignees* is a dummy variable equal to one if among the patent assignees there is at least one Public Research Organization (PRO), *firm assignee* is a dummy variable equal to one if among the patent assignees there is at least one company, *university assignee* is a dummy variable equal to one if among the patent assignees there is at least one University, *extended from grace* is a dummy variable equal to one if a patent with an original USPTO priority has been subsequently extend to the EPO. The IPC dummy variables measures the sectoral effects with respect to the IPC textiles & papers. Given the high correlation between the dummy variable *single assignee* and *university assignee*, in the models reported in Table 11, we avoid to use the two variables jointly.

Table 10 Testing the effects of US priority on patent-publication lags.

	Lag>= 0		Lag >= 0		Lag>= 0	
lag (publication-patent date)	mean	st.err.	mean	st.err.	mean	st.err.
us patent	-3.538	1.409 **	-2.926	1.435 **	-2.693	1.415 *
single assignee			-3.310	1.732 *		
university assignee					2.824	3.818
PRO assignee					4.037	2.335 *
firm assignee					6.781	2.244 ***
IPC human necessities	-17.528	5.499 ***	-18.506	5.482 ***	-18.616	5.447 ***
IPC performing operations	-17.713	6.007 ***	-17.866	5.963 ***	-17.520	5.962 ***
IPC chemistry & metallurgy	-18.294	5.494 ***	-18.917	5.464 ***	-18.803	5.438 ***
IPC mechanical engineering	-21.468	10.738 **	-21.264	10.659 **	-20.782	10.544 **
IPC physics	-15.291	5.638 ***	-16.006	5.609 ***	-16.194	5.614 ***
IPC electricity	-15.609	5.769 ***	-16.961	5.770 ***	-17.910	5.777 ***
IPC textiles & paper						
constant	34.302	5.384 ***	37.408	5.586 ***	30.792	6.065 ***
Obs	186		186		186	
Adj R-squared	0.059**		0.072***		0.102***	

* p≤0.10, ** p≤0.06, *** p≤0.01

Table 11 Testing the effect of extension from the US on patent publication lags.

	Lag >= 0		Lag >= 0	
lag (publication date - patent date)	mean	st.err.	mean	st.err.
extended from grace	-3.620	1.478 **	-3.923	1.445 ***
university assignee			1.365	3.795
PRO assignee			4.093	2.311 *
firm assignee			7.879	2.165 ***
IPC human necessities	-17.750	5.503 ***	-18.581	5.390 ***
IPC performing operations	-18.899	6.003 ***	-18.015	5.892 ***
IPC chemistry & metallurgy	-18.073	5.501 ***	-18.168	5.388 ***
IPC mechanical engineering	-22.702	10.781 **	-21.995	10.454 **
IPC physics	-16.958	5.638 ***	-17.307	5.545 ***
IPC electricity	-16.608	5.757 ***	-18.462	5.694 ***
IPC textiles & paper				
constant	35.536	5.458 ***	33.464	6.114 ***
Obs	186		186	
Adj R-squared	0.057**		0.120**	

* $p \leq 0.10$, ** $p \leq 0.06$, *** $p \leq 0.01$

The results reported in Table 10 and Table 11 essentially confirm the findings of the t-tests. In particular, even after accounting for the technological classification of patents, the fact that a patent has an original priority in a patent system that allows for a grace period exception is negatively correlated to the time lag between the patent priority and publication of the matched scientific article. This holds also when restricting the analysis to the sub sample of patent-publication pairs with a positive lag.

Applications to the EPO that come as an extension from a patent system allowing for the grace period (USPTO) are likely to experience a reduced lag to publication of 3.6 months, after controlling for both the technological classification and the typology of assignees. The overall evidence reported above can be summarised along the following points.

The empirical methodology developed to identify couples of patent and publications on the basis of text and content analysis seem to be a reliable tool for investigating the relationship between patenting and publishing behaviours of academic inventors. In fact, the preliminary results shown here turn to be in line with theoretical predictions. First, there is evidence of an actual impact of the grace period on the timing of disclosure of knowledge through the publication of scientific articles.

Second, the typology of the patent assignees has a significant impact on the delay of the publication of scientific results after the patent application, both for EPO and USPTO patents. However, even controlling for the identity of the owner of the patent the fact that a patent system allows for a grace period still has a negative correlation with the time lag.

Third, we find evidence of a longer time lag for those patents that after being originally filed to the USPTO are subsequently extended to a system, the EPO, which does not guarantee a grace period.

In general the magnitude of the difference in time lag (possibly generated by the presence of the grace period) ranges on average around 6-7 months. It is hard to assess which is the actual cost perceived for such delay by authors-inventors, and how which kind of effect it might exert at systemic level.

5. Conclusions

All in all, the contributions of the paper are twofold. First, the methodology we developed allowed us to come to a first estimate of the actual patent-publication lags. So far, empirical data were limited to survey data (Walsh et al., 2005), over which our methodology has the advantage of being replicable and unaffected by social response bias. Second, preliminary evidence provided in this paper gives support to a number of hypothesis raised within the literature on IPR management and academic patenting.

Our results suggested that, in the USPTO, approximately the 23% of academic patents was filed during the grace period. The majority of USPTO academic patents, for which the grace-period was not invoked, was disclosed into scientific journals on average 16 months after filing a patent, while in the EPO it was disclosed nearly 18 months after filing.

In the US, although the general grace period exception is in place, patents filed during the grace period cannot be extended to countries that do not recognize the same right, such as the EPO. This non-harmonization of the international patent systems is likely to nullify the effect of the grace period for all patents that have (or are expected to have) a global market, because compliance to international regulations is compulsory. Even so, USPTO patents extended to the EPO showed on average a (3 months) shorter time to publication than the EPO or EPO-members countries patents.

We also found that when patents are co-assigned to at least one firm, the publication lags is likely to be longer than non-firm co-assigned patents and similar results apply for PROs.

Finally, the publication lag is longer when a patent is co-assigned to many assignees of whatever kind, vis-a-vis single-assegnee patents.

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Annex 1
Resonance Index and related title and abstract match

	resonance index	patent	publication
title	0.8212	Bisbubstrate inhibitors of kinases	Mechanism-based design of a protein kinase inhibitor
abstract		Protein kinase inhibitors have applications as anti-cancer therapeutic agents and biological tools in cell signalling. Potent and selective bisbustrate inhibitors for the insulin receptor tyrosine kinase are based on a phosphoryl transfer mechanism involving a dissociative transition state. One such inhibitor is synthesized by linking ATPγS to a peptide substrate analog via a two-carbon spacer. The compound is a high-affinity competitive inhibitor against both nucleotide and peptide substrate and shows a slow off-rate. A crystal structure of this inhibitor bound to the tyrosine kinase domain of the insulin receptor confirms the key design features inspired by a dissociative transition state, and reveal that the linker takes part in the octahedral coordination of an active site Mg²⁺ ion.	Protein kinase inhibitors have applications as anticancer therapeutic agents and biological tools in cell signaling. Based on a phosphoryl transfer mechanism involving a dissociative transition state, a potent and selective bisubstrate inhibitor for the insulin receptor tyrosine kinase was synthesized by linking ATP gammaS to a peptide substrate analog via a two-carbon spacer. The compound was a high affinity competitive inhibitor against both nucleotide and peptide substrates and showed a slow off-rate. A crystal structure of this inhibitor bound to the tyrosine kinase domain of the insulin receptor confirmed the key design features inspired by a dissociative transition state, and revealed that the linker takes part in the octahedral coordination of an active site Mg2+. These studies suggest a general strategy for the development of selective protein kinase inhibitors.
title	0.7344	Pharmaceutical Compositions Comprising Beta-Turn Peptidomimetic Cyclic Compounds	A designed peptidomimetic agonistic ligand of TrkA nerve growth factor receptors
abstract		Proteolytically stable small molecule beta -turn peptidomimetic compounds have been identified as agonists or antagonists of neurotrophin receptors, such as TrkA. A compound of particular interest binds the immunoglobulin-like C2 region of the extracellular domain of TrkA, competes the binding of another TrkA ligand, affords selective trophic protection to TrkA-expressing cell lines and neuronal primary cultures, and induces the differentiation of primary neuronal cultures. The small beta -turn peptidomimetic compounds of the invention can activate a tyrosine kinase neurotrophin receptor that normally binds a relatively large protein ligand. Such compounds that bind the extracellular domain of Trk receptors are useful pharmacological agents to address disorders where Trk receptors play a role, by targeting populations selectively.	A proteolytically stable small molecule beta-turn peptidomimetic, termed D3, was identified as an agonist of the TrkA neurotrophin receptor. D3 binds the Ig-like C2 region of the extracellular domain of TrkA, competes the binding of another TrkA agonist, affords selective trophic protection to TrkA-expressing cell lines and neuronal primary cultures, and induces the differentiation of primary neuronal cultures. These results indicate that a small beta-turn peptidomimetic can activate a tyrosine kinase neurotrophin receptor that normally binds a relatively large protein ligand. Agents such as D3 that bind the extracellular domain of Trk receptors will be useful pharmacological agents to address disorders where Trk receptors play a role, by targeting populations selectively.
title	0.5624	System and method for 3-D digital reconstruction of an oral cavity from a sequence of 2-D images	A 3-D reconstruction system for the human jaw using a sequence of optical images
abstract		Systems and methods are provided through which a model-based vision system for dentistry which assists in diagnosis, treatment planning and surgical simulation. The present invention includes an integrated computer vision system that constructs a three-dimensional (3-D) model of the patient's dental occlusion using an intra-oral video camera. A modified shape from shading technique, using perspective projection and camera calibration, extracts the 3-D information from a sequence of two-dimensional images of the jaw. Data fusion of range data and 3-D registration techniques develop a complete 3-D digital jaw model. Triangulation of the 3-D digital model is then performed, and optionally, a solid 3-D model is reconstructed.	This paper presents a model-based vision system for dentistry that will assist in diagnosis, treatment planning, and surgical simulation. Dentistry requires an accurate three-dimensional (3-D) representation of the teeth and jaws for diagnostic and treatment purposes. The proposed integrated computer vision system constructs a 3-D model of the patient's dental occlusion using an intraoral video camera. A modified shape from shading (SFS) technique, using perspective projection and camera calibration, extracts the 3-D information from a sequence of two-dimensional (2-D) images of the jaw. Data fusion of range data and 3-D registration techniques develop the complete jaw model. Triangulation is then performed, and a solid 3-D model is reconstructed. The system performance is investigated using ground truth data, and the results show acceptable reconstruction accuracy.

title	0.3799	Adaptive sigma-delta modulation with improved dynamic range	Stability and performance analysis of an adaptive sigma-delta modulator
abstract		An adaptive sigma-delta modulation and demodulation technique, wherein a quantizer step-size is adapted based on estimates of an input signal to the quantizer, rather than on estimates of an input signal to the modulator.	This work develops an adaptive sigma-delta modulator that is based on adapting the quantizer step-size using estimates of the quantizer input rather than the modulator input. The adaptive modulator with a first-order noise shaping filter is shown to be bounded-input bounded-output stable, Moreover, an analytical expression for the signal-to-noise ratio is derived, and it is shown to be independent of the input signal strength. Simulation results confirm the signal-to-noise ratio performance and indicate considerable improvement in the dynamic range of the modulator compared to earlier structures.
title	0.226	Method for manufacturing an array of indented diamond cylinders	Periodic submicrocylinder diamond surfaces using two-dimensional fine particle arrays
abstract		A cylinder array of diamond having a dent in its cylinder top face is manufactured by subjecting a cylinder array of diamond to a plasma etching.	Periodic submicroscale diamond-cylinder arrays were fabricated on diamond surfaces using two-dimensionally ordered arrays of SiO2 particles. For the preparation, the diamond surface was etched by means of reactive ion etching with oxygen plasma through two-dimensionally ordered arrays as masks. The etching time has an important influence on the diameter and depth of the diamond cylinders. The Raman spectra of these films indicate that they consist mostly of diamond, with small amounts of sp(2) carbon.
title	0.1969	Composite materials having substrates with self-assembled colloidal crystalline patterns thereon	Bragg diffraction from indium phosphide infilled fcc silica colloidal crystals
abstract		Composite materials having colloidal photonic crystals patterned in substrates for use in different technologies including lab-on-chip and photonic chip technologies. The colloidal crystals are patterned either on or within surface relief patterns in the substrates of the composite materials and each colloidal crystal exhibits Bragg diffraction.	Here we present results on Bragg diffraction in the optical range from indium phosphide infilled solid face-centered-cubic silica colloidal crystals. Scanning electron microscopy and optical properties indicate that the semiconductor is homogeneously grown within the three-dimensional lattice of voids in the colloidal crystal. The photonic-crystal behavior of the periodic dielectric is enhanced as a result of the high contrast of dielectric constants when InP is introduced.
title	0.1801	Methods For Preserving Cut Flowers Using Thidiazuron	Thidiazuron - a potent inhibitor of leaf senescence in Alstroemeria
abstract		This invention relates to compositions and methods for preserving plants and plant parts. In particular, it relates to compositions comprising compounds of Formula I to inhibit senescence in plants.	The time to flower senescence and leaf yellowing in 20 cut flower cultivars of Alstroemeria was studied. In deionized water (DI), the time to abscission of the first petal ranged from 9 to 16 days. Time to leaf yellowing ranged from 5 to 18 days. These two processes proceeded independently so that in some cultivars leaf yellowing occurred long before flower senescence, and in others, much later. Thidiazuron (TDZ, N-phenyl-N'-1,2,3-thiadiazol-5-ylurea), a substituted phenylurea with cytokinin-like activity, markedly extended leaf longevity. TDZ was much more effective than two other substituted phenyl-urea compounds tested, in delaying leaf yellowing. A single 24-h pulse treatment with 10 muM TDZ prevented yellowing of isolated leaves for more than 2 months.
title	0.1783	Diagnosis Of Pre-Eclampsia	A longitudinal study of biochemical variables in women at risk of preeclampsia

abstract		The present invention relates to a method of predicting pre-eclampsia (PE). The present invention also relates to a diagnostic kit for performing a method of predicting PE. In particular, the method determining the level of two or more markers selected from placenta growth factor (PIGF), plasminogen activator inhibitor-1 (PAI-1) plasminogen activator inhibitor-2 (PAI-2) and leptin.	OBJECTIVE: The purpose of this study was to characterize gestational profiles of biochemical markers that are associated with preeclampsia in the blood of pregnant women in whom preeclampsia developed later and to compare these markers with the markers of women who were delivered of small-for-gestational-age infants without preeclampsia and with women who were at low risk for the development of preeclampsia. STUDY DESIGN: This was a prospective case control study. The subjects were women at risk of preeclampsia who were enrolled in the placebo arm of a clinical trial. Indices of antioxidant status, oxidative stress, placental and endothelial function, and serum lipid concentrations were evaluated from 20 weeks of gestation until delivery in 21 women in whom preeclampsia developed later, in 17 women without preeclampsia who were delivered of small-for-gestational-age infants, and in 27 women who were at low risk for the development of preeclampsia. RESULTS: Ascorbic acid was reduced early in preeclampsia and small-for-gestational-age pregnancies. Leptin, placenta growth factor, the plasminogen activator inhibitor (PAI-1)/PAI-2 ratio, and uric acid were predictive of the development of preeclampsia. CONCLUSION: Gestational profiles of several markers were abnormal in the group with preeclampsia, and some of the markers that may prove useful in the selective prediction of preeclampsia were identified.
title	0.1652	Membrane scaffold proteins	Self-assembly of discoidal phospholipid bilayer nanoparticles with membrane scaffold proteins
abstract		Membrane proteins are difficult to express in recombinant form, purify, and characterize, at least in part due to their hydrophobic or partially hydrophobic properties. The membrane scaffold proteins (MSP) of the present invention assemble with target membrane or other hydrophobic or partially hydrophobic proteins or membrane fragments to form soluble nanoscale particles which preserve their native structure and function; they are improved over liposomes and detergent micelles. In the presence of phospholipid, MSPs form nanoscopic phospholipid bilayer disks, with the MSP stabilizing the particle at the perimeter of the bilayer domain. The particle bilayer structure allows manipulation of incorporated proteins in solution or on solid supports, including for use with such surface-sensitive techniques as scanning probe microscopy or surface plasmon resonance. The nanoscale particles, which are robust in terms of integrity and maintenance of biological activity of incorporated proteins, facilitate pharmaceutical and biological research, structure/function correlation, structure determination, bioseparation, and drug discovery.	Nanoparticulate phospholipid bilayer disks were assembled from phospholipid and a class of amphipathic helical proteins termed membrane scaffold proteins (MSP). Several different MSPs were produced in high yield using a synthetic gene and a heterologous expression system and purified to homogeneity by a one-step purification. The self-assembly process begins with a mixture of the phospholipid and MSP in the presence of a detergent. Upon removal of detergent, 10-nm diameter particles form containing either saturated or unsaturated phospholipid. The ratio of components in the initial mixture was found to be crucial for formation of a monodisperse population of nanoparticles. Exploration of the phase diagram of the lamellar to phospholipid-detergent mixed micelle transition reveals that self-assembly proceeds from the mixed micellar phase. In this case a homogeneous and monodisperse population is formed. In contrast, particle formation from the detergent-phospholipid lamellar phase results in altered size, yield, composition, and heterogeneity of the resultant particles. The nanodisks contain approximately 160 saturated or 125 unsaturated lipids and can be formed from designed amphipathic alpha-helical scaffold proteins. The 10-nm particles can thus contain two molecules of MSP1 or a single molecule of an MSP1 fusion (MSP2). The phospholipid bilayer main phase transition temperature is preserved in the nanodisks as determined by fluorescence spectroscopy. Scanning probe microscopy shows a monolayer of nanodisks on a mica surface with a diameter of 10 nm and the thickness of a single phospholipid bilayer (5.7 nm), confirming the presence of a bilayer domain. The gentle method of self-assembly and robustness of the resulting nanodisks provides a means for generating soluble lipid bilayer membranes on the nanometer scale and opens the possibility of using these nanostructures to incorporate single membrane proteins into a native-like environment.
title	0.1453	Methods and compositions for stabilizing microtubules and intermediate filaments in striated muscle cells	Regulation of microtubule dynamics and myogenic differentiation by MURF, a striated muscle RING-finger protein

abstract		The present invention discloses new muscle ring finger (MURF) proteins designate MURF-1, MURF-2 and MURF-3. The genes encoding these MURFs also are provided. MURFs interact with microtubules and thus play a role in cytoskeletal function, mitosis and cell growth. Thus, the uses of MURFs in diagnosis, treatment and drug screening, in particular relation to cardiomyopathies, are described.	The RING-finger domain is a novel zinc-binding Cys-His protein motif found in a growing number of proteins involved in signal transduction, ubiquitination, gene transcription, differentiation, and morphogenesis. We describe a novel muscle-specific RING-finger protein (MURF) expressed specifically in cardiac and skeletal muscle cells throughout pre- and postnatal mouse development. MURF belongs to the RING-B-box-coiled-coil subclass of RING-finger proteins, characterized by an NH2-terminal RING-finger followed by a zinc-finger domain (B-box) and a leucine-rich coiled-coil domain. Expression of MURF is required for skeletal myoblast differentiation and myotube fusion. The leucine-rich coiled-coil domain of MURF mediates association with microtubules, whereas the RING-finger domain is required for microtubule stabilization and an additional region is required for homo-oligomerization. Expression of MURF establishes a cellular microtubule network that is resistant to microtubule depolymerization induced by alkaloids, cold and calcium. These results identify MURF as a myogenic regulator of the microtubule network of striated muscle cells and reveal a link between microtubule organization and myogenesis.
title	0.127	Selective nixtamalization process for the production of fresh whole corn masa, nixtamalized corn flour and derived products	Effect of the components of maize on the quality of masa and tortillas during the traditional nixtamalisation process
abstract		A process for the production of fresh masa, nixtamalized flour and derived produts is disclosed. Water-lime cooking of pericarp fractions of the corn, and appropriate hydration of the germ and endosperm fractions of the corn is achieved to prepare fresh masa, nixtamalized corn flour and derived products. The pericarp fractions are cooked with lime and water at a temperature between about 50° C. to about 300° C. The germ and endosperm fractions are hydrated with water. The pericarp fractions and the germ-endosperm fractions are milled separately, and the milled pericarp, germ and endosperm fractions are then mixed for producing fresh corn masa. The fresh corn masa can be dehydrated and milled for producing nixtamalizaed corn flour. Also, the pericarp, germ and endosperm fractions can be dried in order to produce nixtamalized corn flour.	In this work the importance of maize pericarp and germ in relation to the overall quality of masa and tortillas was studied. Alkaline-cooking originated alterations in the outer layers of the grain. Its components were hydrated and the pericarp fraction assumed a gummy and sticky texture. During the liming process, some components from the germ, pericarp and tip cap fractions released 'maize hull gums', increasing the contents of xylose, galactose and D-glucuronic acid. The presence of gums and insolubilised germ that remained after the traditional washing of the nixtamal improved the viscosity, cohesiveness and adhesiveness of the masa and tortillas as compared to the dry masa and tortillas from nixtamal with the germ removed and from exhaustively washed nixtamal, where most of the hull gums and germ were removed. Fresh tortillas or tortillas stored for 24h at room temperature prepared using the traditional process of nixtamalisation (washed twice) were more stretchable, elastic and resistant to tearing and cracking than tortillas prepared with exhaustively washed nixtamal or with nixtamal washed twice with the germ removed. Tortillas from nixtamal with the germ removed showed the worst texture, rollability and puffing.
title	0.1064	Method For Preparing Colloidal Particles In The Form Of Nanocapsules	Study of the emulsion-diffusion of solvent: Preparation and characterization of nanocapsules

abstract		Colloidal dispersible systems in the form of nanocapsules are prepared by mixing a solution of one monomer alpha with a solution of a second monomer beta and incorporating in the solution of alpha , a substance (B) along with suitable surfactants in the two phases. The solvent for monomer beta is a non-solvent for monomer alpha and for (B). Process for the preparation of colloidal dispersible systems in the form of nanocapsules in which the wall is composed of a polymer obtained by polycondensation of two monomers alpha and beta and in which the centre comprises substance (B) characterized in that the capsules are prepared as follows: (1) a first plastic phase is prepared which consists of a solution of monomer alpha containing at least one surface active agent as well as substance (B) in solution or suspension; (2) a second liquid phase is prepared consisting of non-solvent(s) (of monomer alpha and substance (B)), and containing monomer beta and at least one surface active agent. The first phase solvent(s) are miscible in all proportions with the non-solvent(s) of the second phase and the molar concentration of monomer beta is at least 5 times that of monomer alpha ; (3) the first phase is added to the second phase with stirring to obtain a colloidal suspension of nanocapsules, the stirring being maintained until the polymerisation of monomers alpha and beta is complete; and (4) if required, part or all of the (non)solvent(s) is/are removed to provide a colloidal suspension of nanocapsules at the required concentration.	The objective of this work was to obtained stable nanocapsules (NC), that is to say a core shell structure by a recently patented method, the emulsion diffusion of solvent. To study the capacity of encapsulation, the aim was first to control the nanocapsules size distribution before the characterization of the membrane. Nanocapsules (NC) were prepared by an emulsion-diffusion method. The emulsion was prepared using a high-speed stirrer (Ultraturrax T25), and the droplet size distributions were determined. The mechanism of particle formation is based on the diffusion of the solvent followed by the deposition of the polymer around the oil droplet. The solvent partially soluble in the water and included in oil droplets diffuses into the outer aqueous medium after the emulsion dilution with water. It is then removed under reduced pressure. In order to control the NC sizes, we studied the effect of various emulsion parameters such as the nature and the concentration of the polymer, the stabilizer, the organic/aqueous phases ratio on NC morphology and size. The mean size of NC was about 500 nm, but we could have NC with diameter size between 200 to 1,000 nm. Size distributions were found to be function of the polymer/oil ratio in the organic phase, and of the solvent volume in the droplet. The suspension of nanocapsules were characterized by Transmission Electron Microscopy (TEM), Nuclear Magnetic Resonance (NMR), density gradient centrifugation, and Differential Scanning Calorimetry (DSC). The formation of nanocapsules involves mass transfer of solvent, polymer, and oil between phases. The physicochemical properties of the system can be classified into transport parameters such as solvent diffusion into the non-solvent and interaction parameters such as solvent solubility in the water and the polymer. The mechanism of NC formation was investigated experimentally by monitoring the solvent concentration as a function of time in the continuous phase after different dilutions. The solvent elimination in the NC was complete after a dilution step followed by an evaporation under reduced pressure. This NC study gave some important information on their structure (core shell). The mechanism of formation based on the diffusion of solvent towards the aqueous phase was very rapid and depended on the volume of water at a kinetic level. We also showed that the state of the polymer changes and that the polymer forms the shell around the oil.
title	0.1032	Method And Apparatus For Transmitting And Receiving Multimedia Data	Enhancing TCP performance over wireless network with variable segment size
abstract		An apparatus for transmitting/receiving multimedia data including video data via a wireless packet in a radio transmitting/receiving system, and a method thereof are provided. The method comprises the step of performing uneven error- protection with respect to one source packet or a plurality of source packets. According to the present invention, error resilience of multimedia data (especially that of video data) can be increased by unevenly error-protecting with respect to the source packets without changing the stack of transmission/reception protocol in a conventional packet network such as H. 323	TCP, which was developed on the basis of wired links, supposes that packet losses are caused by network congestion. In a wireless network, however, packet losses due to data corruption occur frequently. Since TCP does not distinguish loss types, it applies its congestion control mechanism to non-congestion losses as well as congestion losses. As a result, the throughput of TCP is degraded. To solve this problem of TCP over wireless links, previous researches, such as split-connection and end-to-end schemes, tried to distinguish the loss types and applied the congestion control to only congestion losses; yet they do nothing for non-congestion losses. We propose a novel transport protocol for wireless networks. The protocol called VS-TCP (Variable Segment size Transmission Control Protocol) has a reaction mechanism for a non-congestion loss. VS-TCP varies a segment size according to a non-congestion loss rate, and therefore enhances the performance. If packet losses due to data corruption occur frequently, VS-TCP decreases a segment size in order to reduce both the retransmission overhead and packet corruption probability. If packets are rarely lost, it increases

			the size so as to lower the header overhead. Via simulations, we compared VS-TCP and other schemes. Our results show that the segment-size variation mechanism of VS-TCP achieves a substantial performance enhancement.
title	0.073	Wireless Atm Network	Determining the optimal configuration for the Relative Distance Microdiscovery Ad Hoc Routing protocol
abstract		A method of transmitting non-real-time data over a wireless link from a terminal (2) to an ATM switch (6) comprising the steps of generating in the terminal (2), a plurality of ATM cells derived from a protocol data unit, marking the last ATM cell of the protocol data unit, sequentially transmitting the ATM cells over the wireless link, determining in the ATM switch for each transmitted cell, whether that cell contains an error, and sending an error message back to the terminal if an ATM cell is determined to contain an error, the terminal (2) being arranged on receipt of the error message, to cease transmitting any remaining ATM cells of the protocol data unit from which the erroneous ATM cell was derived. Also, an ATM protocol stack for wireless ATM communications in which the physical layer below the ATM layer, has been adapted to include a radio access layer, the radio access layer including a medium access control protocol layer and a partial packet discard mechanism.	The Relative Distance Microdiscovery (RDM) Ad Hoc Routing (RDMAR) protocol is an on-demand protocol that reactively discovers and repairs routes within a local region of the network. This is accomplished by a simple distributed route searching algorithm, which we refer to as RDM, using a probability model for estimating the relative distance between two nodes as the basis for routing searching and, thus, for routing decisions. Relative distance (RD) between two nodes is the hop-wise distance that a message needs to travel from one node to the other. Knowledge of this RD is leveraged by the RDMAR protocol to improve the efficiency of a reactive route discovery/repair mechanism. Previous work has demonstrated that localization of routing control messaging serves to minimize communication overhead and overall network congestion. In this paper, we analyze the RDMAR protocol and its individual mechanisms, and determine their effectiveness and the manner in which they interact in order to contribute to the overall protocol performance. A framework for the modeling and analysis of the RDM algorithm is also presented and, based on this, a method for estimating a nearly optimal (RD) between two mobiles is then introduced. As demonstrated through simulations, the performance of RDM is very close to this of an optimal route searching policy while the query localization protocol is able to reduce the routing overhead significantly, often in the neighborhood of 48-50% of the flooding-based schemes.
title	0.0448	Method for manufacturing betulinic acid	The correct method of calculating energy savings to justify adjustable-frequency drives on pumps

abstract		[From equivalent US20010007908A1] The present invention provides a method for preparing betulin-3-acetate including alcoholyzing betulin 3,28-dibenzoate; a process for preparing betulin-3-acetate including: (1) acylating betulin to provide betulin 3,28-dibenzoate and (2) alcoholyzing betulin 3,28-dibenzoate to provide betulin-3-acetate; and a process for preparing betulinic acid including: (1) acylating betulin to provide betulin 3,28-dibenzoate; (2) alcoholyzing betulin 3,28-dibenzoate to provide betulin-3-acetate; (3) oxidizing betulin-3-acetate to provide betulinic aldehyde-3-acetate; (4) oxidizing betulinic aldehyde-3-acetate to provide betulinic acid-3-acetate; and (5) deprotecting betulinic acid-3-acetate to provide betulinic acid.	It is easy to make a bad business decision when using electrical energy savings as a justification to install adjustable-frequency drives (AFDs) on pumps. The simple hydraulic formulas and "rules of thumb" are easily misapplied and the errors will almost always economically favor the AFD installation. To use energy savings as a justification for an AFD installation it is necessary to accurately determine these savings over the life of the equipment. These savings are not dependent upon the AFD or motor characteristics but depend upon the characteristics of the process system. This paper is a tutorial in nature and will, show why AFDs save electricity, give examples of the common errors that are made in performing the savings calculations, show how to do these calculations correctly, show how to mathematically model the process to assist in performing the analysis, and show how to perform the economic calculations to arrive at a rate of return and net present value on the AFD investment.
title	0.0051	Device And Method For Introducing And/Or Collecting Fluids From The Interior Of The Uterus Of An Animal	Further studies on RpoS in enterobacteria: identification of rpoS in Enterobacter cloacae and Kluyvera cryocrescens
abstract		It comprises a tube or catheter (1) that is introduced into the animal's vagina up to the cervix duct (19); characterized in that it additionally comprises a flexible probe (6) constituted of a first flexible tubular body (12), and the outside of which is covered by a layer of a flexible material; all to allow that the probe, after reaching the distal end of the tube (1), may progress through the cervix duct (19) and thereafter through the cervix horn (22). This structure allows to introduce a fluid with spermatozoids, embryos or therapeutic solutions to the anterior third of the uterus horn, or to obtain embryos from the anterior portions of the uterus horn, and all this without sedation or anesthesia and without disturbing the animal's well-being.$qTo facilitate obtaining embryos, the probe includes an elastic small external coating (28) that is inflated through a flexible tube (27) for adapting itself to the uterus horn (22) preventing refluxes when carrying out absorption.$qIt is essentially applied to porcine livestock, small ruminants and any other animal species.	RpoS, the alternative sigma factor sigma (s), is important for bacterial survival under extreme conditions. Many enterobacteria are opportunistic human pathogens and their ability to survive in a changing environment could be an essential step for their virulence. To determine the presence of this gene in enteric bacteria, an Escherichia coli rpoS probe was constructed and used to detect the presence of this gene in different species. A gene homologous to rpoS was found in Citrobacter amalonaticus, Enterobacter cloacae, Klebsiella planticola, Kluyvera cryocrescens, Serratia rubidaea, Shigella sonnei, and Yersinia ruckeri. Providencia stuartii and Proteus vulgaris were the only tested enterobacteria that did not show any signal with the E. coli rpoS probe or that did not lead to amplification of an rpoS fragment using specific primers. The rpoS gene from E. cloacae and from K. cryocrescens was cloned and sequenced and a mutant allele was constructed in E. cloacae. Survival rates under different harsh conditions were followed in order to determine the effect of rpoS inactivation in exponential- and stationary-phase cells of both strains. E. cloacae rpoS mutants were more sensitive to extreme pH, high osmolarity, and high temperature than the wild-type.

Annex 2

Sensitivity analysis: results of t-test carried out using a resonance threshold equal to 0.1767.

Table 3bis Sensitivity check

	Freq.	did not use grace	used grace	% that did not use grace	% that did not use grace	did not use grace: mean lag	used grace: mean lag	ttest Ha: mean_diff≠ 0
USPTO priorities patents	64	48	16	75.0%	25.0%	16.756	-8.750	***
IPC human necessities	20	16	4	80.0%	20.0%	15.463	-14.017	***
IPC performing operations	2	1	1	50.0%	50.0%	11.233	-3.667	
IPC chemistry & metallurgy	18	16	2	88.9%	11.1%	16.704	-11.183	***
IPC mechanical engineering	1	1	0	100.0%				
IPC physics	0	0	0					
IPC electricity	13	8	5	61.5%	38.5%	18.046	-2.753	***
IPC textiles & paper	10	6	4	60.0%	40.0%	16.583	-11.033	***
firm	9	7	2	77.8%	22.2%	26.738	-0.933	***
university	61	45	16	73.8%	26.2%	15.981	-8.750	***
PRO	10	9	1	90.0%	10.0%	24.337	-0.867	***
single assignee	51	37	14	72.5%	27.5%	14.762	-9.812	***
university-only assigned	46	33	13	71.7%	28.3%	13.128	-10.692	***

Table 4bis Sensitivity check

	variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
I	Non grace priority country	21	16.873	3.290	8.494	0.012
	Grace priority country	64	8.379	1.830		
II	Non grace priority country	20	18.962	2.672	4.206	0.068
	Grace priority country	48	14.756	1.411		

Table 5bis Sensitivity check

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
US extended	26	12.978	2.426	7.746	0.018
US non extended	38	5.232	2.496		

Table 6bis Sensitivity check

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
US priority extended to EPO	26	12.978	2.426	-3.895	0.168
EPO priority	21	16.873	3.290		

Table 7bis Sensitivity check

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
firm	12	17.864	3.677	8.600	0.0337
no firm	73	9.263	1.780		

Table 8bis Sensitivity check

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
others	23	18.686	2.564	11.253	0.0009
university only	62	7.433	1.906		

Table 9bis Sensitivity check

variable	obs.	mean	st. err.	difference	p-value (Ha : diff>0)
multiple assegnees	17	16.986	2.939	8.136	0.0233
single assignee	68	8.850	1.871		

The Fifth Scenario

"Software and Silicon"

The future of patents and the patent system in the new Digital Society

by Pieter Hintjens
President of the FFII,
CEO, iMatix Corporation

EPIP, Lund, September 2007

Class struggles

I use the phrase "rich man's poker" very deliberately as this is a game much better suited to companies with long pockets than to the small.

Alison Brimelow, President, EPO

Public opinion?

If a civil engineer, or any other professional gives an opinion like that, they have a liability if they are wrong. The EPO can do far more damage, but has no liability for when it's wrong.

Anonymous comment
The Register, 4th July 2007

What happened?

The Digital Revolution is what happened

Software and Silicon changed the world

New digital societies

New digital economics

New digital politics

New digital societies

On-line communities

Diverse, independent, and competitive

Aggregations of diverse opinion
vs
Traditional top-down expertise

New digital economies

Serving the on-line communities

The new Digital Cities

The demise of Industrial Capitalism

The rise of Digital Capitalism

Did the patent system adapt?

USA: allow patents on software
EU: allow patents on "CIIs"

No protection for software components
but rather for "machines"

More of the same, not adaptation

It fought Digital Society... which fought back

And the result...

Chemical / pharma ++

Software --

Jim Bessen, Boston University

The Digital Society hates...

Patents

Slow - takes years
Analogue - everything done by hand
Expensive - no competitive market
Broad - covers problems, not solutions
Unfair - serious ethical concerns
Not scalable - quantity = disaster

The Digital Society loves...

Domain names

Fast - search, register, pay online
Digital - everything is bits
Cheap - €11.00/year (many registrars)
Narrow - reasonably precise
Fair - reasonable meritocracy
Scalable - millions? billions!

Don't forget old friends

Copyright

Fast - instant and automatic
Digital - it's all become bits
Cheap - zero point zero Euro
Narrow - extremely precise
Fair - absolute meritocracy
Scalable - the more the better

Scalable?

3,000,000,000+ people now take part
in the Digital Society

That is a lot of entrepreneurs

Most of them are very small
Any property system must work for them

Or, be(come) irrelevant

Ethics = sustainability

- All must be equal before the law
    - No "rich man's game"
- The law must be made by the state
    - Not as a by-product of administrative decisions
- The law must work to benefit society at large
    - Not special interest groups
- The state must be run democratically
    - The worst system except for all the rest

A political theory

Just Societies stem from the middle classes

Entrepreneurs don't discriminate
They deconstruct political systems
and they fix them

Political elites try to stop this process
using any tools at hand

The patent system is such a tool

The future

I am not clear that we will ever get ourselves back to the position that can be regarded as "healthy balance".

Alison Brimelow, President, EPO

Pandora's Box

Software patents are Pandora's Box

Nightmares have been unleashed

Europe's place in the Digital Society is at risk

Humanity's technological future is at risk

A less pessimistic opinion

The patent system could survive
the Digital Revolution

It could even help

But some *big* changes are needed

Essential steps

Step back from dogma

Return to first principles

Understand the Digital Society

Stop granting software patents

New property for the Digital Society

The Digital Patent

Technically, it's easy

Protect real value
Reward disclosure
Create security
Aggregate knowledge

Work with, not against Digital Society
Fast, digital, competitive, cheap, narrow, fair, scalable

Politically... well, :-)

Making wise laws

Patent office are in the regulatory business

Banish dogma, embrace diversity

Develop policies regionally

Aggregate centrally

Transparency

Ethics

Thank you

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Filing strategies and patent value [µ] [*]

Nicolas van Zeebroeck$^{\sigma}$ *and Bruno van Pottelsberghe de la Potterie*$^{\alpha}$

September 2007

FIRST DRAFT – COMMENTS WELCOME

Abstract

Patenting strategies are suspected to be a significant driver of the surge in the number and size of patent applications filed around the world, increasing workloads and backlogs at patent offices and resulting in a higher legal uncertainty on the markets. This paper proposes some measures to identify different dimensions of strategic filing behaviours (the filing route to reach the EPO and the style of drafting: oversized claims, drafting by assembly, divisional filings) and shows how they have evolved at the EPO over the past two decades. The main result of this paper is to show that these strategies are consistently and positively associated with patent value and may hence be used as a new class of determinants. The empirical implementation relies on a unique dataset made of about 250,000 EPO patent grants and uses 6 different indicators of patent value as dependent variables, offering as a complementary result a large-scale sensitivity test of most established determinants of patent value to the indicator and the sample used in the estimates, all subject to a comprehensive review of the literature. The results of this exercise confirm some of the established determinants of value in their role, but also spot strong dependencies of the results to the dependent variables and sampling methodologies, prescribing much care in generalizing such results.

Keywords: Patent systems, Patent quality, Patent value, Patenting strategies

JEL classification codes: O31; O34; O50

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[*] Nicolas van Zeebroeck gratefully aknowledges financial support from Université Libre de Bruxelles, the European Patent Office, and the Marie-Christine Adam Foundation.

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1. Introduction

Patent systems worldwide have been characterized by two common trends: an unprecedented boom in the number of patent applications and a parallel increase in their size. The growing number of patent filings is due to many factors (e.g., the globalization of markets, new generic technologies, the emergence of new countries like China, and the arrival of new actors like universities). One of these factors, strategic patenting, is believed to substantially affect patent systems because it both increases the number of patent applications and reduces their average quality (firms apply for more patents for a given invention or have a higher propensity to patent inventions of a lower quality). The direct consequences of these evolutions is a sharp increase in the workloads – and hence backlogs – for patent offices, leaving much uncertainty on the markets for technology.[1] An indirect consequence has been the burgeoning economic and managerial literature on patent value.

Over the past 20 years research scholars, led by Narin et al. (1987), Trajtenberg (1990), Scherer and Harhoff (2000) and Hall et al. (2001), have developed various models essentially aiming at finding an appropriate weighting scheme to count patents, or at identifying the most promising patents within the ocean of codified knowledge published each year by major patent offices. The early surveys provided by Reitzig (2004a) and Sapsalis and van Pottelsberghe (2007) show that two broad types of variables have been used to predict the potential value or the quality of patents. The first one is based on various characteristics of patents (e.g. the number of forward citations, the occurrence of an opposition, the number of backward patent citations or citations to the scientific literature), and the second one is related to the applicants' profile and ownership structure (e.g. the type and size of the firm, cross-border ownership, co-application). The present paper builds on the existing literature by adding a new class of potential determinants of patent value: the filing strategies adopted by firms.

The main objective of the present paper is precisely to investigate whether the different dimensions of a patent filing strategy affect the value or importance of patents.[2] Several dimensions of filing strategies have been described by Harhoff (2006) and Stevnsborg and van Pottelsberghe (2007). They range from the form and quality of the drafted document (the number of claims filed or abandoned in the course of the examination), the construction of patents by assembly or disassembly, and the filing of divisional applications, to the route chosen to reach the EPO (via the PCT process or not) and the request for accelerated search. Harhoff has show that some of these strategies have been increasingly used over the past two decades and the typology provided by Stevnsborg and van Pottelsberghe explicitly suggests that some strategies essentially aim at slowing down the examination process. This paper investigates whether they may as well be used as factors indicative of a higher or smaller value of patents.

To address this research question empirically we rely on a unique dataset containing a large number of variables on all granted patents that were filed before the EPO between 1990 and 1995 (about 250,000 patents). This unique 'size' and 'breadth' of the dataset allows to provide a second contribution to the literature, which is to test whether and to what extent the existing results have been affected by sampling methodologies or by the chosen indicator of patent value.

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[1] The determinants and consequences of the boom in patent applications has been analysed by Kortum and Lerner (1999) and Jaffe and Lerner (2004) for the US patent system and by Guellec and van Pottelsberghe (2007) for the European patent system. The sharp increase in voluminosity (in terms of the average number of pages and/or claims included in a patent) is thoroughly documented by van Zeebroeck et al. (2006a) and Archontopoulos et al. (2007). van Pottelsberghe and van Zeebroeck (2007) provide evidence suggesting that the average value of the patents granted by the EPO between 1985 and 1995 has constantly decreased. Bessen and Meurer (2005) illustrate the intensifying number of patent litigations in the US.

[2] Throughout the remainder of this paper the various measures of patent value used as dependent variables will be referred to as 'patent value indicators', though they are only used as proxies for the unobserved monetary value.

In terms of dependent variables, five different indicators of patent value, based on patent data and widely used in the literature, are used in the present paper as well: forward citations, European family size, triadic, renewals, and opposition incidences.[3] As these classical indicators capture different dimensions of patent value, a single composite index developed by van Zeebroeck (2007) is also used. The different features of filing strategies and the more classical determinants (patent characteristics and type of ownership) are to be tested against each of the five established measures and the composite index. The size of the dataset allows testing for the stability of the estimated parameters to the geographical origin of the patents and their technological area.

The paper is organised as follows. Section 2 introduces the different dimensions of patent filing strategies, some related measures and their evolution. Section 3 summarizes a comprehensive review of the empirical literature on patent value (covering 66 distinct empirical works), and familiarizes the reader with established indicators and determinants. Section 4 presents the empirical implementation. The results are discussed in section 5 and section 6 concludes.

The results of this paper first show that most dimensions of patent filing strategies are positively, significantly and consistently associated with more valuable or more important patents. This is particularly the case with the number of claims and priorities, with the choice of the PCT route and divisional applications. This suggests that when a knowledge asset is more valuable, a patentee tends to recourse to more aggressive filing strategies. The results further confirm the positive impact of some of the most popular determinants (such as the number of claims and inventors and the PCT option), but also points out strong sensitivities to the sampling methodology (country- or industry-wise) and the patent value indicator used as dependent variable.

2. Filing strategies

As patent systems evolve and become increasingly popular, new strategies emerge in terms of managing patenting processes and maximizing the legal protection of inventions. Harhoff (2006) has developed the notion of patent constructionism,[4] illustrating how firms play with patents as with Lego's to build patent portfolios. Stevnsborg and van Pottelsberghe (2007) scrutinize the numerous options patentees are offered along the patenting process at the EPO and identify strategic behaviours clearly aiming at exploiting every procedural possibility offered by the system to delay the granting process or to obtain the broadest possible scope of protection.

The costs and additional red tape associated with most of these strategies suggest at first sight that the underlying inventions must be worth these burdens and hence that the resulting patents should be of higher value. The main objective of this paper is precisely to address this question and by so doing to contribute to the literature on the determinants of patent value. This objective requires the construction of several variables to identify the various strategies, which are described in Table 1. They are essentially twofold: some of them relate to the path followed to reach the EPO and get a European patent granted, the others pertain to the way the application has been drafted. The former group of strategies has already been accounted for in different papers, but the second – to the best of our knowledge – has never been tested as determinants of value so far.

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[3] van Zeebroeck (2007) provides a detailed and comprehensive analysis of those indicators and their evolution over time for European patents.

[4] Harhoff (2006) defines patent constructionism as the "strategies and tactics used by patent applicants to construct patent portfolios by constructing overlapping, multiple filings with high similarity from smaller building blocks (claims, first filings) or by recombination of smaller building blocks (claims, first filings)."

Filing routes

The Patent Cooperation Treaty (PCT) multiplied the number of potential routes toward the EPO[5] which are now entirely part of the strategic choices that any patent applicant needs to make before reaching the EPO. Since the Paris Convention (1883), applicants have one year from the date of their first (priority) filing to extend their patent application to any other country in the world. Therefore, until recently, most patentees used to file an application at their domestic patent office and transfer it to other offices where they sought protection within 12 months. Until the mid-eighties, this was the case for more than 90% of all applications filed to the European Patent Office (EPO). Since then, the PCT – entering into force in 1978 – has offered patent applicants a new option to delay the international extension of their priority filings from 12 to 30 months while more easily and efficiently managing the transfer of their filings to patent offices worldwide.

These benefits have convinced many applicants to opt for the PCT process, so that about 53% of applications filed to the EPO in 2005 were transferred to the EPO under the PCT.[6] Over the period considered in the present analysis (1990-1995), about 30% of the granted patents were filed via the PCT option. Because of these benefits, the PCT procedure may carry applications that are clearly aimed at being widely extended worldwide and may hence be associated with more value. But it may also concern applications that were filed very early in the innovation process, at a time when the invention's market potential was still unclear (van Zeebroeck et al., 2006a). In such a case, the patentee may have preferred to delay by an extra 18 months the time when a final decision as to whether the application is worth being extended abroad or not would have to be made, and the application itself may hence be of much or of very little value, if any. Therefore, the overall association between the PCT option and patent value is a priori unclear.

Whereas the PCT route has as main effect a substantial delay in the patenting process, at the time the application is filed at the EPO the patentee is allowed to file a request for accelerated search and/or examination in order for the file to be processed more rapidly. Table 1 shows that accelerated searches (*ACCSRC*) are requested in as low as about 2% of the cases. One particular strategy associated with this procedural option consists in filing a Euro-Direct application (i.e. non-PCT) with an accelerated search request, so that a preliminary opinion on the patentability of the invention may be obtained very quickly and a decision to pursue the granting process may be taken within a short period of time when applicants are unsure about their chances to get a patent grant. Accelerated searches and examinations may also be used by patentees who are very confident about the patentability of their invention and just want their patent to be granted as fast as possible. As a consequence, the association between accelerated search requests and patent value is also a priori ambiguous.

Drafting styles

The drafting style of patent applications, instrumentalized by some applicants in an attempt to reinforce the legal strength of their patents, to circumvent the disclosure requirement, or to create smoke screens or uncertainty in a specific area, is made of three main dimensions.

One, van Zeebroeck et al. (2006a) have shown that the severe inflation in the size of patent applications at the EPO was notably due to a progressive harmonization of drafting styles toward American drafting modes, themselves largely influenced by legal changes in the US patent system. The authors observed in addition that the number of claims in an application is strongly influenced by the technology at stake (biotechnologies and computers being associated with the largest numbers). The literature on patent value has frequently used the number of claims as a proxy for the

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[5] See Stevnsborg and van Pottelsberghe (2007) for a comprehensive overview of these routes.

[6] EPO Annual Report, 2005.

breadth or complexity of patents (Tong and Frame, 1994), suggesting – and empirically demonstrating – a positive correlation with patent value. However, raw counts of claims may be biased by technology specific practices and their evolution over time. Therefore, the number of claims as such does not provide a fair indication on the strategic behaviour of a patentee in drafting an application. Rather, the deviation of the number of claims a given application contains as compared with the average number of claims contained in applications from the same sector and filed in the same year provides a very interesting measure of the relative oversize of an application, potentially denoting a strategic behaviour. This deviation is computed within the '*CLMDEV*' variable according to Equation 1.

$$CLMDEV_i = \frac{C_i}{\frac{1}{n(S_i,Y_i)} \sum_{j=1}^{n(Si,Yi)} C_j} \qquad (1)$$

In this equation, $CLMDEV_i$ is the relative deviation in number of claims of application i, C_i is the number of claims contained in application i, and $n(S_i,Y_i)$ is the number of applications filed in the same technology joint cluster (S_i) and year (Y_i) as application i, with $i \in \{1,...,n(S_i,Y_i)\}$. Table 1 shows that the average number of claims as a percentage of the same year country average is about 99%, that is the deviation is on average very small or event close to 0. However, extreme values ranging from 6% to 2867% suggest the presence of large outliers and a high level of skewness in the distribution. To deal with this severe skewness, the variable will be taken in logarithm within the estimation equations. Given the cost incurred by excess claims (the EPO charges additional fees for claims in excess of 10) and because excess claims may represent more robust or larger patents (including more fall-back positions or encapsulating a larger scope of protection), this variable is expected to be positively associated with patent value.

Table 1 - Summary Statistics of Filing Strategies Variables

Variable	Obs.	Mean	St. Dev.	Min	Max
PCT	248,856	0.29	0.45	0.00	1.00
ACCSRC	248,856	0.02	0.13	0.00	1.00
CLMDEV	248,848	0.99	0.73	0.06	28.67
CLMLS	245,194	1.63	6.28	-152.00	350.00
CLMLS (as % of # claims at grant)	245,194	0.29	1.05	-1.00	116.50
PRIO	248,856	1.20	0.84	0.00	49.00
EQUIV	248,856	0.13	0.53	0.00	24.00
HASDIV	248,856	0.04	0.20	0.00	1.00
ISDIV	248,856	0.03	0.16	0.00	1.00

Source: Own calculations based on EPO data – Granted patents filed 1990-1995

As a complement, the share of claims abandoned in the course of the examination proceedings (*CLMLS*) may be a good indicator of potentially abusive drafting strategies. It should be recalled here that the examination process often takes the form of an interactive process between the examiner and the patent agent, which ends up in a final set of claims that would be allowed for grant by the examiner. In this respect, the number or share of claims abandoned is informative of the scope of protection that has been refused by the examiner (Stevnsborg and van Pottelsberghe, 2007), and is therefore expected to have a detrimental effect on patent value. Here again, whereas the average number of claims lost is about 1.6, extreme cases range between 152 claims added to the application and 350 claims abandoned.

Two, the progressive shift from single patent strategies to patent portfolio strategies has led patentees to no longer rely on a single patent to protect an invention but rather to build a set of intellectual property rights. The size and strength of the patent portfolio therefore matters more than the quality of each individual patent. This change in reliance on and use of the patent system contributed to the well known surge in patent filings around the world (Kortum and Lerner, 1999) and has given rise to new schemes in constructing patent filings (Harhoff, 2006). In particular, applicants increasingly split national priority filings into a set of applications with a common root that they file or extend to the EPO (cf. Harhoff's Type I construction), and conversely merge several national priority filings to form one single EPO application (cf. Harhoff's Type III construction).[7] The average number of EP equivalents (EP filings having at least one priority in common) or *EQUIV* is about 0.13 but ranging from 0 (no EP equivalents) to 24 (extreme case of Type I construction), and the average number of priorities per EPO application (*PRIO*) is just over 1 (about 1.2) but actually ranges from 0 (EPO first filings) to 49 (extreme case of Type III construction).[8] At first sight, the drafting and procedural costs associated with such strategies suggest that only higher value inventions would justify them, and the corresponding variables should be associated with more valuable patents as a result. However, should a given scope of protection be split into different filings, one could hardly foresee the way the value of the underlying invention will spread across these filings. Assuming that most value could remain concentrated into one application in case of a Type 1 construction, such a strategy would generate one highly valuable filing and several ones of much less value. Hence, the expected sign of the association between construction strategies and patent value is uncertain.

Three, an additional feature of the European Patent System which has met an increasing success over the past two decades is the possibility to split one European application into several divisional filings that will follow their own track in the examination process while keeping the same filing date as the parent application from which they originate. This option is mostly used when the original application is said to lack unity and would hence be refused as such by the examiner. In such a scenario, the applicant may isolate different subsets of the initial claims and encapsulate them into different divisionals while the now smaller original filing follows its initial path up to grant, usually carrying the core of the claims. Therefore, the case of divisional filings usually reveals excessively large or unfocused applications, sometimes resulting from the premature patenting of an invention or from a deliberate willingness to deceive competitors and examiners by hiding the true invention in the middle of many non inventions or to maintain a case pending for as long as possible.

This way, divisional filings sometimes emerge as a new form of *de facto* submarine patents (Graham and Mowery, 2004; van Zeebroeck et al., 2006a; Stevnsborg and van Pottelsberghe, 2007). Indeed, although Article 76(1) of the European Patent Convention provides that divisionals "*may be filed only in respect of subject-matter which does not extend beyond the content of the earlier application as filed*", some applicants file divisional applications beyond this requirement to amended them later, during prosecution. Some even file divisionals of divisionals that they amend even later in the process. This has led to concerns that the divisionals system can be abused, thereby reducing legal certainty for third parties.[9] Nonetheless, the administrative burden induced by the filing of divisionals suggests that such strategies would only be used when the root application is

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[7] Harhoff's Type II construction referring to the possibility for applicants to file independent priority filings covering a same invention and extend them to the EPO as such is much more difficult to identify for such applications are not related by common priority numbers.

[8] Note that the computation of the *EQUIV* variable excluded from recognized equivalents those applications that were in fact divisionals of the original filing, see below.

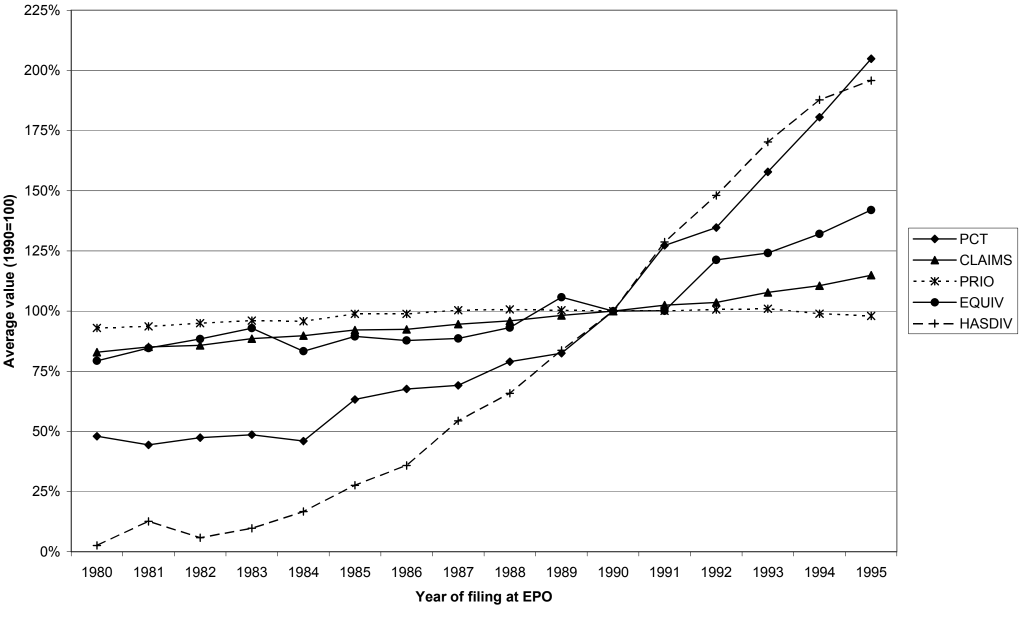
[9] Nurton, J., "EPO Enlarged Board rules on divisionals", in MIP Weekly News July 4, 2007.

unusually valuable. Hence parents of divisionals are expected to be strongly associated with patent value. The sign of the association between divisional filings is much less clear, as no one could predict which part of the subject matter from the original filing (the core of the invention or some accessory features) will be encapsulated into each divisional. Should the two effects materialize (divisionals concern more valuable patents but most value remains within the original filing), the association should be ambiguous. From Table 1, one may notice that about 4% of all granted patents filed to the EPO in the period considered have given rise to divisional filings (*HASDIV*) and 3% only were divisionals themselves (*ISDIV*). Since by definition each parent has given rise to at least one divisional application, this difference readily suggests that divisional filings are less likely to be granted than their parents.

The numerous combinations of these different strategic dimensions induce different patterns described by Stevnsborg and van Pottelsberghe (2007) as fast vs. slow tracks and good-will vs. abusive behaviours. For example, a jumbo application (with an outrageous number of claims) followed by several generations of divisionals is clearly suggestive of an attempt to abuse the system and slow down the examination process as much as possible. To the contrary, a short application, filed to the EPO with a request for accelerated search or examination, quickly giving place to a granted patent with the exact same set of claims is a clear indication of a good-willing patentee whose application has been efficiently and honestly drafted.

Figure 1 depicts the evolution of the different dimensions of patent filing strategies for the period 1980-1995. It shows at first sight that all these strategies have become increasingly frequent over the period considered. The most striking evolutions are the share of applications filed through the PCT route and the share of applications which were followed by one or more divisional applications. With less pronounced an evolution, the average number of claims and of EP equivalents have also experienced a continuous increase over the entire period, whereas the average number of priorities has remained remarkably stable around 1 priority, suggesting that the construction by assembly, though more frequent nowadays than before, remains largely exceptional.

Figure 1 - Evolution of Patent Filing Strategies at the EPO (1980-1995)



Sample: All applications filed to the EPO in the period 1980-1995

Whereas most patent value indicators have decreased or remained mitigated over the same period,[10] all strategic indicators exhibit a (sometimes severe) upward trend. These opposite evolutions could actually suggest a negative impact of filing strategies on patent value, against the common sense intuition evoked earlier in this section. This further emphasizes the need for an empirical investigation of this relationship.

3. The literature on patent value

The burgeoning empirical literature on patent value has been surveyed by Reitzig (2004), Sapsalis and van Pottelsberghe (2007) and Greenhalg and Rogers (2007).[11] A particularity of the numerous contributions in this field of research is that they cannot be easily summarized, as their empirical design diverge over three dimensions: i) in the measure of patent value used as dependent variable; ii) in the number and type of explanatory variables (i.e. the potential determinants of value), and iii) in the adopted sampling strategy. Most empirical implementations take the following form:

$$V_i = f(PC_i, PO_i, II_i) \qquad (2)$$

Where V_i is a measure of the value of patent *i*, PC_i is the vector of characteristics of patent *i*, PO_i is the vector defining the characteristics of patent *i*'s ownership, and II_i is a vector of variables characterizing the underlying invention and the context in which it was made or patented. The heterogeneity across the literature comes from the various measures of *V* and from the numerous determinants within each of the three classes included in the empirical models.

<u>Diversity in indicators of patent value</u>

Roughly speaking, established measures of patent value used on the left-hand side of Equation 2 can be divided into two broad categories: those that come from outside the patent system and those that come directly from it, respectively 'market-based' and 'patent-based' measures, as summarized in Table 2. The former measures mainly consist of financial or economic indicators, the most popular being Tobin's *q* and stock market values for works at the firm level, and surveyed estimates for studies at the patent level. In the case of firm market values, the heroic underlying assumption is that the value of a firm's patent portfolio should be somehow reflected in its market value, provided that financial markets are efficient. In the case of the surveyed monetary value of patents, the underlying rationale is no less heroic as it assumes that inventors or managers know the financial value of their patents.

The latter group of measures, henceforth designated 'patent-based', are much more diverse in nature and rationale. Four indicators are most frequently used in the literature: forward patent citations, patent family sizes, survival (or renewal) data and legal disputes (oppositions or litigation). First, forward patent citations consist in counting the number of citations that each patent received from subsequent patent filings (Trajtenberg, 1990) and are hence easily and freely available from the search reports published by patent offices with each patent application. They are taken as indicators of value, or turn out to be highly correlated with financial value indicators, because they reveal subsequent inventions based on the cited patent. The fact that other companies enter into the same technological space or that the applicant pursues investments around a given invention indicates a potentially valuable market.

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[10] See van Zeebroeck (2007) and below in section 4.

[11] Reitzig (2004) discusses in particular the theoretical and conceptual meaning of various indicators and determinants.

Second, patent family sizes are made of the number of countries in which a given patent has been filed. Given the costs and administrative efforts required to obtain such international coverage, economists logically assume that wider international families of patents would denote higher value patents (Putnam, 1996). This indicator can be computed in several different ways: triadic patent families (Dernis et al., 2001) consist in patents that have been filed simultaneously at the USPTO, the JPO and the EPO, whereas counts of countries of protection may be obtained at different levels, e.g. worldwide or in terms of EPC member States where EPO granted patents were validated (van Pottelsberghe and van Zeebroeck, 2008).

Table 2 - Typology of patent value indicators in the literature

Group	Indicator	Notation in Table 5
Market-based measures		*MKT*
Firm value	Tobin's *q*	
	Stock Market	
	Sales/ Benefits	
	New firm creation	
	Technologic Strength	
	R&D Performance	
Estimated patent value	Royalties	
	Dollar assessment by inventors or managers	
	Sleeping vs. Active	
	Buy-outs	
Patent-based measures		
Technological importance	Forward citations	*CIT*
Geographical scope (Families)		*FAM*
	Triadic	
	Number of countries worldwide	
	Number of EPC validation States	
Length (Renewals)	Age at lapse	*REN*
	Patent has been granted	*GRT*
Legal disputes		*DIS*
	Litigation incidences	*LIT*
	Opposition incidences	*OPP*
	Opposition outcomes	*OTC*

Third comes the age at which patents ultimately fall into the public domain (or lapse), namely their lifespan or duration, which provides one of the most appealing indicators of value, whose theoretical foundations have been provided by Dernburg and Gharrity (1961) and Pakes and Schankerman (1984). As renewal fees are requested each year to keep a patent active, patents that are renewed for several years are considered to be 'worth it'. If one wants to consider not only patent grants but also all non-granted applications filed within patent portfolios, one should first acknowledge that only granted patents will ever be renewed, and that the grant of a patent determines its enforceability. The positive outcome of granting procedures has therefore been used as an alternative indicator of patent value (Guellec and van Pottelsberghe, 2000). Note anyway that most empirical studies on patent value – including the present one – only take into account patents which have been granted.

The fourth indicator of value is related to the occurrence of legal disputes, mostly litigation in the US (increasingly frequent according to Bessen and Meurer, 2005) and oppositions in Europe.[12] Both types of disputes have been intensively used as revealers of high value patents, as they generally concern inventions that are already exploited on the market place.

Table 3 proposes a typology of the empirical studies available so far on patent value, based on the value indicator used and the sample construction method (Table A1 in the appendix provide the names of the authors of the studies depicted in Table 3). It appears first that some indicators of value are much more popular than others, namely market-based measures, citations and oppositions.

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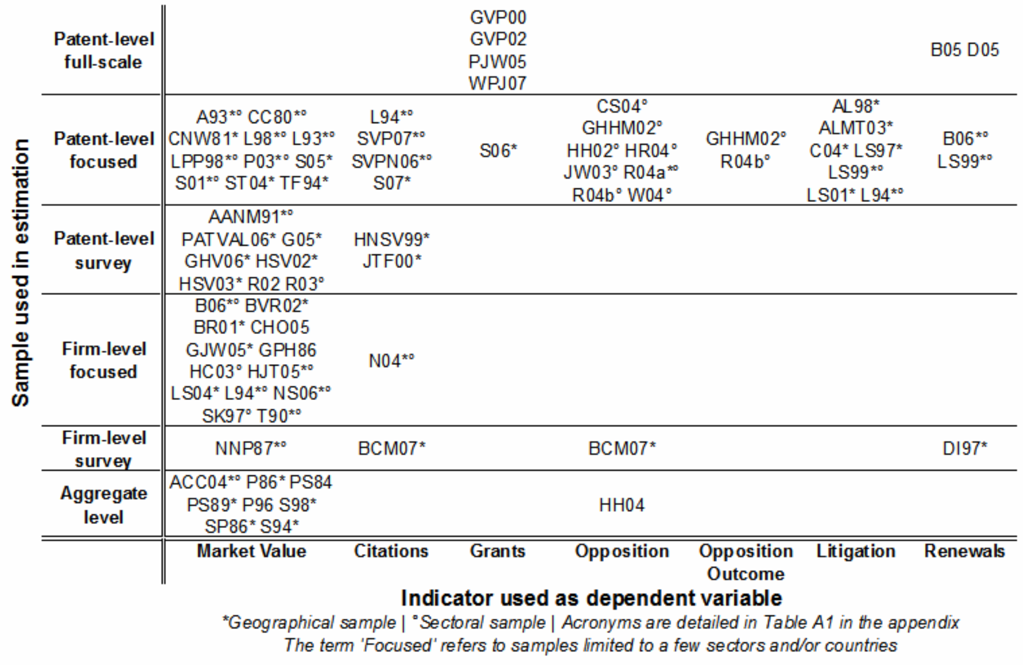
[12] Post-grant review systems and their advantages have been carefully examined by Hall et al. (2003).

Second, many indicators have never been used at a large scale (this is logically the case for market value measures over a full sample, since such measures can only be gathered manually – hence selectively – at the patent level). Third, very few studies have relied on full samples of patents, i.e. without making any arbitrary choice on the sample construction to be made. Focused approaches are clearly the most frequent, with 35 studies at the patent level and 14 at the firm level. As the joint information on patent and firm characteristics is not easy to obtain, focused approaches are a logical solution.

Table 3 - Typology of the empirical literature on patent value



Sample used in estimation	Market Value	Citations	Grants	Opposition	Opposition Outcome	Litigation	Renewals
Patent-level full-scale			GVP00 GVP02 PJW05 WPJ07				B05 D05
Patent-level focused	A93*° CC80*° CNW81* L98*° L93*° LPP98*° P03*° S05* S01*° ST04* TF94*	L94*° SVP07*° SVPN06*° S07*	S06*	CS04° GHHM02° HH02° HR04° JW03° R04a*° R04b° W04°	GHHM02° R04b°	AL98* ALMT03* C04* LS97* LS99*° LS01* L94*°	B06*° LS99*°
Patent-level survey	AANM91*° PATVAL06* G05* GHV06* HSV02* HSV03* R02 R03°	HNSV99* JTF00*					
Firm-level focused	B06*° BVR02* BR01* CHO05 GJW05* GPH86 HC03° HJT05*° LS04* L94*° NS06*° SK97° T90*°	N04*°					
Firm-level survey	NNP87*°	BCM07*		BCM07*			DI97*
Aggregate level	ACC04*° P86* PS84 PS89* P96 S98* SP86* S94*			HH04			

Indicator used as dependent variable

**Geographical sample | °Sectoral sample | Acronyms are detailed in Table A1 in the appendix*
The term 'Focused' refers to samples limited to a few sectors and/or countries

<u>*Diversity in sampling strategies*</u>

Despite the richness of the empirical literature, there are as many samples as papers. First, sampling strategies vary widely, from a few dozens observations in studies at the aggregate level to full-scale samples with up to tens of thousands of patents. Many papers work at the patent level, but many others test value indicators at the firm level, while a few others study patent value at the industry or country level. Second, most samples are limited to one specific country or industry. They are called 'focused' samples in opposition with full-scale samples, which comprise a full cohort of patents from one patent office, no matter the country or industry. Obviously, samples based – even partially – on the answers to any survey are constrained by the unavoidable selection inherent to any survey. The different levels of observation (aggregate, firm, or patent) and types of samples (surveyed, focused or full-scale) are represented on the vertical axis in Table 3. It clearly appears that 'focused' approaches are by far the most frequently used. These studies are most frequently limited to a particular industry in a given country. One may logically wonder to what extent the empirical results found in such 'focused' pieces of research can be generalised.

<u>*Diversity in the determinants*</u>

Summarizing the literature is complex not only for the diversity of dependent variables that have been used or for the high heterogeneity in the sampling strategies, but also because the type and number of explanatory variables vary widely across studies. To start with, some explanatory variables which are significantly correlated with an independent value measure of proven reliability have subsequently been used as new indicators of value on their own. This has been the case for instance with forward patent citations, which are the most important determinant of patent value for market-based measures but have been used as dependent variable in at least 8 studies. This is also the case with renewals and legal disputes. In addition to these measures with well established though imperfect reliability, the authors have identified a range of extra features or characteristics of patents as new potential value determinants, which can be grouped into the three different classes of variables introduced in Equation 2: various characteristics of each patent application, the characteristics of patent owners, and some contextual information gathered from surveys, pertaining to the context of the invention or the patenting motives pursued by the applicant. This typology of patent value determinants is summarized in Table 4.

Table 4 - Typology of patent value determinants

Group	Determinant	Notation in Table 5
Patent characteristics (PC)		
Technological importance		*CIT*
	Forward citations (after N years)	
	Number of X or Y citations (after N years)	
	Institutional origin of forward citations	
Geographical scope (Families)		*FAM*
	Triadic	
	Number of countries worldwide	
	Number of EPC validation States	
Length (Renewals)	Age at lapse	*REN*
	Granted	*GRT*
Legal disputes		*DIS*
	Litigation incidences	*LIT*
	Opposition incidences	*OPP*
	Opposition outcomes	*OTC*
	Multiple opponents	*MOP*
Complexity	Number of backward patent citations	*BPC*
	Share of Self Citations (by same applicant)	
	Generality index	
	Basicness/Originality index	
	Number of backward non-patent citations	*NPC*
	Number of claims	*CLM*
	Number of IPC classes (at different levels)	*IPC*
	Number of inventors listed	*INV*
Filing route	PCT (Chapter I/Chapter II) vs. EP Direct	*PCT*
	Accelerated Search Request	*ASR*
	Accelerated Examination Request	*AEX*
Patent Ownership (PO)		
Ownership structure	Co-Applicants	*COA*
	Cross-border ownership	*CBO*
Applicant profile	Portfolio size	*CUM*
	Market size	*APS*
	Academic	*ACA*
	Independent	*APP*
	Inexperience	*OCC*
Insider information (from surveys only) (II)		
Patenting motives		*MOT*
	Offensive vs. Defensive	
	Blocking vs. Protection	
	Research Collaboration	
Invention context		*ICH*
	Difficulty to invent around	
	Inventors' profiles	
	R&D Structure	
	Environment	

The class of determinants based on patent characteristics include different subsets of variables with very different rationales. The first four subsets correspond to the four groups of patent-based indicators described here above, which have been used on both sides of Equation 2: forward citation counts (and derived measures), measures of the geographical scope (patent families), measures of the length (renewals), and variables identifying legal disputes, their characteristics and outcomes. The rationale of these four subsets of variables has been detailed here above and all suggest a positive association with patent value which has already been established. These four types of measures will constitute the dependent variables for the model presented in the next section and will therefore only be used as indicators (i.e. on the left-hand side of Equation 3) in this paper.

However, two additional subsets of determinants in the same class have been widely tested in the literature: measures of complexity and indications on the filing route followed. The former set includes backward patent citations (indicating the existing market potential of the invention) and derived measures,[13] non patent citations (denoting the link of the invention to basic research (Carpenter et al., 1980; Narin et al., 1987)), the number of claims (supposedly informative on the legal breadth of the protection (Tong and Frame, 1994)), the number of IPC classes (a proxy for the technological scope or architectural nature of the invention (Lerner, 1994)), and the number of inventors listed in the application (indicating the research effort made to design the invention (Reitzig, 2004a,b)). All those complexity indicators are expected to be positively correlated with patent value and have proved so in some empirical studies. The latter set summarizes the path followed by each application to reach a given patent office and is considered in the present paper as fully part of its filing strategy discussed in section 2. The corresponding variables will therefore be included in our model as dimensions of filing strategies.

The second class of determinants represent the characteristics of a patent's ownership. This class first includes the structure of the ownership: the presence of multiple applicants introduced by Duguet and Iung (1997) denotes joint research efforts, and the cross-border ownership of patents (i.e. at least one inventor and one applicant residing in different countries) established by Guellec and van Pottelsberghe (2000) indicates an international organization of research. Both measures are expected to be associated with more valuable inventions and thus to be positively correlated with patent value. The second set of determinants in this class act as 'qualifiers' for the applicant and include different measures. One, the market size of the applicant (Lanjouw and Schankerman, 1997) has an ambiguous relationship with patent value (larger firms may produce higher quality research but may also be less discriminating in choosing which invention to patent or not). For the same reason, independent inventors (Gambardella et al., 2006) also have an unclear expected relationship with patent value. Two, academic patents (Harhoff et al., 2002) are thought to relate to more basic research, which is expected to produce higher value inventions. But universities do not necessarily choose which invention to make and to patent on the basis of its market potential, hence academic patents might be of a higher scientific value but of a lower market value, and the association between this academic nature of an applicant and patent value is therefore expected to depend on the indicator. Three, the inexperience of a patentee with the patent system (Allison et al., 2003) may be the sign of a highly valuable invention (valuable enough to convince a newcomer to enter the patent arena) or of a small invention that did not pass a careful screening prior to being patented. As a result, here again the expected relationship of this determinant with patent value is unclear. And four, the size of the applicant's patent portfolio (Shane, 2001) has also been included in many empirical models. On the one hand, the larger this number, the more experienced the applicant should be with the patent system and the most valuable his patents could be. On the other hand, very large portfolios may be a sign of patentees who have a very high propensity to patent, possibly inducing many applications of lower value to be filed. Therefore, the expected sign of the association between portfolio sizes and patent value is undetermined.

As a complement to the richness of the information available from patent databases, various dimensions of the inventing and managerial processes underlying a patent have been explored thanks to inventors surveys, providing some sort of 'insider information' on the context in which a

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[13] Czarnitzki et al. (2005) and Hall et al. (2005) observe that self backward patent citations (i.e. made to patents owned by the same individual or firm) are more valuable than citations coming from third-party patents, while Palomeras (2003) and Sapsalis and van Pottelsberghe (2007) obtain more nuanced results, except for self non-patent citations.

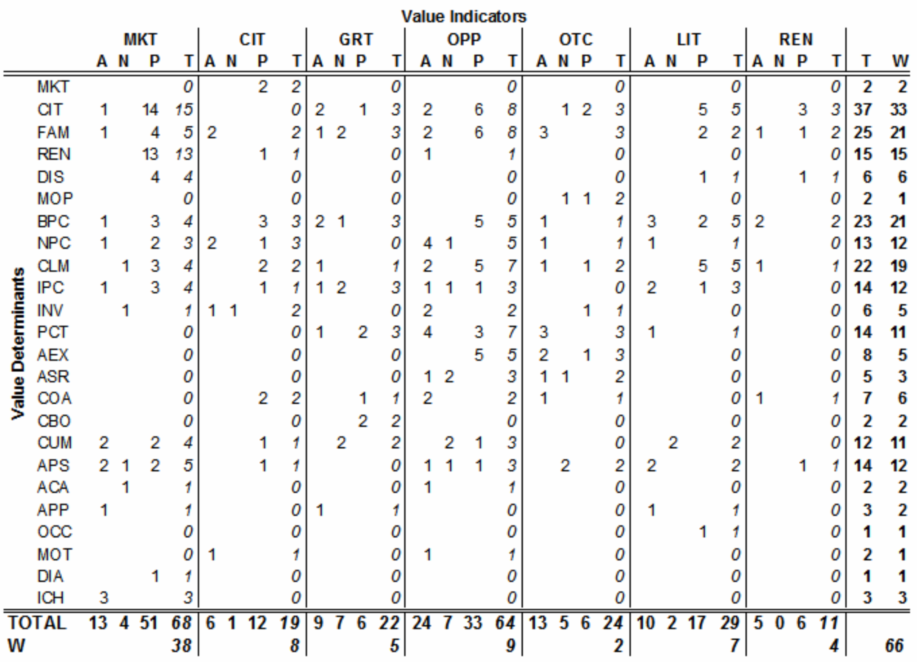
given invention was made and on the motivations to patent it. These variables make the third class of patent value determinants, which is more in an embryonic state so far. A large scale example of such surveys has been conducted in Europe a few years ago under the name PatVal, the authors of which gathered detailed information on about 9000 European patents and their underlying invention (Gambardella, 2005; Brusoni et al., 2006; Gambardella et al., 2006).[14]

Consistency across the empirical literature

The main results obtained by most contributing papers in the field are summarized in Table 5, which shows the number of empirical estimates in which each potential value determinant appeared associated with each potential indicator. At first sight, some areas appear obviously much more crowded than others. It first confirms that the most popular indicators used as dependent variables are market value indicators with 71 estimated parameters (at the patent or firm level), followed by oppositions and forward citations, with respectively 67 and 24 estimated parameters. This last variable is however the most frequently used determinant, followed by families, backward patent citations and claim counts, then renewals, IPC classes, PCT, the size of the applicant, non-patent references, and patent portfolio sizes.

A closer look at the table shows that many inconsistencies have burgeoned in the literature. Whereas renewals and forward citations have almost always been positively associated with patent value indicators, backward patent citations and even more so backward non-patent references, claims, and IPC classes – not to mention many less frequently tested measures – seem to have a much more ambiguous or instable relationship with the different value indicators. All these results and the notable inconsistencies that have appeared across the various settings and models tested in the literature call for a more comprehensive exercise conducted at the largest possible scale to investigate any potential indicator, geographical or industrial patterns in the observed correlations.

Table 5 – Empirical evidence on value indicators so far



Value Indicators

	MKT				CIT				GRT				OPP				OTC				LIT				REN					
Value Determinants	A	N	P	T	A	N	P	T	A	N	P	T	A	N	P	T	A	N	P	T	A	N	P	T	A	N	P	T	T	W
MKT				0			2	2				0				0				0				0				0	2	2
CIT	1		14	15				0	2		1	3	2		6	8		1	2	3			5	5			3	3	37	33
FAM	1		4	5	2			2	1	2		3	2		6	8	3			3			2	2	1		1	2	25	21
REN			13	13			1	1				0	1			1				0				0				0	15	15
DIS			4	4				0				0				0				0			1	1			1	1	6	6
MOP				0				0				0				0		1	1	2				0				0	2	1
BPC	1		3	4			3	3	2	1		3			5	5	1			1	3		2	5	2			2	23	21
NPC	1		2	3	2		1	3				0	4	1		5	1			1	1			1				0	13	12
CLM		1	3	4			2	2	1			1	2		5	7	1		1	2			5	5	1			1	22	19
IPC	1		3	4			1	1	1	2		3	1	1	1	3				0	2		1	3				0	14	12
INV		1		1	1	1		2				0	2			2			1	1				0				0	6	5
PCT				0				0	1		2	3	4		3	7	3			3	1			1				0	14	11
AEX				0				0				0			5	5	2		1	3				0				0	8	5
ASR				0				0				0	1	2		3	1	1		2				0				0	5	3
COA				0			2	2			1	1	2			2	1			1				0	1			1	7	6
CBO				0				0			2	2				0				0				0				0	2	2
CUM	2		2	4			1	1		2		2		2	1	3				0		2		2				0	12	11
APS	2	1	2	5			1	1				0	1	1	1	3		2		2	2			2			1	1	14	12
ACA		1		1				0				0	1			1				0				0				0	2	2
APP	1			1				0	1			1				0				0	1			1				0	3	2
OCC				0				0				0				0				0			1	1				0	1	1
MOT				0	1			1				0	1			1				0				0				0	2	1
DIA			1	1				0				0				0				0				0				0	1	1
ICH	3			3				0				0				0				0				0				0	3	3
TOTAL	**13**	**4**	**51**	**68**	**6**	**1**	**12**	**19**	**9**	**7**	**6**	**22**	**24**	**7**	**33**	**64**	**13**	**5**	**6**	**24**	**10**	**2**	**17**	**29**	**5**	**0**	**6**	**11**		
W				**38**				**8**				**5**				**9**				**2**				**7**				**4**		**66**

A: Ambiguous, N: Negative, P: Positive, T: Total, W: Distinct Works

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[14] Earlier examples in the US included Scherer (1965), Carpenter and Narin (1983), Narin et al. (1987), Albert et al. (1991), Cohen et all (2000), and Jaffe et al. (2000) and in Europe, Crépon et al. (1996), Duguet and Iung (1997), Harhoff et al. (1999, 2002, 2003), Scherer and Harhoff (2000), Scherer et al. (2000), Kleinknecht et al. (2002), Reitzig (2002, 2003), and Silverberg and Verspagen (2004).

Finally, one may notice that the dimensions of patent filing strategies discussed in section 2 have hardly (if at all) been accounted for in the existing literature, besides a few exceptions with filing routes. The next section precisely aims at testing the association between the filing strategy indicators presented in section 2 and different measures of patent value.

4. Empirical implementation

To analyze the association between filing strategies and patent value and to test the robustness of some classical variables as determinants of patent value, a specific dataset needed to be constructed from different sources: OECD (2004), PATSTAT (2006), Harhoff (2006) and different internal EPO databases. Due to data truncation and timeliness issues (the measurability horizon of most value indicators is about 10 years) this dataset is composed of all applications filed to the EPO between 1990 and 1995 that were granted by the Office no later than in January 2006. This makes a total of about 250,000 European patents.

The model to be estimated is an extension of the classical model represented by Equation 2:

$$V_i = f(FS_i, PC_i, PO_i, CV_i) \tag{3}$$

Where FS_i is the vector of variables characterizing the filing strategy adopted by patent *i*'s applicant and CV_i is a vector of dummy control variables. The endogenous and exogenous variables included in the model are described in what follows.

Dependent variables (value indicators)

Since our objective was to perform an econometric analysis at the patent level and on a full-scale basis, our dataset is limited to the information that can be found within patent databases, therefore excluding any market value as dependent variable. However, in order to obtain results that would be independent to the indicator chosen, a multi-indicator approach is preferred, in which the same model will be estimated with different indicators as dependent variables (*V*). Building on a companion paper (van Zeebroeck, 2007), five classical indicators are used in order to approximate patent value on the left-hand side of the models, which represent the four different types of patent-based value measures discussed in section 3: the number of forward citations received by each application within 5 years from its filing date (*CITE5*),[15] the number of EPC Contracting States in which the granted patent has been validated after grant (*EPCFM*),[16] whether the patent was still enforced in at least one EPC Contracting State 10 years after it had been filed (*SRV10*), whether the patent is a member of a triadic patent family (i.e. has been applied for or granted at the USPTO and JPO)[17] (*TRIAD*), and whether the granted patent has been opposed at the EPO (*OPPOS*). Note that the two former indicators are discrete variables and the three latter are binary. In addition, a sixth indicator (*COMPO*) is made of the composite value index ranging from 0 to 20 defined by van Zeebroeck (2007) according to Equation 4:

$$CV_i = \max\left\{ r\left[\max\left\{ \frac{SYI_i}{10} - 2; 0 \right\} + 2.TRI_i + C_i + 2.OPP_i + 3.REJ_i - 2.REV_i - 1 \right]; 0 \right\} \tag{4}$$

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[15] See Webb at al. (2005) for a detailed overview of the main issues with patent citations data.

[16] Using EPO databases for renewals, validation records with a lapse within the first year from the date of grant are discarded as they denote in fact lapses '*ab initio*' (see van Zeebroeck, 2007).

[17] See Dernis et al. (2001), Dernis and Khan (2003) and Webster et al. (2007)

Where CV_i is the composite value of application *i*, *r(x)* is a function that rounds its given parameter to the closest integer, SYI_i is the Scope-Year index (a composite measure of the geographical scope and term of maintenance defined in van Pottelsberghe and van Zeebroeck (2008)), TRI_i is a dummy variable equal to 1 if application *i* is a triadic one and 0 otherwise, OPP_i is a dummy variable taking value 1 if the application has been opposed and 0 otherwise, REJ_i is equal to 1 if the opposition was rejected or closed, and REV_i takes value 1 if the application was revoked as a result of the opposition procedure. Finally,

$$C_i = \begin{cases} (1+\ln(CITE5_i)) & \text{if } CITE5_i > 0 \\ 0 & \text{if } CITE5_i = 0 \end{cases} \tag{5}$$

By its definition, this indicator balances the five dimensions represented by the five indicators listed above. As such, this composite value indicator may be expected to provide a synthetic view of the aggregate effect of each explanatory variable in the model, should these effects differ from one indicator to the other.

Table 6 - Summary Statistics of Endogenous Variables

Variable	Obs.	Mean	St. Dev.	Min	Max	Model
TRIAD	248,856	0.66	0.47	0	1	Probit
SRV10	243,894	0.50	0.50	0	1	Probit
OPPOS	248,856	0.06	0.24	0	1	Probit
CITE5	248,856	0.56	1.19	0	46	Neg. Bin.
EPCFM	243,886	5.38	3.51	1	16	Poisson
COMPO	248,856	3.54	2.79	0	18	Neg. Bin.

Source: Own calculations based on EPO data – Granted patents filed 1990-1995

Summary statistics of these six dependent variables are provided in Table 6. It shows that about 66% of patents in the sample belong to a triadic family, 50% have been maintained for at least 10 years from their filing date, and 6% have been opposed. The average number of citations received within 5 years is about 0.5 with a minimum (and mode) of 0 and a maximum of 46, the number of EPC Contracting States in which patents in the sample were validated ranges from 1 to 16 with an average of over 5 countries,[18] and the average composite value in the sample is about 3.54, ranging from 0 to 18. The evolution of these six indicators over time is depicted in Figure 2. As discussed in van Zeebroeck (2007), most of the indicators have experienced some decrease in value between 1985 and 1995, with the exceptions of the number of citations and the rate of 10-year survival which have increased, and the share of triadic patents which has remained stable. Hall et al. (2001) nevertheless observe that the increase in the number of forward citations is probably influenced by systemic factors which may not be associated with any increase in value (essentially relating to changes in the nature and creation of citations), and van Zeebroeck (2007) points out that the increase in the rate of 10-years survival is tempered by a contraction in the geographical scope of protection and a dilatation of the grant lag.

The model described in Equation 3 will be regressed on each of these 6 value indicators, using probit regressions for dummy variables and maximum likelihood estimations for discrete ones, with a Poisson specification for *EPCFM* and a negative binomial distribution for citation counts and the composite index.

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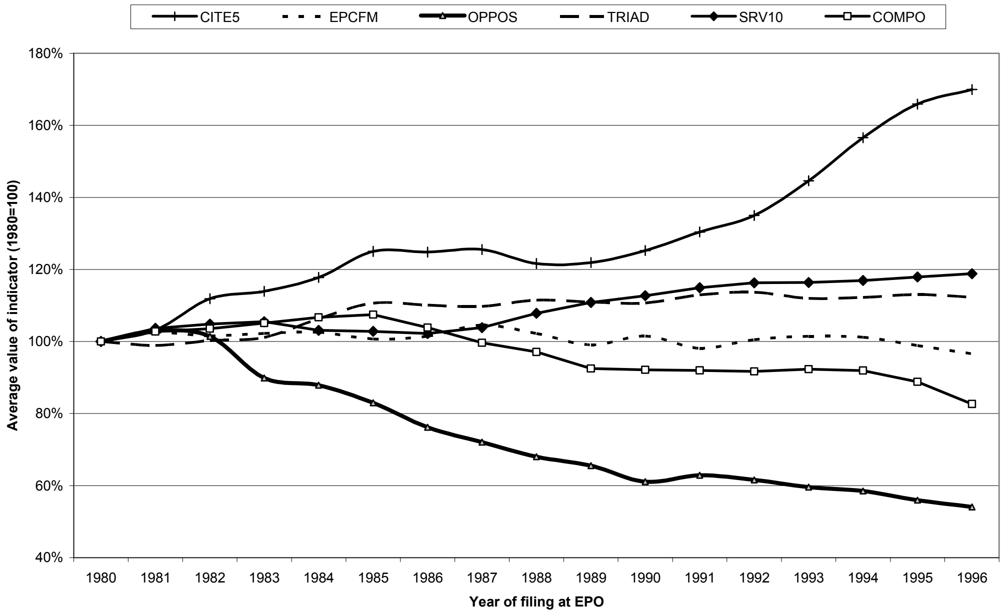
[18] Note that data on validations and renewals at the Italian Patent Office are excluded due to data unavailability.

Figure 2 - Evolution of Patent Value Indicators 1980-1995



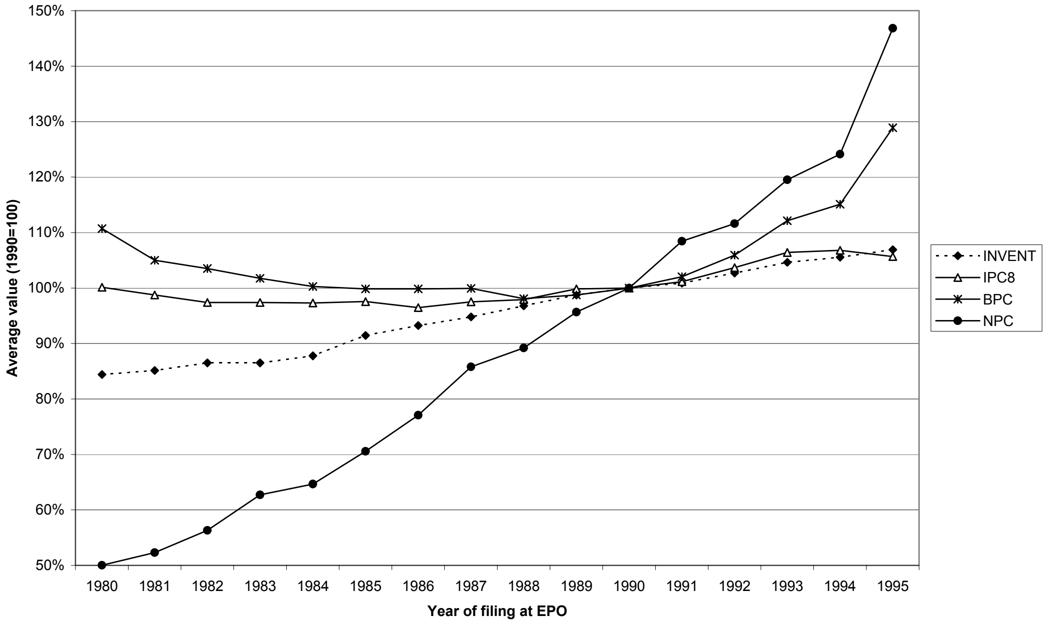
Sample: All applications filed at EPO in the period 1980-1995

<u>*Explanatory variables (value determinants)*</u>

The present model extends the classical one in the sense that it adds to Equation 3 the indicators of filing strategies introduced in section 2, representing filing routes and drafting styles. However, as compared with Equation 3, the present model excludes any insider information (*II*) due to the size of the dataset used, and uses the first four sets of patent characteristics only on the left-hand side of the equation as indicators of patent value. This leaves only measures of complexity from the class of patent characteristics, and the different measures of patent ownership (structure and profile). To complete the model, three sets of binary control variables will allow to account for potential industry, country and time effects. Descriptive statistics for the complexity, ownership, and control variables are provided in Table A2 in the appendix.

The complexity measures (*PC*) included in the model include four variables: the number of inventors listed in the application (*INVENT*), ranging from 1 to 32 with an average of 2.4 inventors; the number of IPC classes at 8 digits associated with the patent (*IPC8*), a number ranging from 1 to 43 with an average of about 2 classes per patent; the number of references made by each patent to earlier patent documents (*BPC*), ranging from 0 to 99 with about 4.5 backward citations on average, and the number of references made by each patent to non patent documents such as scientific papers (*NPC*), which has a maximum of 61 and an average of about 1 non patent citation per patent. The evolution of these four complexity measures is depicted in Figure 3. It shows that most complexity indicators have increased in the period 1980-1995, especially the number of patent and non patent references to the existing state of the art. This may reveal that inventions are becoming more incremental or architectural nowadays – an intuition which is supported by the concomitant but slower increase in the number of IPC classes and inventors – but may also be driven by systemic factors such as better electronic documentation and search techniques allowing examiners to more easily find relevant pieces of the prior art. As reviewed in section 3, the theoretical foundations of these four variables suggest that they should be positively associated with patent value, but the numerous empirical models found in the literature have produced many ambiguous results. The present implementation, conducted over a large sample and with 6 different value indicators, will allow sensitivity tests to the indicator and the sample to be performed.

Figure 3 - Evolution of the complexity of patent applications



The ownership characteristics (*PO*) included in the present model account for most determinants in this class: *CUMUL* gives the total number of applications filed to the EPO by the same applicant in the same year and the five previous years (in addition to the application being considered), providing an overview of the cumulative portfolio size of the applicant (van Zeebroeck et al., 2006a), which represents on average about 410 EPO applications with a maximum of 4832. *OCCAS* is a dummy variable taking value 1 if the cumulative portfolio size (*CUMUL*) is 0 (in which case the application being considered is the first one applied by the same applicant over the past 5 years) and 0 otherwise. This variable therefore identifies those filings made by inexperienced patentees, which was the case for about 21% of the patents in the sample. *ACAD* is a dummy variable identifying patent applications originating from academic institutions and public research centres, which represents about 2% of all patents in the sample.[19] Finally, *CBOWN* is a dummy variable identifying patents with at least one applicant residing in another country than the country of one inventor, also known as cross-border ownership (Guellec and van Pottelsberghe, 2000). This is the case with about 1 patent out of 10 in the sample and should be related with higher value patents as they denote an international organization of research activities.

To complete the model and account for potential industry, country, or time effects, three sets of dummy variables have been constructed as control variables (*CV*): 14 dummy variables represent the 14 Joint Clusters representing different technological areas at the EPO (Archontopoulos et al., 2007), 19 country dummies identify the country of residence of the applicants, and 6 year dummies represent the year of filing of each patent at the EPO (ranging 1990 to 1995). The three sectors with the largest number of patents granted from the sample are 'handling and processing', 'organic chemistry' and 'industrial chemistry', with 14, 13 and 12% of the patents respectively, and the 3 largest countries of residence of applicants represent about 70% of the sample (the US, 26%; Japan, 22%; and Germany, 20%). With about 9% of the sample, France is clearly lagged by the three largest countries, but well before the UK (5%), the Netherlands and Switzerland (4% each), and Italy (3%). Note that the sample is well balanced over the period considered as 16 to 17% of the patents had been filed in each of the 6 years in the period.

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[19] This variable has been created based on the presence of the roots of the words "*University*", "*Institute*" and "*Centre*" in the name of the applicant. It is therefore largely imperfect and should be interpreted with care.

5. Empirical results

The main results of the six model estimations are provided in Table 7. The first observation to be made is that most parameters are significant and positive, evidencing that patent filing strategies are positively correlated with patent value. Generally speaking, the log-deviation in claims (*CLMDEV*), the number of priorities (*PRIO*), the parents of divisionals (*HASDIV*), and the PCT route (*PCT*) are associated with the most significant parameters across all indicators. Nonetheless, some discrepancies appear across indicators that are worth being emphasized.

Filing strategies

According to most papers, the number of claims is positively associated with patent value, although it has been reported as non significant or at least ambiguous in a few papers[20] and even negative in one.[21] Consistently with most the literature, the log-deviation in claims is associated with a significant and positive coefficient on all six value indicators. But whereas it is among the 2 or 3 most significant parameters of the model in five cases out of six (especially with the number of citations and the composite indicator), it appears relatively less significant with the likelihood to be opposed. It sounds therefore logical that the share of claims abandoned in the course of the examination has a detrimental effect on patent value, except that it does not reduce anyhow the likelihood to be opposed. With other words, the number of claims seems strongly related with patent value. Patents with excess claims are associated with more citations (arguably because the scope of the patent is then larger and hence increases the probability that future applications will overlap with it), tend to be applied for in more countries within and outside the EPC, and tend to live longer. However, claims have much smaller an effect on oppositions. This result may arguably be seen as surprising since the main objective of oppositions is to reduce or destroy the legal scope of protection provided by a patent, which is made of the claims. In a nutshell, this result suggests that opponents target the substance defined by the independent claims rather than the subtleties such as fall back positions (mostly made of dependent claims) of a patent.

The two constructionism variables differ in significance but not in sign across indicators. Their correlation with patent value is positive in most cases but insignificant with some indicators. The number of priorities is associated with a particularly strong positive coefficient for citations, triadicness and composite value, but – consistently with the claims – has no effect on oppositions. Conversely, the number of equivalents is associated with a positive coefficient on all indicators, including oppositions, but except on the number of citations. The interpretation of these results is not straightforward.

A patent linked to a larger number of priorities can be seen as an aggregate of several domestic first filings. If one assumes that its scope may therefore be larger than the standard application, it might explain why they tend to receive more citations from subsequent applications. This extra substance embedded into the patent may also explain why it tends to be validated in more countries in and outside Europe and why it seems more likely to be still active after 10 years. However, that such patents are not more likely to be opposed suggests that their complex construction does not increase the probability that a third party will find them embarrassing enough to incur the costs and risks associated with filing an opposition. Should this reasoning be true, there would be no reason to believe that patents with sibling (equivalent) EP filings should receive more citations, hence the non significance of the parameter on the number of citations might have been expected. But their belonging to a kind of bundle of filings aimed at protecting a same core invention shows that the applicant found the invention important enough to opt for this costly construction strategy. It would

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[20] Lanjouw and Schankerman, 1999; Graham et al., 2002; Schneider, 2006; Calderini and Scellato, 2004; Wagner, 2004.

[21] Palomeras, 2003.

then seem consistent that the applicant extends its patent to more countries and maintain it for longer as is suggested by the econometric results. In particular, this strategy is strongly associated with triadic patents. The higher likelihood for such patents to be opposed may reveal that at least some of the patents in the family are expanding the scope of protection in such a way that third parties are more likely to find one of the members embarrassing.

Table 7 – Econometric estimates for the 6 indicators of patent value

	5yrs Citations		EPC Family		Triadic		Survived 10yrs		Opposed		Composite	
Variables	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z	Coef.	z
Patent Filing Strategies												
ln(CLMDEV)	0,29	45,64 (**)	0,03	19,18 (**)	0,10	20,79 (**)	0,07	17,33 (**)	0,03	4,47 (**)	0,10	39,77 (**)
CLMLS	-0,02	-7,00 (**)	-0,01	-12,73 (**)	-0,03	-8,49 (**)	-0,01	-2,36 (*)	0,01	1,66	-0,01	-9,97 (**)
PRIO	0,10	20,63 (**)	0,01	6,38 (**)	0,20	34,70 (**)	0,03	7,01 (**)	0,00	0,85	0,03	17,54 (**)
EQUIV	0,01	1,25	0,01	3,13 (**)	0,12	15,63 (**)	0,04	6,19 (**)	0,04	5,52 (**)	0,02	7,32 (**)
HASDIV	0,23	13,68 (**)	0,12	27,62 (**)	0,20	11,39 (**)	0,33	22,93 (**)	0,30	15,61 (**)	0,20	27,34 (**)
ISDIV	-0,28	-10,20 (**)	0,03	5,38 (**)	0,45	19,20 (**)	0,44	23,69 (**)	0,11	3,73 (**)	0,12	11,35 (**)
PCT	0,09	9,59 (**)	0,09	44,08 (**)	0,28	39,40 (**)	0,07	11,46 (**)	0,01	0,70	0,14	37,44 (**)
ACCSRC	0,07	2,46 (*)	0,04	5,18 (**)	0,07	3,00 (**)	0,17	7,97 (**)	0,12	3,61 (**)	0,06	5,23 (**)
Applicant Profiles												
CUMUL	0,01	1,23	-0,05	-37,40 (**)	0,13	35,13 (**)	0,02	6,70 (**)	-0,11	-17,72 (**)	-0,02	-8,55 (**)
OCCAS	-0,06	-5,73 (**)	0,04	16,55 (**)	-0,39	-53,23 (**)	-0,13	-18,63 (**)	0,08	7,90 (**)	-0,07	-16,28 (**)
ACAD	0,08	3,24 (**)	0,00	0,34	-0,13	-5,63 (**)	-0,05	-2,31 (*)	-0,11	-3,40 (**)	-0,01	-1,28
CBOWN	0,06	4,46 (**)	0,03	10,30 (**)	-0,05	-5,43 (**)	0,01	1,28	0,10	6,87 (**)	0,03	5,92 (**)
Technical Complexity												
INVENT	0,06	26,17 (**)	0,01	15,49 (**)	0,05	22,75 (**)	0,02	13,18 (**)	0,01	4,84 (**)	0,02	26,43 (**)
IPC8	0,12	42,25 (**)	0,01	20,60 (**)	0,03	13,10 (**)	0,02	7,21 (**)	-0,01	-2,93 (**)	0,03	29,00 (**)
BPC	0,03	24,16 (**)	0,00	-6,31 (**)	-0,01	-11,31 (**)	0,00	3,98 (**)	0,04	26,58 (**)	0,01	10,73 (**)
NPC	0,01	6,03 (**)	0,00	2,61 (**)	0,03	14,11 (**)	0,03	15,99 (**)	0,03	12,37 (**)	0,01	10,98 (**)
EPO Joint Clusters (Reference = Industrial Chemistry)												
JC-02 - Organic Chemistry	0,18	14,24 (**)	0,27	89,39 (**)	0,22	19,86 (**)	0,15	14,81 (**)	0,04	2,51 (*)	0,26	48,67 (**)
JC-03 - Polymers	0,26	21,40 (**)	0,07	24,76 (**)	0,14	12,99 (**)	0,12	13,54 (**)	0,19	14,35 (**)	0,15	30,06 (**)
JC-04 - Biotechnology	0,49	35,92 (**)	0,27	85,42 (**)	0,07	5,86 (**)	0,31	29,05 (**)	0,03	1,85	0,29	51,36 (**)
JC-05 - Telecommunications	0,58	29,47 (**)	-0,02	-4,44 (**)	-0,10	-5,55 (**)	0,31	19,38 (**)	-0,28	-8,85 (**)	0,13	14,52 (**)
JC-06 - Audio/Video/Media	0,21	11,78 (**)	-0,17	-33,52 (**)	0,21	13,30 (**)	0,26	19,90 (**)	-0,23	-9,34 (**)	-0,03	-4,10 (**)
JC-07 - Electronics	-0,03	-2,28 (*)	-0,14	-36,22 (**)	0,09	7,63 (**)	0,14	13,91 (**)	-0,17	-9,08 (**)	-0,07	-11,91 (**)
JC-08 - Electricity	-0,16	-11,36 (**)	-0,14	-42,14 (**)	-0,03	-2,46 (*)	-0,06	-6,75 (**)	-0,14	-8,56 (**)	-0,14	-25,03 (**)
JC-09 - Computers	0,16	7,46 (**)	-0,17	-28,58 (**)	-0,04	-2,14 (*)	0,16	10,67 (**)	-0,15	-5,21 (**)	-0,09	-10,26 (**)
JC-10 - Measuring Optics	-0,24	-16,61 (**)	-0,20	-56,73 (**)	0,07	6,12 (**)	-0,03	-2,69 (**)	-0,24	-13,84 (**)	-0,16	-28,52 (**)
JC-11 - Handling & Processing	-0,34	-25,16 (**)	0,00	1,26	-0,12	-12,45 (**)	-0,08	-9,08 (**)	0,03	2,32 (*)	-0,06	-12,12 (**)
JC-12 - Vehicles	-0,27	-17,81 (**)	-0,16	-45,75 (**)	-0,17	-17,15 (**)	-0,07	-7,30 (**)	-0,13	-8,24 (**)	-0,25	-42,33 (**)
JC-13 - Civil Engineering	-0,38	-22,88 (**)	-0,07	-18,47 (**)	-0,37	-34,13 (**)	-0,18	-17,63 (**)	-0,05	-2,91 (**)	-0,21	-33,41 (**)
JC-14 - Human Necessities	0,12	9,49 (**)	-0,01	-2,38 (*)	-0,11	-11,35 (**)	0,03	2,92 (**)	0,00	0,33	0,01	1,54
Country of residence of applicants (Reference = France)												
AT	-0,06	-1,34	0,06	7,25 (**)	-0,33	-12,11 (**)	0,03	1,18	0,10	2,49 (*)	0,04	2,50 (*)
AU	0,15	2,78 (**)	-0,09	-6,85 (**)	0,31	7,68 (**)	0,50	12,61 (**)	-0,30	-4,71 (**)	0,00	0,05
BE	0,12	2,91 (**)	0,00	-0,43	0,18	6,36 (**)	0,30	10,66 (**)	-0,02	-0,45	0,09	5,82 (**)
CA	0,28	7,15 (**)	-0,15	-15,68 (**)	0,26	8,48 (**)	0,38	12,74 (**)	-0,16	-3,24 (**)	-0,02	-0,91
CH	0,10	3,85 (**)	0,10	21,06 (**)	0,31	18,26 (**)	0,34	20,82 (**)	0,03	1,17	0,25	27,44 (**)
DE	0,02	1,35	0,03	10,53 (**)	-0,25	-23,92 (**)	0,16	15,10 (**)	0,17	10,69 (**)	0,05	7,92 (**)
DK	0,22	4,65 (**)	0,02	1,66	-0,11	-3,14 (**)	0,39	11,56 (**)	0,22	4,77 (**)	0,09	4,83 (**)
ES	-0,30	-3,63 (**)	0,07	4,86 (**)	-0,23	-4,79 (**)	0,35	7,78 (**)	-0,14	-1,91	-0,03	-1,20
FI	0,33	8,19 (**)	0,01	0,75	0,13	4,38 (**)	0,60	20,46 (**)	0,16	3,72 (**)	0,20	12,28 (**)
GB	0,22	10,65 (**)	-0,08	-17,56 (**)	0,10	6,53 (**)	0,20	13,72 (**)	0,04	1,83	-0,02	-2,34 (*)
IL	0,39	5,93 (**)	-0,05	-3,25 (**)	0,21	4,08 (**)	0,30	5,77 (**)	-0,02	-0,31	0,05	1,69
IT	-0,05	-1,82	0,02	3,21 (**)	-0,19	-11,02 (**)	0,46	27,30 (**)	-0,03	-1,24	-0,06	-5,51 (**)
JP	0,17	10,48 (**)	-0,46	-123,43 (**)	1,07	89,36 (**)	0,44	40,97 (**)	-0,24	-13,46 (**)	-0,10	-16,27 (**)
KR	-0,11	-1,54	-0,41	-22,38 (**)	0,57	11,50 (**)	0,51	11,11 (**)	-0,21	-2,48 (*)	-0,20	-7,11 (**)
NL	0,08	3,49 (**)	0,01	1,36	0,17	10,04 (**)	0,42	26,02 (**)	0,22	9,25 (**)	0,12	12,63 (**)
SE	0,16	5,19 (**)	-0,03	-4,14 (**)	0,51	23,06 (**)	0,51	24,15 (**)	0,12	3,70 (**)	0,16	13,13 (**)
US	0,40	26,73 (**)	-0,16	-48,94 (**)	0,58	53,09 (**)	0,46	43,61 (**)	-0,10	-6,40 (**)	0,05	8,45 (**)
RoW	0,02	0,63	-0,01	-1,37	0,10	4,59 (**)	0,19	8,42 (**)	-0,22	-5,93 (**)	0,00	0,09
Time dummies (Reference = 1990)												
1991	0,04	3,15 (**)	-0,03	-10,18 (**)	-0,02	-1,92	0,02	1,99 (*)	0,01	0,51	-0,03	-6,55 (**)
1992	0,09	6,86 (**)	-0,02	-6,65 (**)	-0,02	-1,85	0,04	4,32 (**)	-0,02	-1,25	-0,06	-10,74 (**)
1993	0,15	11,38 (**)	-0,03	-8,42 (**)	-0,06	-6,34 (**)	0,01	1,39	-0,06	-4,10 (**)	-0,09	-16,83 (**)
1994	0,21	15,81 (**)	-0,04	-11,87 (**)	-0,08	-7,48 (**)	0,00	0,00	-0,08	-5,39 (**)	-0,10	-18,55 (**)
1995	0,22	16,15 (**)	-0,07	-21,82 (**)	-0,07	-7,15 (**)	-0,02	-1,91	-0,13	-8,91 (**)	-0,13	-24,64 (**)
Model												
# Observations	242048		239528		242048		239536		242048		242048	
Pseudo R²	0,05		0,10		0,20		0,05		0,04		0,04	
Log likelihood	-229590		-584809		-124665		-157567		-52387		-539708	
LR chi² (P>chi²)	25606,3 (0,00)		124439,48 (0,00)		61 020 (0,00)		16 911 (0,00)		4 681 (0,00)		40122 (0,00)	
LR Test of alpha=0 (P>chibar²)	42000 (0,00)										51000 (0,00)	

Source: Own calculations based on EPO data – Patents filed 1990-1995
Coefficients significant at the 5% probability level (*) or at the 1% probability level (**)

The dummy variables identifying divisional strategies provide very interesting results as well. The *HASDIV* variable is one of the very few variables associated with a highly significant positive coefficient with all 6 indicators. That is, parents of divisional filings are significantly associated with more important patents, no matter the way value is measured: they are more likely to receive citations, to be validated in more countries, to be applied in the trilateral offices, to be maintained 10 years at least and to be opposed. However, the *ISDIV* variable, identifying divisional filings themselves, presents similar results though with smaller significativity levels on oppositions and families and a negative coefficient on citations received. That they tend to survive longer may be a mere consequence of a longer application and examination process. It is in the very nature of divisionals to be associated with longer pendency times as discussed here above; hence the likelihood for them to be still active at the end of their tenth year from filing is systematically higher. Similarly, if the parents are triadic, than the children will necessarily be considered triadic as well since triadic families are built on priority numbers. But the fact that they are less significantly associated with large EPC families and high opposition rates than their parents, and more importantly their negative coefficient on citations received suggest that most value of divisional applications remains within the original application. This could explain why the parents are more likely to be cited, opposed, and validated in more countries. With other words, it is likely that applicants making use of divisionals tend to keep the core or essence of their invention defined in the root application and spread surrounding inventions or secure fall back positions into divisionals.

Confirming a well known result, the PCT option is also associated with higher value. The *PCT* variable is particularly well performing in predicting the size of the family or the likelihood to be triadic, which is in both cases a highly expected result given the very objective of the Patent Cooperation Treaty to simplify the extension of domestic patents abroad. It is therefore no surprise at all that patent applications filed in the three major offices (JPO, USPTO and EPO) or extended in many European Countries, given their international promise, were filed through the PCT route. PCT filings being associated in addition with more forward citations and a higher likelihood to be maintained for ten years confirms earlier evidences that the PCT route drives more valuable patent applications (Guellec and van Pottelsberghe, 2000, 2002; Graham et al., 2002; Reitzig, 2004a). Nonetheless, these results are counterbalanced by the fact that the *PCT* variable has no effect on the likelihood to receive an opposition, which is consistent with Harhoff and Hall (2002), Harhoff and Reitzig (2004), Reitzig (2004b) and Wagner (2004).

Finally, the request for accelerated search is associated with a positive and significant coefficient with all 6 indicators. This result is in contradiction with earlier empirical evidence (Graham et al., 2002; Jerak and Wagner, 2003; Reitzig, 2004a), though the *ACCSRC* variable had only been tested as a determinant of oppositions. However, the same authors as well as Harhoff and Hall (2002) found positive and significant coefficients for accelerated *examination* requests. Our results support the idea that the strategy consisting in getting the patent granted faster is also associated with patents of higher value and that this effect prevails.

Complexity

The set of variables expressing the technical complexity of patents are also associated with many significant coefficients. Most of them are consistent with the literature. The number of inventors is associated with strong positive coefficients on all indicators (in line with Reitzig, 2004b), as is the case for non patent references (in line with Carpenter et al. (1980) and Narin et al. (1987), but in contradiction with Reitzig (2004b) who obtained a negative coefficient, and Allison and Lemley (1998), Harhoff and Hall (2002), Harhoff et al. (2002), Harhoff and Reitzig (2004), and Wagner (2004) who all obtained non-significant correlations).

The number of IPC classes (a measure of the technological scope according to Lerner (1994)) gets similar coefficients, except it is associated with a slightly smaller probability for the patent to be opposed. The same variable was associated with a negative coefficient in Guellec and van Pottelsberghe (2000, 2002) as well as Harhoff and Reitzig (2004), and a non significant or ambiguous parameter in Lanjouw and Schankerman (1997, 2001), Harhoff et al. (2002), Reitzig (2004a) and Schneider (2006). One of the most frequently tested determinant, backward patent citations have been found positively correlated in 13 empirical pieces of research listed in Table A1 in the appendix and 9 times non significant, but negative in only one case, on the probability for a patent to get granted (Schneider, 2006). In the present estimations, backward patent citations counts are associated with more citations and a higher likelihood to be maintained 10 years or opposed, but also with smaller EP families and a smaller likelihood to be triadic, making it one of the most instable variables across indicators.

Patent ownership

The three variables identifying different types of applicants bring some additional light on these results. Two preliminary observations may be made when looking at the *CUMUL* and *OCCAS* variables, expressing the experience or lack of experience of applicants in terms of their cumulative portfolio of patent applications at the EPO: first that the sign of their coefficient varies widely from indicator to indicator, and second that they are usually in opposition with each other: the coefficient of these two variables (*CUMUL* and *OCCAS* respectively) is non significant vs. negative on citations, negative vs. positive on EPC family size and opposition likelihood, then positive vs. negative on likelihood to be triadic and maintained for 10 years. These puzzling results – in line with the literature – may be interpreted as follows.[22] As compared to large applicants, inexperienced patentees are less likely to get their patents cited, to build triadic patent families and to maintain their patents for 10 years or more, but they tend to validate their patents in more European countries and are more likely to see their patents opposed.[23] To the contrary, academic patents are associated with slightly more forward citations, but slightly lower probabilities to be triadic, maintained for 10 years or opposed.[24] Finally, the dummy variable identifying cross-border applications (*CBOWN*) is associated with more citations, larger EPC families and more frequent oppositions, but also with a smaller likelihood to be triadic and no particular survival rates.[25]

Country and industry effects

When looking at country and industry dummies, the most striking observation is that there seem to be very significant geographical and industrial effects, and that the coefficients are highly variable from one indicator to the other – even more so with countries than industrial sectors. In terms of industries, the most significant parameters are to be found with the chemical and biotechnology clusters. The coefficients associated with the respective dummy variables are always positive and highly significant, except with biotechnologies having no effect on oppositions. In particular, organic chemistry and biotechs are associated with the most significant variables of the model in explaining the European family size, that is patent families seem significantly larger in these clusters than in others. The roots of this result are probably to be found in market structures, competitive processes and the importance of R&D in these sectors.

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[22] The portfolio size has been found 2 times non significant, 4 times positive and 6 times negative on 5 different indicators throughout the literature listed in Table A1 in the appendix.

[23] Allison et al. (2003) found a positive correlation of a similar measure of inexperience with a probability of litigation.

[24] Gambardella et al. (2006) found a negative correlation of academic patentees with the surveyed monetary value of patents and Harhoff and Hall (2002) found no effect of the same variable on the probability of opposition.

[25] Guellec and van Pottelsberghe (2000, 2002) found the same variable positively correlated with the probability to get granted.

Four sectors seem to be characterized by more forward citations on average: organic chemistry, polymers, biotechnologies and telecommunications, which may be due to inventions being more frequently incremental in these areas (hence patent applications are more frequently or more intensively relying on the state of the art), or to the state of the art being more easily identifiable in these fields, possibly thanks to a higher degree of codification and standardization in the description of inventions. Triadic families and oppositions also look more frequent in pretty much the same areas, but patents are also more frequently triadic in the multimedia industry. The industries experiencing the longest survival rates are biotechnologies, multimedia and telecommunications, and oppositions look also more frequent in the automotive industry, an industry otherwise associated with lower value patents. At the lower end of the ranking, handling and processing, automotive, civil engineering, electricity and measuring optics sectors are associated with significant negative coefficients on almost all indicators, especially citations, triadic and survival rates. In particular, the measuring optics cluster is associated with the smallest family sizes and lowest opposition rates.

These large discrepancies across industries are also observable across countries of applicants, but indicator to indicator variations are even more perceptible. The most remarkable countries are also the largest patent filers at the EPO: the United States, Japan and Germany, all with very striking fluctuations across indicators. Japanese and US patents are logically the most triadic ones (for two-thirds the way to a triadic family is done when a Japanese or US patent is filed at the EPO) along with patents from Nordic European countries. US and Japanese patents are also the most frequently cited (along with British ones) and experience the highest survival rates (together with Italian ones). But they are associated with the smallest EPC families and the lowest opposition rates. This might suggest that patents from Japan or the US extended to and granted by the EPO are of higher value on average, but that patentees from these two countries are more selective in choosing the States where they would like their inventions to be protected (supposedly they target the most relevant European countries to their business, usually the three largest according to van Pottelsberghe and van Zeebroeck (2008)) and produce patents that are less likely to be opposed. This might be an indication of lower value, but it may also very well be that having successfully passed the granting process in one or two major triadic offices and having crossed at least one ocean to reach the EPO, these patents are more robust and less likely to be successfully challenged in oppositions. Conversely, German patents are characterized on average by the largest EPC families (along with their Austrian and Swiss counterparts) and exposed to the highest risk of being opposed (together with Danish and Dutch patents), but they are the least likely to be triadic and among the least cited.

It is very likely that these discrepancies across countries are to a large extent related with home disadvantage biases. Being a European applicant, one is more likely to file a patent at the EPO as this is the first natural step for any European patentee willing to seek protection beyond one's domestic borders.[26] But since a European applicant could be less selective in which patents to extend to the EPO, the average value of his EPO filings might be lower than that of Japanese or US applicants who had to make a more difficult decision to cross the ocean or not and were then probably more selective.

In addition to these results, it may be observed that coefficients associated with time dummies suggest a negative trend with all indicators (hereby suggesting a significant decline in patent value over the period 1990-1995) except with the number of forward citations received which seems to have continuously increased over the same period. This is consistent with conjectures on a declining trend in patent quality made by Jaffe and Lerner (2004) and Guellec and van Pottelsberghe (2007),

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[26] This is the classical argument of the well-known home advantage bias (van Zeebroeck et al., 2006b).

as well as with statistical evidence reported by van Zeebroeck (2007) and van Pottelsberghe and van Zeebroeck (2008).

Finally, note that the regression on the composite value indicator provides excellent aggregate effects that may be used to summarize the correlation of each explanatory variable with the different indicators of patent value into one aggregate coefficient. Therefore, in the remaining of this section, we will focus on regression coefficients on the composite value indicator.

On the consistency of the results

For the sake of robustness, several additional specifications of the model have been tested, which confirm the robustness of our specification.[27] In addition, it appeared highly valuable to check for a sensitivity of the results to the sample used in the regression, (i.e. to investigate potential country or industry specific effects). To do so, the main model presented in Table 7 has been run for each of the six value indicators on 14 industry samples and 18 country samples. For each indicator, the number of times each explanatory variable got a positive (+), negative (-), or non-significant (/) estimated coefficient was then computed and reported in Table A3 for the 14 industry regressions and Table A4 for the 18 country regressions. Both tables are found in the appendix.

By looking at each indicator in isolation (in Table A3), one can easily assess the stability of the explanatory power of each variable on the value indicator considered. When explaining the number of citations received, five parameters appear as perfectly stable (and positive): *CLMDEV*, *PRIO*, *INVENT*, *IPC8*, and *BPC*. A few additional variables are fairly stable but lost their significance in a few (less than half of) sectors: *CLMLS* (-), *HASDIV* (+), *ISDIV* (-), *PCT* (+), *NPC* (+). The latter variable, *NPC*, even turned significantly negative in one case (polymers). Finally, some variables loose their significance in a majority of industries: *ACCSRC* (+), *OCCAS* (-), *ACAD* (+), and *CBOWN* (+). With EPC family sizes as the dependent variable, only parents of divisionals (*HASDIV*) and the PCT route are perfectly stable (and positively significant). *CLMDEV* (+), *CLMLS* (-), *IPC8* (+) and *OCCAS* (+) lost their significance in 2 or 3 sectors, whereas the latter variable even turned negative in 2 cases. All other variables appear much less stable.

The results of the triadic estimations look slightly more stable than with the two previous indicators: *CLMDEV* (+), *PRIO* (+), *EQUIV* (+), *ISDIV* (+), *PCT* (+), *CUMUL* (+), and *OCCAS* (-) are close to perfectly insensitive to the industrial sector chosen. *HASDIV* (+), *INVENT* (+), *BPC* (-), and *NPC* (+) kept the significativity and sign of their coefficient across 11 or 12 industries out of 14. The stability of the estimates across sectors differs again slightly when the dependent variable is the likelihood to be maintained 10 years. Indeed, only six variables were associated with fairly to perfectly stable coefficients: *CLMDEV* (+), *HASDIV* (+), *ISDIV* (+), *OCCAS* (-), *INVENT* (+), and *NPC* (+). The most sensitive results were obtained with the opposition regression, where only the number of backward patent references (*BPC)* kept a significant and positive sign throughout the industries. To a lesser extent, *HASDIV* (+), *CUMUL* (-), and *OCCAS* (+) are associated with fairly stable coefficients. All other variables lost their significance entirely in a majority of the sectors.

When looking at the overall stability as measured with the regression on the composite value, six variables appear (almost) perfectly stable (and all significantly positive): *CLMDEV*, *PRIO*, *HASDIV*, *PCT*, *INVENT*, *IPC8*. Four additional ones kept their sign across industries but sometimes lost their significativity level: *CLMLS* (-), *EQUIV* (+), *ISDIV* (+), and *CUMUL* (-). All other variables either lost their significativity in a majority of the cases, or changed in sign in some industries.

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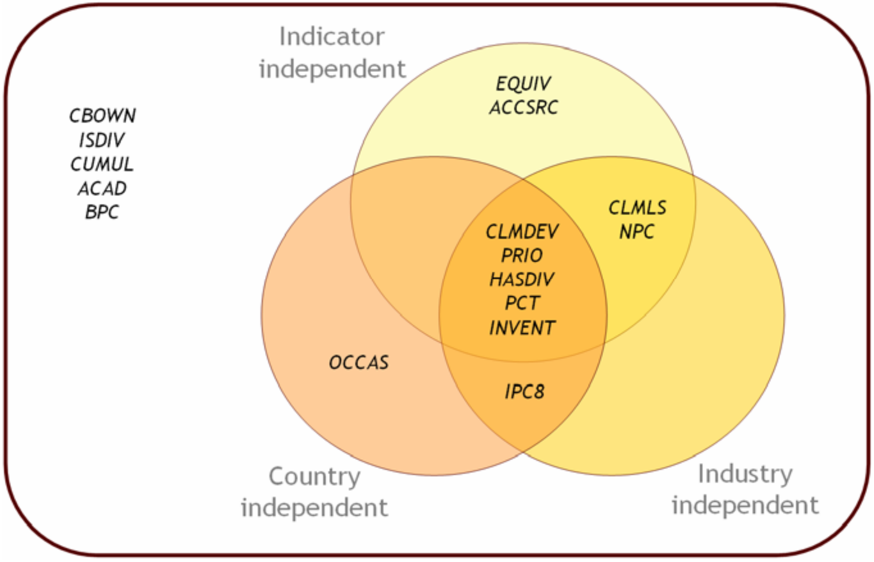
[27] The results of these robustness estimates are available upon request.

The same exercise conducted with 18 country-per-country regressions for each indicator (reporter in Table A4) leads to a similar conclusions of high dependence of many determinants to the sample chosen. With the number of forward citations received as a dependent variable, only four variables preserved their significativity and positive sign in at least two-third of the countries: *CLMDEV*, *INVENT*, *IPC8*, and *BPC*. Although less stable, *PRIO* and *HASDIV* both remained significant and positive in a small majority of the cases. When the EPC family size is regressed, the sensibility to the country is even stronger, with only three variables (*HASDIV* (+), *PCT* (+) and *CUMUL* (-)) constant in sign and significativity in a majority of the estimations. Here again, the results are much better when the dependent variable is the triadic nature of patents. Seven variables are here strongly stable: *CLMDEV*, *PRIO*, *EQUIV*, *ISDIV*, *PCT*, *CUMUL* and *OCCAS*, the latter being the only one associated with a negative coefficient. With the likelihood to survive 10 years, the sensibility to the sample rises again with four variables only being stable in a small majority of the cases: *HASDIV* (+), *ISDIV* (+), *OCCAS* (-), and *NPC* (+). The results are no better with the opposition regression as *HASDIV* (+), *CUMUL* (-), BPC (+), and *NPC* (+) are the only variables to be stable in a majority of the regressions. These high sensibilities translate with the composite value indicator regressions into a very small set of robust (and positive) coefficients: *CLMDEV*, *HASDIV*, *PCT*, *INVENT* and *IPC8*. Albeit slightly less stable, the *OCCAS* variable remains negative and significant in two thirds of the regressions.

All these results have highlighted a number of country and industry dependencies in the correlation between filing strategies and technical characteristics of patents and 6 different value indicators. These sensibilities are summarised in Figure 4. In order to dichotomise the robustness or sensitivity of each variable with respect to the indicator, country or industry used, we define the following thresholds: a variable is considered robust (independent) with respect to one dimension if its coefficient kept the same sign in all regressions across this dimension and remained significant at the 5% probability level in at least two thirds of the regressions. This means no more than 2 non-significant parameters in the six indicators regressions (from Table 7), maximum 4 in industry regressions on the composite indicator (from the sixth column in Table A3) and 6 in country regressions on the composite indicator (from the sixth column in Table A4).

Figure 4 - Stability or instability of explanatory variables



From Figure 4, it appears that only 5 variables would pass this independence test: excess claims, priorities, parents of divisionals, the PCT route and the number of inventors. Five variables appear as sensitive to the three dimensions: cross-border ownership, divisionals, applicant's portfolio, academic patentees and the number of backward patent references.

6. Concluding remarks

The surge in the size of applications is associated with the exploitation of all procedural possibilities offered by patent systems to build the most suitable filing strategy (van Zeebroeck et al., 2006; Stevnsborg and van Pottelsberghe, 2007). The present paper empirically establishes that these filing strategies consisting in drafting excessively long patents – often by assembly or disassembly – and in particular the filing of divisional applications, are indicative of more important patents.[28]

The benefits of such divisional or construction strategies to patent holders, resulting in a set of patents covering a single invention, are guessable: they increase the cost of opposition for competitors and may induce complexity and uncertainty on the relevant market. However, according to Harhoff (2006), such strategies may more likely be an endogenous response to value: because a knowledge asset is more valuable, a patentee would assemble bundles of patents to protect it, that is, the owner will strengthen the legal protection of the invention by creating a web of partly overlapping patents whose overall structure may be more robust than a single patent could be.

Although the factual or empirical evidence in this matter is very scarce, the risk is high that such strategies could derive to real abuses of the patent system (see Stevnsborg and van Pottelsberghe, 2007). For instance, by re-filing the same subject-matter again and again by means of divisionals over several generations, a patentee could unduly keep alive some subject-matter from a parent application that had been refused for grant by the Office. By filing divisionals of the application, embedding the valuable subject matter, and then divisionals of divisionals, and so on for up to twenty years, such a strategy could provide the applicant with a provisional protection as provided by Article 67 EPC[29] over some subject-matter which had already been judged unpatentable by the Office. In a recent ruling,[30] the EPO Enlarged Board of Appeal confirmed that this strategy is a legitimate exploitation of the procedural possibilities afforded by the EPC as it is, although some consider it "*an abuse in relation to the law as they think it ought to be [...]*." The Board nonetheless acknowledged that it is "*unsatisfactory that sequences of divisional applications each containing the same broad disclosures of the original patent application* [i.e. with the same description] *should be pending for up to twenty years.*" But the Board decided that "*it would be for the legislator to consider where there are abuses and what the remedy could be.*"[31]

By means of a comprehensive sample containing a large number of variables over the full cohort of patents granted by the EPO and filed between 1990 and 1995, this paper significantly contributes to the understanding of patent filing strategies and demonstrates their association with patent value. These results confirm that developments in patent filing strategies are something policy makers and all stakeholders of the patent system at large should care about for they signal more important patents that will become unavoidable in the state of the art (they are more frequently cited), remain active for longer in more countries (they have higher survival rates and larger family sizes), and tend to be more frequently opposed (clearly witnessing economic value on the relevant market).

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[28] One limitation of the present research is that it relies only on patents granted. As a consequence, from all applications filed using some of the strategies discussed here, only those that successfully went through the examination procedure are accounted for and are found to be more valuable than others. It remains therefore possible that these strategies are in fact associated with below average grant rates, suggesting that they actually carry many applications of dubious value.

[29] According to Article 67 EPC, a pending application provisionally confers upon the applicant the same rights in all designated States as if the patent was granted (see van Zeebroeck, 2007).

[30] Cases G0001/05 and G0001/06, decided on June 28th, 2007. The full transcription of the decision is available on the EPOLINE website.

[31] EPO EBA Decision in case G0001/05 rendered on June 28, 2007, pp. 44-45.

The exceptional size and richness of the dataset constructed for this study also made it possible to test at a larger scale the association between many classical determinants of patent value and different established indicators of patent value. This exercise does confirm some existing empirical evidence: the number of claims, the PCT procedure, and the number of inventors are significantly and consistently indicative of higher value patents, so are two new determinants proposed in this paper: the number of priorities and whether a patent is the parent of divisional filings. But this paper also clearly demonstrates that most of the existing estimates are actually highly sensitive to the sampling and/or the dependent variable used. In particular, well established indicators of patent value such as backward patent citations and the applicant's patent portfolio size appeared to have a very ambiguous relationship with patent value, which heavily depends upon the country from which patents originate, the technology area they are related to, and the value indicator chosen.

This sensitivity of many determinants to the dependent variable used as indicator patent value confirms the results of an earlier paper (van Zeebroeck, 2007), which showed that the different indicators actually capture different dimensions of the value and hence may have different drivers, calling for the construction of a composite measure of value that would encapsulate the different dimensions into one indicator. Adding to it the dependence of most results to the country or the industry as presented in this paper, these results further suggest that most empirical evidence on the indicators of patent value should be generalized with much care.

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Appendixes

Table A1 – Codes used to refer to the state of the art on patent value in the tables

Code	Short Reference	Code	Short Reference	Code	Short Reference
AANM91	Albert et al. (1991)	GVP00	Guellec and van Pottelsberghe (2000)	P86	Pakes (1986)
AL98	Allison and Lemley (1998)	GVP02	Guellec and van Pottelsberghe (2002)	PS84	Pakes and Schankerman (1984)
ALMT03	Allison et al. (2003)	HC03	Hagedoorn and Cloodt (2003)	PS89	Pakes and Simpson (1989)
ACC04	Arora et al. (2004)	H99	Hall (1999)	PJW05	Palangkaraya et al. (2005)
A93	Austin (1993)	HH04	Hall and Harhoff (2004)	P03	Palomeras (2003)
B06	Bessen (2006)	HMG06	Hall and MacGarvie (2006)	P96	Putnam (1996)
B05	Betran (2005)	HJT01	Hall et al. (2001)	R02	Reitzig (2002)
BCM07	Blind et al. (2007)	HGHM03	Hall et al. (2003)	R03	Reitzig (2003)
BVR02	Bloom and van Reenen (2002)	HJT05	Hall et al. (2005)	R04a	Reitzig (2004a)
BR01	Bosworth and Rogers (2001)	HH02	Harhoff and Hall (2002)	R04b	Reitzig (2004b)
PATVAL06	Brusoni et al. (2006)	HR04	Harhoff and Reitzig (2004)	SVP07	Sapsalis and van Pottelsberghe (2007)
CS04	Calderini and Scellato (2004)	HNSV99	Harhoff et al. (1999)	SVPN06	Sapsalis et al. (2006)
CN79	Campbell and Nieves (1979)	HSV02	Harhoff et al. (2002)	S98	Schankerman (1998)
CN83	Carpenter and Narin (1983)	HSV03	Harhoff et al. (2003)	SP86	Schankerman and Pakes (1986)
CC80	Carpenter et al. (1980)	HWW05	Hunter et al. (2005)	S65	Scherer (1965)
CNW81	Carpenter et al. (1981)	JTF00	Jaffe et al. (2000)	SH00	Scherer and Harhoff (2000)
CG88	Cockburn and Griliches (1988)	JW03	Jerak and Wagner (2003)	SHK00	Scherer et al. (2000)
CS99	Cornelli and Schankerman (1999)	KT86	Kamien and Tauman (1986)	S06	Schneider (2006)
C04	Cremers (2004)	KVMB02	Kleinknecht et al. (2002)	S07	Schneider (2007)
CDK96	Crépon et al. (1996)	K90	Klemperer (1990)	S99	Scotchmer (1999)
CHO05	Czarnitzki et al. (2005)	KL99	Kortum and Lerner (1999)	SG90	Scotchmer and Green (1990)
D05	Deng (2005)	K98	Kremer (1998)	S05	Serrano (2005)
DG61	Dernburg and Gharrity (1961)	L93	Lanjouw (1993)	S01	Shane (2001)
DI97	Duguet and Iung (1997)	L98	Lanjouw (1998)	SK97	Shane and Klock (1997)
G92	Gallini(1992)	LS97	Lanjouw and Schankerman (1997)	ST04	Sherry and Teece (2004)
G05	Gambardella (2005)	LS99	Lanjouw and Schankerman (1999)	SV04	Silverberg and Verspagen (2004)
GHV06	Gambardella et al. (2006)	LS01	Lanjouw and Schankerman (2001)	S94	Sullivan (1994)
GS90	Gilbert and Shapiro (1990)	LS04	Lanjouw and Schankerman (2004)	T86	Teece (1986)
GHHM02	Graham et al. (2002)	LPP98	Lanjouw et al. (1998)	T06	Teece (2006)
GS95	Greene and Scotchmer (1995)	L94	Lerner (1994)	TF94	Tong and Frame (1994)
GR06	Greenhalgh and Rogers (2006)	MN90	Merges and Nelson (1990)	T90	Trajtenberg (1990)
GR07	Greenhalgh and Rogers (2007)	MT05	Meyer and Tang (2005)	VBVZ08	van Pottelsberghe and van Zeebroeck (2008)
GJW05	Griffiths et al. (2005)	N04	Nagaoka (2004)	VZ07	van Zeebroeck (2007)
G81	Griliches (1981)	NNP87	Narin et al. (1987)	W04	Wagner (2004)
G89	Griliches (1989)	NS06	Noel and Schankerman (2006)	WPJ07	Webster et al. (2007)
GPH86	Griliches et al. (1986)	ODST98	O'Donoghue et al. (1998)		

Table A2 – Summary Statistics of classical determinants and control variables

Variable	Obs	Mean	StDev	Min	Max
Applicant Profiles					
CUMUL (/1000)	248856	0,41	0,88	0,00	4,83
OCCAS	248856	0,21	0,41	0	1
ACAD	248855	0,02	0,13	0	1
CBOWN	248856	0,10	0,29	0	1
Technological complexity					
INVENT	248856	2,40	1,71	1	32
IPC8	248532	1,93	1,29	1	43
BPC	245961	4,48	2,88	0	99
NPC	245963	0,99	1,79	0	61
EPO Joint Clusters					
JC-01 - Industrial Chemistry	248856	0,12	0,33	0	1
JC-02 - Organic Chemistry	248856	0,13	0,34	0	1
JC-03 - Polymers	248856	0,11	0,31	0	1
JC-04 - Biotechnology	248856	0,10	0,30	0	1
JC-05 - Telecommunications	248856	0,03	0,18	0	1
JC-06 - Audio/Video/Media	248856	0,05	0,22	0	1
JC-07 - Electronics	248856	0,08	0,27	0	1
JC-08 - Electricity & Elec. Machines	248856	0,11	0,32	0	1
JC-09 - Computers	248856	0,03	0,18	0	1
JC-10 - Measuring Optics	248856	0,09	0,29	0	1
JC-11 - Handling & Processing	248856	0,14	0,35	0	1
JC-12 - Vehicles & Gen. Technology	248856	0,10	0,30	0	1
JC-13 - Civil Engineering / Thermodynamics	248856	0,09	0,29	0	1
JC-14 - Human Necessities	248856	0,11	0,31	0	1
Country of residence of applicant					
AT Applicant	248856	0,01	0,10	0	1
AU Applicant	248856	0,00	0,07	0	1
BE Applicant	248856	0,01	0,10	0	1
CA Applicant	248856	0,01	0,09	0	1
CH Applicant	248856	0,04	0,19	0	1
DE Applicant	248856	0,20	0,40	0	1
DK Applicant	248856	0,01	0,08	0	1
ES Applicant	248856	0,00	0,06	0	1
FI Applicant	248856	0,01	0,09	0	1
FR Applicant	248856	0,09	0,28	0	1
GB Applicant	248856	0,05	0,22	0	1
IL Applicant	248856	0,00	0,05	0	1
IT Applicant	248856	0,03	0,18	0	1
JP Applicant	248856	0,22	0,41	0	1
KR Applicant	248856	0,00	0,06	0	1
NL Applicant	248856	0,04	0,19	0	1
SE Applicant	248856	0,02	0,14	0	1
US Applicant	248856	0,26	0,44	0	1
Applicant from the ROW	248856	0,02	0,13	0	1
Year of filing					
1990	248856	0,17	0,37	0	1
1991	248856	0,16	0,37	0	1
1992	248856	0,16	0,37	0	1
1993	248856	0,17	0,37	0	1
1994	248856	0,17	0,38	0	1
1995	248856	0,17	0,38	0	1

Table A3 – Industry dependencies in the main model (14 industry-specific regressions per value indicator)

	5yrs Citations			EPC Family			Triadic			Survived 10yrs			Opposed			Composite			Total			
Variable	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	TOT
CLMDEV	0	0	14	3	0	11	0	0	14	2	0	12	8	1	5	0	0	14	13	1	70	84
CLMLS	6	8	0	3	11	0	6	8	0	11	3	0	10	2	2	3	11	0	39	43	2	84
PRIO	0	0	14	10	0	4	0	0	14	8	0	6	11	1	2	0	0	14	29	1	54	84
EQUIV	12	1	1	11	0	3	0	0	14	8	0	6	9	0	5	5	0	9	45	1	38	84
HASDIV	4	0	10	0	0	14	3	0	11	0	0	14	2	0	12	0	0	14	9	0	75	84
ISDIV	4	10	0	9	0	5	0	0	14	1	0	13	9	0	5	5	0	9	28	10	46	84
PCT	5	0	9	0	0	14	1	0	13	4	1	9	12	1	1	1	0	13	23	2	59	84
ACCSRC	9	1	4	12	0	2	12	0	2	8	0	6	9	0	5	11	0	3	61	1	22	84
CUMUL	9	2	3	0	14	0	0	0	14	4	3	7	3	11	0	5	9	0	21	39	24	84
OCCAS	4	6	4	1	2	11	0	14	0	1	13	0	3	1	10	3	8	3	12	44	28	84
INVENT	0	0	14	5	3	6	3	0	11	2	0	12	7	1	6	1	0	13	18	4	62	84
IPC8	0	0	14	2	0	12	5	0	9	8	0	6	10	2	2	0	0	14	25	2	57	84
BPC	1	0	13	9	3	2	2	12	0	6	2	6	0	0	14	3	3	8	21	20	43	84
NPC	4	1	9	3	7	4	2	0	12	3	0	11	5	1	8	2	2	10	19	11	54	84
CBOWN	11	0	3	3	3	8	8	6	0	7	3	4	8	0	6	6	2	6	43	14	27	84
ACAD	9	0	5	7	3	4	9	5	0	9	5	0	11	3	0	11	2	1	56	18	10	84
APP_AT	11	1	2	6	1	7	4	10	0	6	3	5	12	0	2	6	2	6	45	17	22	84
APP_AU	13	0	1	7	6	1	6	1	7	3	0	11	9	4	0	6	4	4	44	15	24	83
APP_BE	13	0	1	8	2	4	8	1	5	4	0	10	7	3	3	4	2	8	44	8	31	83
APP_CA	9	0	5	5	9	0	6	0	8	4	0	10	12	2	0	11	2	1	47	13	24	84
APP_CH	9	1	4	2	1	11	5	0	9	1	0	13	10	1	3	2	0	12	29	3	52	84
APP_DE	8	4	2	1	3	10	1	13	0	3	0	11	5	0	9	3	3	8	21	23	40	84
APP_DK	11	0	3	10	1	3	9	4	1	3	0	11	8	0	6	8	1	5	49	6	29	84
APP_ES	12	2	0	9	0	5	10	4	0	7	0	7	12	1	0	12	2	0	62	9	12	83
APP_FI	10	0	4	9	3	2	8	2	4	2	0	12	12	0	1	5	1	8	46	6	31	83
APP_GB	9	0	5	4	10	0	6	0	8	3	0	11	13	1	0	8	4	2	43	15	26	84
APP_IL	6	0	8	13	1	0	11	0	3	8	0	6	12	0	1	12	0	2	62	1	20	83
APP_IT	11	3	0	5	4	5	5	8	1	0	0	14	8	4	2	7	6	1	36	25	23	84
APP_JP	4	2	8	0	14	0	0	0	14	1	0	13	1	13	0	5	7	2	11	36	37	84
APP_KR	12	1	1	0	14	0	2	0	12	5	0	9	13	0	0	6	8	0	38	23	22	83
APP_NL	10	1	3	5	4	5	4	4	6	0	0	14	6	3	5	2	2	10	27	14	43	84
APP_SE	10	0	4	7	4	3	0	0	14	1	0	13	10	0	3	0	0	14	28	4	51	83
APP_US	0	0	14	0	14	0	0	0	14	0	0	14	4	10	0	6	2	6	10	26	48	84
APP_OT	13	0	1	7	4	3	6	3	5	5	1	8	8	6	0	4	5	5	43	19	22	84
FY_1991	11	0	3	3	11	0	14	0	0	11	1	2	13	0	1	6	8	0	58	20	6	84
FY_1992	5	0	9	7	7	0	11	2	1	9	0	5	12	1	1	2	12	0	46	22	16	84
FY_1993	1	0	13	2	11	1	8	6	0	11	1	2	10	4	0	1	13	0	33	35	16	84
FY_1994	0	0	14	3	10	1	7	7	0	8	3	3	6	7	1	1	13	0	25	40	19	84
FY_1995	0	0	14	1	13	0	10	3	1	10	3	1	6	8	0	0	14	0	27	41	16	84
_cons	0	14	0	0	0	14	4	8	2	3	11	0	0	14	0	0	0	14	7	47	30	84

Source: Own calculations based on EPO data – Patents filed 1990-1995

Table A4 - Country dependencies in the main model (18 country-specific regressions per value indicator)

	5yrs Citations			EPC Family			Triadic			Survived 10yrs			Opposed			Composite			Total			
Variable	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	/	-	+	TOT
CLMDEV	2	0	16	7	1	9	3	0	15	9	0	9	13	1	4	3	0	15	37	2	68	107
CLMLS	14	4	0	10	7	0	11	7	0	16	2	0	14	1	3	12	6	0	77	27	3	107
PRIO	8	0	10	8	0	9	2	0	16	13	1	4	13	0	5	6	0	12	50	1	56	107
EQUIV	16	1	1	11	2	4	4	0	14	13	0	5	8	1	7	10	1	7	62	5	38	105
HASDIV	7	0	11	4	0	13	8	0	10	5	0	13	5	0	12	3	0	15	32	0	74	106
ISDIV	15	3	0	14	0	3	5	0	13	7	0	11	15	0	1	8	2	8	64	5	36	105
PCT	11	1	6	5	0	12	1	1	16	10	2	6	16	1	1	4	0	14	47	5	55	107
ACCSRC	16	0	2	14	0	3	16	0	2	16	0	2	12	0	4	13	0	5	87	0	18	105
CUMUL	15	1	2	5	11	1	5	0	13	11	3	4	7	11	0	12	6	0	55	32	20	107
OCCAS	13	4	1	11	2	4	4	14	0	7	11	0	14	0	4	6	12	0	55	43	9	107
INVENT	6	0	12	8	0	9	7	0	11	9	0	9	13	1	4	3	0	15	46	1	60	107
IPC8	3	0	15	8	0	9	9	0	9	12	1	5	16	2	0	4	0	14	52	3	52	107
BPC	5	0	13	13	2	2	11	7	0	15	0	3	4	0	14	9	0	9	57	9	41	107
NPC	12	1	5	10	1	6	10	1	7	7	0	11	7	0	11	9	0	9	55	3	49	107
CBOWN	12	0	6	7	3	7	12	4	2	7	5	6	15	1	2	9	2	7	62	15	30	107
ACAD	15	1	2	13	2	2	12	6	0	13	2	2	11	3	0	15	1	2	79	15	8	102
JC_02	8	0	10	0	0	17	8	1	9	3	0	15	13	2	3	1	0	17	33	3	71	107
JC_03	7	0	11	7	2	8	8	1	9	10	1	7	8	0	10	8	0	10	48	4	55	107
JC_04	2	0	16	4	0	13	9	1	8	2	0	16	13	3	2	3	0	15	33	4	70	107
JC_05	6	0	12	9	4	4	13	3	2	7	0	11	11	6	0	8	0	10	54	13	39	106
JC_06	10	0	8	9	8	0	10	1	7	10	0	8	7	6	2	13	4	1	59	19	26	104
JC_07	12	3	3	7	10	0	12	1	5	10	0	8	14	3	0	11	5	2	66	22	18	106
JC_08	12	6	0	7	10	0	9	7	2	10	6	2	12	6	0	8	10	0	58	45	4	107
JC_09	12	1	5	11	6	0	14	3	1	9	1	8	15	3	0	14	3	1	75	17	15	107
JC_10	11	7	0	3	14	0	11	1	6	13	3	2	8	9	0	5	13	0	51	47	8	106
JC_11	7	11	0	8	6	3	10	7	1	11	7	0	13	0	5	6	10	2	55	41	11	107
JC_12	6	12	0	6	11	0	5	12	1	13	5	0	12	5	0	2	16	0	44	61	1	106
JC_13	5	13	0	7	10	0	6	12	0	8	10	0	15	3	0	5	13	0	46	61	0	107
JC_14	12	1	5	10	6	1	11	7	0	9	7	2	14	2	2	7	7	4	63	30	14	107
FY_1991	17	0	1	10	7	0	13	3	2	14	2	2	15	2	1	14	4	0	83	18	6	107
FY_1992	11	1	6	13	4	0	11	4	3	14	0	4	16	2	0	12	6	0	77	17	13	107
FY_1993	11	0	7	10	4	3	12	5	1	12	2	4	15	3	0	9	9	0	69	23	15	107
FY_1994	8	1	9	12	5	0	11	5	2	14	2	2	12	5	1	8	10	0	65	28	14	107
FY_1995	11	1	6	9	8	0	10	5	3	14	2	2	11	7	0	5	13	0	60	36	11	107
_cons	0	18	0	0	0	17	7	9	2	10	8	0	0	18	0	0	0	18	17	53	37	107

Source: Own calculations based on EPO data – Patents filed 1990-1995

The effect of patent protection on the timing of alliance entry

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This paper analyzes how a start-up biotech firm's patent rights affect if and when it enters into an alliance with a pharmaceutical firm. The existing literature presents conflicting predictions of how obtaining patent rights affects alliance entry. The literature on markets for technology argues that obtaining patents increases the firm's protection during pre-contractual negotiations, hence increasing the likelihood of alliance entry. However, research in finance suggests that obtaining patents also increases the ability to access outside funding, which in turn enables the firm to delay entry into an alliance with a pharmaceutical firm. Using a dataset comprising information on 650 U.S. biotech firms founded over the period 1976-2002, I estimate the effect of a firm's patent protection on the hazard of it entering into an alliance with a pharmaceutical firm. I find that while the likelihood of a firm entering into an alliance increases with the firm's patent filings, it decreases as those patents issue. This result is robust to different methods of dating the patent filing, as well as to weighting the patent count by both the number of forward citations and a more general index of patent quality. This suggests that, while filing patents over the technology enables the biotech firm to transact with a pharmaceutical firm, the issue of those patents increases the biotech firm's outside options and hence enables it to delay the timing of alliance entry until the optimal stage in the commercialization process.

Keywords: patents, intellectual property, alliances, biotechnology, R&D finance.

I wish to thank Hank Chesbrough, Bronwyn Hall, Ben Hermalin, Jenny Lanjouw, Mark Lemley, Robert Merges, David Mowery, David Teece, and participants in the Economics of Innovation and the Business & Public Policy seminars at the Haas School of Business for their comments on earlier drafts of this paper. I would also like thank Mark Edwards, Storn White, and Mike McCully at Recombinant Capital for generously giving me access to their data, and Hank Chesbrough and John Wolpert of the Australian Innovation Exchange for facilitating a series of interviews related to this research. I gratefully acknowledge the support of the Institute for Innovation, Management, & Organization at the Haas School of Business and the Center for Law & Biosciences at Stanford Law School for financial support of my research. All errors are my own.

1. Introduction

The importance of patent protection for profiting from innovation in the biopharmaceutical industry is well established. Evidence from the Carnegie-Mellon survey (Cohen, Nelson, & Walsh, 2000) shows that – in contrast to most industries – patent rights provide the primary means for appropriating the returns to innovation in this industry. Moreover, using evidence from renewal fees, Schankerman (1998) shows that firms in this industry are willing to pay to maintain these patents for the full life of the patent. However, the effect of patent protection on the commercialization strategy of start-up biotech firms, and in particular the timing of alliance entry, is less clear.

The choice of timing for entering into an alliance is critical for the biotech firm to maximize the returns it captures from its innovation. Since an established pharmaceutical firm supplies the funding necessary to get the product to market, delaying alliance entry may mean the biotech firm runs out of cash to maintain development and thereby misses a potential market opportunity. Moreover, since the pharmaceutical firm can also offer expert advice on how to advance the product through development process, the sooner the biotech firm enters an alliance, the easier will be the path to market. Nevertheless, to induce the pharmaceutical firm to enter into the alliance, the biotech firm must give up a share of the expected returns from the innovation and compensate the pharmaceutical firm for the risk that the product will never get to market. If the biotech firm is better able (or more willing) to bear the technological risk, it may be able to capture a larger share of the returns by delaying alliance entry. Hence there are also advantages to waiting, and the timing of alliance entry involves a strategic trade-off between these offsetting factors.

The biotech firm's patent protection over its technology impacts the timing of entry into an alliance to commercialize that technology. On the one hand, pharmaceutical firms typically refuse to enter an alliance until the biotech firm has established a “clean and unencumbered” patent position that will translate into exclusivity on the pharmaceutical product market. At the same time, since patent rights give the biotech firm protection against expropriation by the pharmaceutical firm during pre-contractual negotiations (Merges, 2005), obtaining patent protection may facilitate transacting (Gans, Hsu, & Stern, 2006) and hence potentially increase the likelihood that the firms will enter into an alliance. Nevertheless, patent rights also provide a positive signal of the technology’s value to third parties, increasing the biotech firm’s ability to raise funding from other financial investors (Hsu & Ziedonis, 2007; Mann & Sager, 2007), and hence reducing the urgency for the biotech firm to enter into an alliance with a pharmaceutical firm. Therefore, obtaining patent protection may at the same time both accelerate and delay the biotech firm’s entry into an alliance.

In this paper I seek to distinguish between these two conflicting effects, taking advantage of the difference between filed and issued patents. I present an empirical analysis of the entry timing that draws on a unique dataset of patenting and licensing information from 650 start-up biotech firms founded in the United States between 1976 & 2002. The dataset combines information from the Recombinant Capital database and the NBER patent file (Hall, Jaffe, & Trajtenberg, 2001), as well as data from my own internet research. In order to measure the effect of the biotech firm’s patent rights on entry into its first deal with a pharmaceutical firm, I estimate a proportional hazards model with time-varying covariates (Wooldridge, 2001). The results show that the likelihood of a start-up biotech firm entering into its first alliance at a particular point in time (i.e., the hazard rate) is positively correlated with the number of filed patents but negatively correlated with the proportion of those patents that have issued.[1] This result is robust to different methods of dating the patent filing, as well as to weighting the patent count by either the number of forward citations the patent receives within 5 years of issue or the more general patent quality index developed by Lanjouw & Schankerman (2004). When the analysis is limited to the subset of firms that entered into an alliance during the observation period, the effect of patent issue on the hazard rate – although still negative – is not significant. Nevertheless, the effect of patent issue is significantly *more* negative for those firms that enter into a deal in the pre-clinical stages of commercialization.

The results of this analysis indicate that patent filing and patent issue have very different implications for biotech commercialization strategy. Patent filing unambiguously increases the likelihood of the biotech firm entering into an alliance. This suggests that while filing a patent application gives the biotech and pharmaceutical firms the assurances necessary to transact over the technology, it does not significantly affect the biotech firm's other options, in particular its ability to raise money on financial markets. By contrast, as patents issue the likelihood of the biotech firm entering into an alliance decreases, thereby delaying the biotech firm's entry into an alliance. The most likely explanation for this result is that patent issue increases the willingness of outside investors to finance independent development of the technology, and thereby enables it to delay entry until the optimum stage in the commercialization process.

The next section of this paper presents a brief review of the prior, related literature. Section 3 discusses several different ways in which patent protection affects commercialization strategy. Section 4 sets out the empirical analysis of the relationship between a start-up biotech firm's patent protection and the timing of entry into its first alliance with an established pharmaceutical firm. Section 5 discusses the results and concludes.

2. Literature review

Much of the prior empirical research involving patents treats patent rights merely as a proxy for technology (i.e., patent stock) or innovation (i.e., as a flow); see, for instance, Hall, Jaffe, & Trajtenberg (2005). However, recent literature has focused on the role that patent rights themselves play in firm strategy. Gans, Hsu & Stern (2007) used a very similar empirical set-up to that used in this paper (i.e., estimating the hazard of a firm licensing its technology) to examine how patent issue affects transactions in the market for technology. They found that the likelihood of licensing a technology increases dramatically immediately after the patent issues (relative to the period shortly before), suggesting that patent issue significantly affects the willingness of firms to transact over the technology. However, in contrast to this paper, they only examined technologies which were already covered by a patent application and focused on what they identified as the primary patent protecting that technology. This paper looks more generally at the effect of patent protection on the timing of alliance entry, and aggregates across all assigned patents in the firm's portfolio.

Other researchers have studied the effect of obtaining patent rights on the ability to raise finance for firms in other industries. Mann & Sager (2007) looked at the relationship between patenting and the progress of software firms through the venture capital cycle, and found a strong relationship between a firm's patent stock and the likelihood of raising additional rounds of venture capital. Hsu & Ziedonis (2007) performed a similar study for semi-conductor firms and found a positive relationship between the number of patent applications and the ability to raise capital from venture capital firms. However, neither paper distinguished the effect of higher patent stock from the effect of a stronger technological position (which is highly correlated with patent stock) so do not show how the patent rights *themselves* affect the ability to raise venture capital financing. Moreover, since alliance relationships are not a significant alternative source of finance in the software and semi-conductor industries, neither paper considers how patent rights affect the trade-off between obtaining financing through an alliance and either issuing stock or obtaining venture capital finance.

Another line of literature has directly examined the trade-off that biotech firms make between alliance financing and other sources. Majewski (1998) examined the effect of asymmetric information on this trade-off, and found that firms with higher asystematic risk (i.e., higher volatility in the portion of firm returns that is uncorrelated with market movement) and greater volatility in stock prices are more likely to choose an alliance partner to fund their R&D program (as opposed to issuing stock or obtaining venture capital). Meanwhile, Lerner, Shane & Tsai (2003) looked at the effect of equity market financing cycles on the structure of alliance relationships, and found that when equity markets are tighter, the biotech firm obtains less favorable terms in an alliance arrangement with a pharmaceutical firm. This paper complements the prior literature by examining how the level of the biotech firm's patent protection affects the trade-off between these alternative sources of finance.

3. Theoretical analysis

Obtaining patent protection provides at least three distinct benefits for biotech firms attempting to commercialize an innovation through an alliance:[2]

1. It provides the biotech firm with some protection against expropriation when revealing its technology to potential partners in pre-contractual negotiations.
2. It provides some assurance that the drug generated from the patented invention will have exclusivity on the pharmaceutical product market.
3. It signals the novelty and usefulness, and hence – in principle – the commercial value, of the underlying technology.

The following sections describe these benefits in more detail.

3.1.Protecting against expropriation by an alliance partner

Revealing its technology to another firm during the pre-alliance negotiations exposes the biotech firm to the risk that its partner may expropriate the invention and use it outside the alliance without paying proper compensation. In principle, the biotech firm could prevent expropriation by making its partner agree contractually not use the technology without permission. However, the amorphous nature of knowledge makes it difficult to delineate the biotech firm's invention from the pre-existing technology, so it is often difficult to write a 'complete' contract that protects the invention entirely (Williamson, 1991).

Moreover, a prospective partner may refuse to enter such agreement because of the risk that the biotech firm will use it stop the partner from subsequently bringing *any* related product to market, whether or not the product relied on the biotech firm's technology.[3] For these reasons a biotech firm often must reveal its innovation to a potential partner even before it can rely on contractual protection (Arrow, 1962).

Merges (2005) describes two important roles that patent protection – or property rights more generally – play in facilitating contracting. Firstly, patent rights protect sensitive information that needs to be disclosed during pre-contractual negotiations. Secondly, patent rights give the owner an alternative set of remedies against infringement that are both more flexible and longer lived than contractual remedies. Hence obtaining patent protection gives the biotech firm better protection over its technology from expropriation by an alliance partner.

3.2.Providing exclusivity on the final product market

For pharmaceutical firms attempting to commercialize a new product, obtaining market exclusivity is a primary objective. The enormous costs of taking a pharmaceutical product through clinical trials mean that the firm needs to earn economic rents from sale of the product just to break even. The grant of a patent gives the owner the right to prevent or exclude others from making, using, or selling the claimed invention.[4]

Obtaining a patent on a technological invention, however, does not translate directly into exclusivity on the final product market. The relationship between patent rights and product exclusivity depends on the validity of the patent, the ease of enforcing the patent on alleged infringers, how closely the claimed invention maps onto the final product, and (obversely) how difficult it is for rivals to invent around. In many industries the invention described in a patent bears only a loose relationship to the final product (or a component of that product), so patent rights provide only limited protection against expropriation. Instead inventors must rely on a range of alternative appropriation mechanisms such as secrecy and lead time on competitors to capture the returns when commercializing an invention (Cohen et al., 2000; Levin, Klevorick, Nelson, & Winter, 1987; Teece, 1986). In the life sciences, by contrast, the close relationship between a patentable invention – such as the composition of a chemical compound that has therapeutic effects – and the pharmaceutical product that comes out of that invention means that a patent potentially gives the holder strong and unambiguous rights to exclude others on the product market. Hence, patent rights provide one of the primary means for obtaining exclusivity in this industry (Cohen et al., 2000).

3.3. Signaling the potential value of the firm's underlying technology to financial investors

Regardless of the actual legal protection provided by patent rights, the issue of patent rights also provides a clear signal as to the novelty and usefulness – and hence, potentially, the underlying commercial value – of the firm's technology. While potential alliance partners (or acquirers) can examine the technology in detail during the due diligence process, market analysts and other financial investors only have access to limited publicly available information such annual reports, press releases, and scientific publications. Moreover, even if they were privy to the private information disclosed during due diligence, market analysts and pure financial investors are poorly placed to evaluate the novelty and usefulness of a particular invention as against other technology in the field. Hence, the independent assessment of the patent office on a clear – if arguably weak – standard of novelty, usefulness, and non-obviousness provides a demonstrable signal as to the technology's value.

4. Econometric analysis

The key finding from a set of interviews with biotech and pharmaceutical firm executives reported elsewhere (Wakeman, 2007) is that the primary effect of obtaining patent protection on alliance strategy is likely to be on the “if and when” a biotech firm *enters* a technology commercialization alliance, as opposed to the details of the alliance structure. This section describes an empirical analysis designed to identify the relationship between the biotech firm’s patent protection and the timing of alliance entry.

4.1.Data sources

In order to analyze the effect of obtaining patent protection on alliance entry, I constructed a dataset of the patenting history of start-up biotech firms from their founding to their first alliance with a pharmaceutical firm. The dataset includes information on the year in which each biotech firm was founded, the date on which it signed its first alliance with a pharmaceutical firm (if appropriate), and the filing and issue dates of patents assigned to it over this period. The data comes from three sources.

The data on the alliances (and the base set of the firms used in this analysis) comes from the database compiled by Recombinant Capital (“Recap”), a San Francisco Bay Area-based consulting firm. The database contains records of all publicly announced deals in the biopharmaceutical industry from its inception in the 1970s through to the present day, as well as the actual contracts for those (approximately 50% of the total) which are filed with the U.S. Securities and Exchange Commission (SEC) under the ‘materiality’ requirement.[5] The second source is the NBER patent file, compiled by Bronwyn Hall, Adam Jaffe, and Manuel Trajtenberg (2001). This dataset contains information on all patents issued by the U.S. Patent & Trademark Office (USPTO) from 1963-2002, including (most usefully for this analysis) the name of the firm to which each patent is assigned.[6] I have supplemented this with the raw USPTO data published on the Micropatent CD-ROMs to obtain the exact application date listed on the patent and each patent’s case history. This allows me to trace back to the date of first related patent application.

The third source is the Corp Tech database. Corp Tech compiles the results of a continuous census of all U.S. technology organizations, primarily for the purpose of generating mailing lists of technology companies for direct marketing firms. Most useful for this analysis, it also records the year in which the organization was founded.

4.2.Construction of the dataset

I defined the universe of firms for this analysis to be the set of "Biotech" firms contained in the Recap database.[7] I then used the Recap database to obtain the date of the biotech firm's first transaction with a pharmaceutical firm. In almost every case, firms that appear in the Recap database have at least one transaction.[8] However, these transactions include purely financial transactions, physical asset sales, and agreements with other biotech firms and with universities. Since I am focused on the relationship between the patent protection that the biotech firm has over its technology and alliances to commercialize that technology, not all of these transactions are relevant for this analysis. Instead, I restrict attention to transactions between a biotech and a pharmaceutical firm[9] that involved the transfer (either sale or license) of an intellectual property asset.[10]

I used name matching to link each of the firms in the Recap dataset to its corresponding assignee code in the NBER patent assignee file. If multiple permutations of the firm name appear in the assignee file, I used Google searches to determine which (if any) of the permutations are related to the firm in the Recap database and include multiple assignee codes where appropriate. If the firm name does not appear in the NBER assignee file, I searched the USPTO and Patent Genius (www.patentgenius.com) websites for the first US patent assigned to the firm, then searched for that patent in the NBER patent file to recover the firm's assignee code. If I could not find the assignee code I assumed that the firm had not been assigned any patents by December 31, 2002.

I then used name matching to match each firm to the corresponding record in the Corp Tech database. Where there was a match, I used the information on the year of founding recorded in the Corp Tech database. Otherwise I performed a Google search for the firm's name and the word "founded" to find the year of founding. If I could not find the year of founding then I dropped the firm's record from the database.

Since the NBER patent file finishes in 2002, I restrict the sample to firms that were founded in or before 2002. Meanwhile, since the alliance-based model for commercialization was pioneered by Genentech, which was founded in 1976, I exclude all firms which were founded before that year. Table 1 describes the firms in the dataset, listing them by the year the firm was formed and indicating which firms entered into a deal with a pharmaceutical firm, and which were acquired before doing so.

Table 1: Number of firms that sign a deal with a pharmaceutical firm (by year formed)

Year of founding	Firms founded	Firms acquired before entering a pharma deal	Firms entering first pharma deal by 2002	Percentage of firms entering first pharma deal by 2002
1976-1980	26	2	19	73.1%
1981-1985	97	6	63	64.9%
1986-1990	126	12	91	72.2%
1991-1995	179	21	119	66.5%
1996-2000	181	27	68	37.6%
2001-2002	41	6	3	7.3%
	650	74	363	

4.3.Empirical methodology

4.3.1. Econometric specification

My objective is to measure the effect of the firm's patent protection on the start-up biotech firm's entry into its first alliance to commercialize the technology. The simplest way to do this would be to estimate the effect of the firm's patent count on the time to its first alliance using an OLS specification. However, since the time to first alliance is only available for those firms that were observed entering into an alliance, this analysis would automatically exclude all firms that did not enter an alliance with a pharmaceutical firm during the observation period. Moreover, under this specification the firm's patent protection could only be represented by the patent count at the date the firm enters into the alliance, even though the most interesting aspect is how *changes* in the firm's patent protection over time affect the timing of alliance entry.

To overcome these limitations, I instead estimate a Cox proportional hazards model with time-varying covariates (Wooldridge, 2001). Each firm enters the dataset on the first month of the year in which it was formed and exits either when it signs an alliance with a pharmaceutical firm or when it is acquired (so is no longer entering transactions under its own name). Since Recap reports the date of the alliance only to the nearest month, the time variable is the number of months since formation. The "hazard" is entering into an alliance with a pharmaceutical firm.

4.4.Explanatory variable: Strength of biotech firm's patent protection

To measure the strength of patent protection over its technology, I count the number of patent rights assigned to the biotech firm at each point in time.

4.4.1. Issued vs. filed patents

In order to receive a patent, a firm must first create the invention, reduce it to practice, describe the invention in a patent application, and then file the application with the patent office. The patent office then reviews the application, compares it against the prior art, determines whether the patent fits the requirements of being novel, useful, and non-obvious, and (if it meets these criteria) issues the patent.

The strictest definition of patent rights would only include issued patents counted from the issue date because it is only once the patent issues that the inventor (or the firm as assignee) has a legally enforceable right to the claimed technology.

However, the process of filing a patent application is a significant step, and the cost of doing so means that the firm must have a reasonable expectation that the patent will eventually issue. Moreover, once the patent issues, the legal rights date back to the date of the original application (often called the "priority" date). Hence, I use the number of patent rights counted from the filing date and refer to this as the "count of filed patents". Nevertheless, since the NBER patent data files only contain information on issued patents, it is important to emphasize that this count only includes patents that eventually issue. Moreover, since the most up-to-date version of the NBER patent file only contains information on patents issued prior to 31 December 2002,[11] the count only includes patents which issue prior to that date. Meanwhile, in order to include some information about the status of these patents, I also include a second variable that reflects the share of the patent applications that have issued at a particular point in time.

4.4.2. Application date

Each patent document lists a patent application date, which I extracted from the information on the Micropatent CDs. I use this date to create my first measure of the count of filed patents. However, patents often go through multiple iterations, including divisions into multiple applications and continuations (or continuations-in-part), before issue.[12] Hence the application date listed on the issued patent is not necessarily the date on which the firm filed the first relevant application or from which it claims priority over the claimed invention. Hence, for a sample of the patents in the database I extracted the date of the first related patent application from the patent's case history[13] and use the original filing date to create a second measure of the filed patents.[14]

4.4.3. Patent counts

Since patent rights vary widely in quality, a simple patent count is a very imperfect measure of the level of a firm's patent protection. In the past two decades patent researchers have tried various indicators to proxy for patent quality, including the patent renewals (Schankerman & Pakes, 1986), patent citations (Hall et al., 2005; Trajtenberg, 1990), claims (Tong & Frame, 1994), family size (Lanjouw, Pakes, & Putnam, 1998; Putnam, 1996),[15] forward patent citations, and whether the patent was litigated (Allison, Lemley, Moore, & Trunkey, 2004). However, Lanjouw & Schankerman (2004) pointed out that, while any of these indictors may be correlated with patent quality, if they are also correlated with unobserved variables that are not associated with quality but are correlated with the dependent variable then using these indicators as proxies for quality can be problematic. To correct for this concern in a study of research productivity, they constructed a composite index from the common factor in a factor model of four of these indicators (claims, family size, backward and forward citations):

$$\textit{patent quality} = \beta_1 \cdot \textit{claims} + \beta_2 \cdot \textit{family size} + \beta_3 \cdot \textit{backward cites} + \beta_4 \cdot \textit{forward cites}$$

4.4.3.1. Weighting by Lanjouw-Schankerman quality measure

I weight each patent by the Lanjouw & Schankerman quality measure in order to adjust for patent quality in this analysis. Lanjouw & Schankerman distinguished between 7 technological classes, including biotechnology and pharmaceuticals, and for each class produced a different set of weights for the indicators. In combining the various factors, I use the coefficients that Lanjouw & Schankerman estimated for the biotechnology industry, namely 0.72 for claims, 0.128 for backward citations, and 0.139 for forward citations. Since I do not have information on the fourth variable (family size) I am unable to include it in the calculation of the index. However, according to Lanjouw & Schankerman's calculations, the contribution of this indicator to the quality measure in biotechnology (0.013) is minor and hence its omission is unlikely to significantly affect the results.

4.4.3.2. Weighting by number of "forward" citations

As an alternative, I weight the patent count by the number of "forward" citations – that is, the citations from subsequent patents. The number of forward citations is the most popular indicator of patent quality used in the patent literature. Moreover, this indicator has been shown to proxy for the patent's social value (Trajtenberg, 1990), its private value (Harhoff, Narin, Scherer, & Vopel, 1999), the probability of litigation (Allison et al., 2004), the likelihood of opposition (Harhoff & Reitzig, 2004), and the market value of the firm (Hall et al., 2005).

4.4.4. Further limitations of the patent count measure

Nevertheless, these patent counts, based on issued patents recorded in the NBER patent file, are only approximate measures of all the relevant patent rights held by the biotech firm at a particular point in time.

4.4.4.1. Patents that are filed but never issue

Firstly, these measures omit patent applications that were filed but never issued. The USPTO only started publishing the patent applications themselves on 15 March 2001 (i.e., for patents that were pending on that date), which is right at the end of the observation period for this analysis.[16] Moreover, even for the short period in which this information is available, to my knowledge this data is not available in an easily analyzable format. Therefore it is not possible to capture fully the patent applications that the firm had pending or issued at a particular point in time.

4.4.4.2. Licensed patents

Secondly, in many cases, the biotech firm does not own (i.e., have assigned to it) all the relevant patents rights covering its technology. If the technology was spun out of a university, the patent rights relating to the technology are likely to be licensed from the university to the start-up firm. Even if the technology was developed in-house, another firm may have patents that relate to the technology.

Hence, the biotech firm must usually in-license to those patent rights in order to achieve a clean and unencumbered IP position and so its portfolio will include some licensed patents.

The NBER patent file does not include any information about patent licenses. Moreover, to my knowledge there is no comprehensive dataset of patents licensed to biotech firms,[17] so it is not possible to include the licensed patents in this analysis. The count of assigned patents is, therefore, the best available measure of the patent protection covering the firm's technology.

4.4.4.3. Assigned patents that are not related to the deal

Thirdly, the patents assigned to the biotech firm may include patents that are not related to the technology in the alliance.[18] Since the analysis is focused on start-up firms, the firms in this analysis are unlikely to hold patents over more than one, unrelated technologies so this may not be a big concern. Nevertheless, potentially this may be a limitation of the measures used.

4.4.5. Descriptive statistics & pairwise correlations

Table 2 presents some descriptive statistics for the set of firms used in this analysis. There are 650 firms in the dataset, 363 (or 56%) of which enter into a deal with a pharmaceutical firm to commercialize their technology at some stage during the period of observation (i.e., 1976-2002). Those 363 firms take on average 5.2 years from founding to their first alliance with a pharmaceutical firm, although this ranges from 3 months to over 20 years. 316 firms make an IPO during the observation period and 120 are acquired.[19]

Table 2: Descriptive statistics

Variable	*N*	*mean*	*s.d*	*min*	*max*
Year of founding	650	1991.75	6.28	1976	2002
Firm has a pharma deal during period 1976-2002 (dummy)	650	0.56	0.50	0	1
Years to pharma firm deal[1]	363	5.21	3.75	0.25	20.50
Years to IPO[1]	316	6.16	3.74	0.50	21.08
Years to acquisition[1]	120	10.39	5.24	0.33	21.83
Years to first patent filed (measure #1)[2,3]	465	4.05	3.95	0	22.17
Years to first patent filed (measure #2)[2,4,5]	454	3.34	3.90	0	22.17
Years to first patent filed (measure #2)[2,4,6]	170	3.94	4.71	0	22.17
Years to first patent issued[2]	465	6.57	4.26	0	24.77
Firm has patent rights at time of pharma deal (dummy)	363	0.54	0.50	0	1
Number of patents at time of first pharma deal[1]	363	1.30	3.79	0	41
Number of patents at time of first pharma deal weighted by number of forward citations[1,7]	363	6.37	25.55	0	265
Number of patents at time of first pharma deal weighted by Lanjouw-Schankerman quality measure[1,7,8]	363	14.25	54.26	0	782.55
Number of filed patents at time of first pharma deal (measure #1)[1,3]	363	3.69	7.56	0	57
Number of filed patents at time of first pharma deal (measure #2)[1,4]	141	1.80	5.28	0	48
Stage of commercialization of alliance product at time of signing[9]	241	2.08	1.68	1	8

Notes:

1. For firms that actually sign a deal, receive an issued patent, make an IPO, or get acquired (respectively).
2. For all firms that have patent rights, whether or not they are observed entering a deal with a pharma firm.
3. Counting patent rights from application date listed on the patent that issues.
4. Counting patent rights from first related patent application (from patent case history).
5. Includes any firms for which the original patent filing date was available for at least one patent.
6. Includes only firms for which the original patent filing date was available for all patents.
7. Counting forward citations from only those patents that issue within 5 years of the original patent.
8. Based on weighted sum of forward citations, backward citations, and claims, as described in Lanjouw & Schankerman (2004).
9. Based on 8-stage scale coded by Recap where 1="Discovery" & 8="Approved".

On average it takes around 3.3 years for a firm to file its first patent (measured from the date of the first related patent application) and 6.6 years before its first patent is issued. By the time they sign their first deal with a pharmaceutical firm, the biotech firms have on average 3.6 filed patents (out of those which eventually issue) and have been issued with 1.3 patents. Each of those patents receives on average 4.9 citations within 5 years of being issued and has a Lanjouw-Schankerman quality measure of 10.9.

The low number of patent rights at the time it enters a deal is noteworthy. In part, this reflects the early stage that these firms are in their development. However, since the firms may also have licensed patents or may have patent applications that never issue (neither of which is accounted for in this analysis), this number does not necessarily represent the extent of their patent portfolio.

Table 3 presents pairwise correlations between the explanatory variables used in the analysis. As expected, there is a very high correlation between the two measures of the count of filed patents (0.984). There is also a very high correlation between the number of issued patents and number of filed patents counted from the filing date listed on the issued patent (0.960).[20] The correlation between these two variables is significantly lower at the time of the deal (0.831), indicating that the high correlation is likely due to collinearity between the two variables at early stages of the firm's life.[21] The correlation between these variables is also lower (0.826) when number of filed patents is counted from the filing date on the first related patent application.

Table 3: Correlations between explanatory variables

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Number of issued patents	1.000									
(2)	Number of filed patents (measure #1)[1]	0.960	1.000								
(3)	Number of filed patents (measure #2)[2]	0.826	0.984	1.000							
(4)	Number of filed patents not yet issued (measure #1)[1]	0.629	0.821	0.728	1.000						
(5)	Number of filed patents not yet issued (measure #2)[2]	0.273	0.729	0.782	0.961	1.000					
(6)	Share of filed patents that have issued (measure #1)[1]	0.349	0.308	0.396	0.144	0.034	1.000				
(7)	Share of filed patents that have issued (measure #2)[2]	0.546	0.426	0.370	0.054	0.025	0.951	1.000			
(8)	Number of issued patents at time of first pharma deal[3]	0.055	0.046	0.415	0.015	0.235	0.165	0.184	1.000		
(9)	Number of filed patents at time of first pharma deal (measure #1)[1,3]	0.062	0.073	0.554	0.077	0.509	0.131	0.148	0.831	1.000	
(10)	Number of filed patents at time of first pharma deal (measure #2)[2,3]	0.404	0.565	0.594	0.517	0.541	0.191	0.152	0.653	0.990	1.000

Notes:
1. Counting patent rights from application date listed on the patent that issues.
2. Counting patent rights from first related patent application (from patent case history).
3. For firms that actually sign a deal.

4.5.Results

Table 4 presents the results of the base-line hazard-rate analysis. The dependent variable is the ‘hazard’ of the biotech firm entering into its first deal with a pharmaceutical firm. The explanatory variables used in this analysis are the logged count of filed patents, an indicator variable for whether the firm had filed a patent, and the share of filed patents that had issued.

Panel A shows the results of an analysis using the number of filed patents counted from the filing date listed on the issued patent. The results in Column (1) show that the likelihood of the firm entering a deal with a pharmaceutical firm is positively correlated with the count of filed patents. Column (2) shows that this effect is not explained entirely to filing the first patent – the hazard rate increases with subsequent increases in the count of filed patents. Meanwhile, column (3) shows that the likelihood of entering into an alliance decreases as these patents issue. Column (4) shows that both effects persist when year fixed effects are added.

Panel B shows the results using the alternative measure of the number of filed patents; that is, counting the number of filed patents from the application date of the first related patent application cited in the patent’s case history. The results of this analysis show an even stronger positive effect of the number of filed patents on the hazard rate and a similar negative effect of the share of patents that have issued. However, the effect of the indicator variable is not significant.[22]

Table 4: Effect of biotech firm's patent rights on hazard of first pharma deal (base-line analysis)

Dependent variable: Hazard of first pharma deal

	(1)	(2)	(3)	(4)
Panel A: Counting filed patents from date on issued patent				
Number of filed patents (log)	0.302 (0.051)***	0.182 (0.079)**	0.240 (0.081)***	0.242 (0.081)***
Biotech has any filed patents (dummy)		0.354 (0.167)**	0.459 (0.168)***	0.444 (0.169)***
Share of filed patents that have issued			-0.755 (0.237)***	-0.813 (0.242)***
Year fixed effects	N	N	N	Y
Observations (year-month)	51980	51980	51980	51980
Psuedo R^2	0.01	0.01	0.01	0.02
X^2	31.39	35.81	46.94	74.40
Number of firms	650	650	650	650
Number of firms entering deal	364	364	364	364
Panel B: Counting filed patents from first related patent application				
Number of filed patents (log)	0.491 (0.121)***	0.662 (0.224)***	0.706 (0.221)***	0.620 (0.221)***
Biotech has any filed patents (dummy)		-0.308 (0.351)	-0.154 (0.350)	-0.206 (0.353)
Share of filed patents that have issued			-0.685 (0.356)*	-0.748 (0.360)**
Year fixed effects	N	N	N	Y
Observations (year-month)	27637	27637	27637	27637
Psuedo R^2	0.01	0.01	0.01	0.04
X^2	14.52	15.29	19.29	62.18
Number of firms	355	355	355	355
Number of firms entering deal	142	142	142	142

Standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Notes:

1. Counting patent rights from application date listed on the patent that issues.
2. Counting patent rights from first related patent application (from patent case history).

Table 5 presents the results of the same analysis as in Panel A of Table 4 but with the patent counts weighted by, first, the Lanjouw-Schankerman quality measure (Panel A) and then by the number of forward citations that the patent receives within 5 years (Panel B). The positive effect of filed patents and the negative effect of the issued share are slightly weaker in both cases but still significant. The effect of the indicator variable is insignificant in both cases.

Table 6 shows the results of the analysis repeated on just the subset of those firms observed entering into a deal. This analysis includes dummies for the stage of commercialization of the product at the time of signing, and interaction effects with the two primary explanatory variables. Column (1) shows that the effect of filed patent rights on the hazard rate is the same as in the previous results, but the effect of the share of patents that have issued, although negative, is not significant. These effects persist when the stage dummies and interactions are added in columns (2) to (5). The weaker effect might be due to either the reduction in sample size or the fact that all comparisons are now against firms that eventually sign an alliance.

Table 5: Effect of biotech firm's patent rights on hazard of first pharma deal (using weighted counts)

Dependent variable: Hazard of first pharma deal

	(1)	(2)	(3)	(4)
Panel A: Patents weighted by Lanjouw-Schankerman quality measure[1,2]				
Number of filed patents (log)[3]	0.122	0.055	0.120	0.146
	(0.028)***	(0.073)	(0.074)	(0.073)**
Biotech has any filed patents (dummy)		0.296	0.281	0.281
		(0.292)	(0.288)	(0.284)
Share of filed patents that have issued			-0.052	-0.060
			(0.017)***	(0.017)***
Year fixed effects	N	N	N	Y
Observations	51980	51980	51980	51980
Psuedo R^2	0.00	0.00	0.01	0.02
X^2	18.19	19.20	31.43	67.92
Number of firms	650	650	650	650
Number of firms entering deal	364	364	364	364
Panel B: Patents weighted by number of forward citations[2]				
Number of filed patents (log)[3]	0.188	0.117	0.173	0.183
	(0.034)***	(0.058)**	(0.063)***	(0.063)***
Biotech has any filed patents (dummy)		0.293	0.265	0.262
		(0.190)	(0.191)	(0.190)
Share of filed patents that have issued			-0.097	-0.114
			(0.047)**	(0.049)**
Year fixed effects	N	N	N	Y
Observations	51980	51980	51980	51980
Psuedo R^2	0.01	0.01	0.01	0.02
X^2	28.40	30.72	36.08	67.42
Number of firms	650	650	650	650
Number of firms entering deal	364	364	364	364

Standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Notes:

1. Based on weighted sum of forward citations, backward citations, and claims, as described in Lanjouw & Schankerman (2004).
2. Count of forward citations includes only citations from patents that issue within 5 years of the original patent.
3. Counting patent rights from application date listed on the patent that issues.

Table 6: Interactions between patent rights and stage of commercialization of biotech's first pharma deal

Dependent variable: Hazard of first pharma deal

	(1)	(2)	(3)	(4)	(5)
Number of filed patents (log)[1]	0.374 (0.077)***	0.407 (0.077)***	0.404 (0.077)***	0.398 (0.076)***	0.387 (0.085)***
Share of filed patents that have issued[1]	-0.021 (0.288)	-0.025 (0.288)	-0.031 (0.284)	-0.027 (0.285)	-0.387 (0.343)
Stage of commercialization at signing = Lead Molecule[2] (dummy)		0.160 (0.185)	0.046 (0.157)		
Stage of commercialization at signing = Preclinical[2] (dummy)		-0.136 (0.238)			
Stage of commercialization at signing = Phase I[2] (dummy)		-0.437 (0.303)	-0.580 (0.188)***	-0.548 (0.173)***	-0.935 (0.279)***
Stage of commercialization at signing = Phase II[2] (dummy)		-0.674 (0.260)***			
Stage of commercialization at signing = Phase III[2] (dummy)		-0.491 (0.389)			
Stage of comm. at signing = BLA/NDA Filed[2] (dummy)		-1.038 (1.007)			
Stage of commercialization at signing = Approved[2] (dummy)		-0.123 (0.458)	-0.123 (0.458)		
(Stage = Phase I - Approved)[2] x (Number of filed patents, log)[1]					0.052 (0.188)
(Stage = Phase I - Approved)[2] x (Share of filed patents that issued)[1]					1.659 (0.636)***
Observations	14003	14003	14003	14003	14003
Psuedo R^2	0.01	0.02	0.02	0.02	0.02
X^2	25.41	39.38	37.50	36.60	45.42
Number of firms	241	241	241	241	241
Number of firms entering deal	241	241	241	241	241

Standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Notes:

1. Counting patent rights from application date listed on the patent that issues.
2. Based on stage of commercialization of the alliance product at time the deal is signed.

Column (2) shows the analysis with dummies added for the eight stages of commercialization of the biotech's product at the time it enters the alliance. The omitted variable is the dummy for the "Discovery" stage. Columns (3) and (4) show the same analysis but with the stage variable grouped into four and two categories respectively.[23] Columns (2) to (4) show that, in general, the further along the commercialization process that the product is at the time the biotech firm enters into its first deal, the lower the hazard rate; that is, the longer it takes the biotech firm to sign its first deal with a pharmaceutical firm.

More interesting is the relationship between the effects of filed patents and the clinical-stage dummy on the hazard rate, shown in Column (5). We would expect that the effect of patents on alliance entry to be weaker at later stages in the commercialization process. This is because once a product reaches clinical trials the primary patent rights on the invention have long since been filed, so a marginal increase in the number of patent rights will not greatly affect the risk of expropriation. At the same time, since the technological risk has largely been resolved, financial investors will be more interested in signals of the product's likely progress through clinical trials and will not put as much value on patent rights. Filing additional patent applications may enhance market exclusivity if they 'tighten the net' around the technology or extend the length of patent protection if the new patents claim an improvement over the original one. However, by entering into the alliance before these additional patent applications are filed, the pharmaceutical firm can get directly involved in patent prosecution process and hence increase the likelihood of that happening. Hence, overall we would expect the effect of patent filing on the hazard rate to be lower for deals signed once the product has reached the clinical stage – that is, we would expect the interaction effect between the number of patent rights and the clinical-stage dummy to be negative. Similarly we would expect the effect of patent issue to be less negative (or more positive) – that is, the interaction effect with the clinical-stage dummy would be positive.

The interaction effect between the number of filed patents and the clinical-stage dummy shown in column (5) is not significant. However, the interaction effect between the clinical-stage dummy and the share of issued patents is positive and significant, as predicted. This means that the share of patents that have issued is significantly more positive at the clinical stages. Obversely, the share of patents that have issued is significantly more negative at the pre-clinical stages.

5. Discussion

The result that, in general, the possession of more filed patents is correlated with a greater likelihood of the firm entering a technology commercialization deal is consistent with the Merges (2005) hypothesis that patent rights facilitate transactions, as well as with more general notions in Teece (1986) and Cohen et al. (2000) about the importance of patent rights for appropriating returns in this industry. Nevertheless, since both the number of filed patents and the likelihood of entering into a deal are correlated with improvements in the underlying technology, and the last variable is omitted from this analysis, it is not possible to draw any definite conclusions from this result about the effect of patent rights *per se*.

The finding that the hazard rate decreases with the share of patents that have issued is more interesting, and potentially more substantial. This finding suggests that patent filing and patent issue impact the biotech firm's strategy in different ways – patent filing makes the firm more likely to enter into a deal, while patent issue decreases it. It also provides a way to reconcile the conflicting predictions in section 2. That section argued that, since patent rights mitigate the biotech firm's risk of expropriation and increase the chance of achieving market exclusivity for the final product, obtaining patent rights increases the likelihood that the firm will enter an alliance. However, since obtaining patent rights signals the value of the firm's underlying technology to financial investors, making them more willing to finance independent development by the biotech firm, it may reduce the biotech firm's urgency of entering into an alliance.

The result that patent filing increases the likelihood of entering into an alliance suggests that patent filing enables the firms to transact. Hence filing a patent must be sufficient to provide the biotech firm with some assurance against expropriation and to reassure a prospective partner that the product will have some exclusivity on the market. However, the result that the hazard rate decreases as those patents issue suggests that the biotech firm does not acquire the ability to delay alliance entry until patent issue. Therefore it appears that outside investors are unwilling to finance the biotech firm to develop the technology alone until they see issued patents.

This interpretation accords with what we know about the different capabilities of pharmaceutical firms (on the one hand) and purely financial investors (on the other) with respect to the financing of technology commercialization. A pharmaceutical firm's technological expertise, combined with the ability to examine the patent filings closely during the due diligence process, means that it has both the sophistication and the information to judge for itself whether the patent is likely to be issued. Hence pharmaceutical firms are willing to enter into alliances and invest in the technology at earlier stages in the commercialization process. By contrast, purely financial investors, especially public equity investors, generally lack the information and the sophistication to evaluate the value of an invention for themselves. Hence, they rely to a much greater extent on objective signals such as the determination of the patent office, and so place much greater weight on issued patents than filed patents.

Nevertheless, this interpretation is subject to several caveats. Firstly, I assume that the reason a biotech firm is more likely to delay alliance entry after patent issue is because it is better able to raise finance from outside investors (i.e., other than from pharmaceutical firms). However, I have not tested this assumption directly. Although such a test is beyond the scope of this paper, it would be helpful to clarify what is causing the reduction in the hazard rate. It may be possible to test this relationship by regressing the biotech firm's financing history on its patenting history in a manner similar to Mann & Sager (2007).

Secondly, the finding – and the interpretation that I given to it – about the differential role of filed and issued patents is likely to be industry-specific. We know that while patent rights are generally considered a fairly effective means of protecting intellectual property in the biopharmaceutical industry, they are a less effective mechanism in other technology-based industries such as software and semiconductors (Cohen et al., 2000). We also know that firms in the biopharmaceutical industry typically have fewer patents (Mann et al., 2007), and these patents are more likely to be taken at their face value – that is, other firms are more likely to accept them as valid without the holder establishing in a court (Lemley, 2007) – than firms in those other industries. Hence, while pharmaceutical firms and outside investors may be willing to transact with biotech firms upon patent filing and patent issue (respectively), their counterparts in other industries may require other assurances about the start-up technology firm's intellectual property protection.

Furthermore, the primary of the technology commercialization alliance in commercialization strategy is unique to the biopharmaceutical industry. Start-up firms in the software or semiconductor industries are more likely to commercialize their technology alone (i.e., partnering only with purely financial investors) or alternatively to sell out entirely to an established firm. Hence, although firms in these other industries do enter into alliances, the timing of the alliance may not be such a critical issue and may also be less dependent on the level of intellectual property protection.

In conclusion, this paper has shown that patent filing and patent issue have opposite effects on the timing of alliance entry: while filing patents increases the likelihood of alliance entry (and so brings forward the date of entry), the issue of those patents decreases it (i.e., delays entry). I attribute this result to the different types of assurances that intellectual property protection provides to pharmaceutical firms (on the one hand) and purely financial investors (on the other) before they are willing to transact with a biotech firm.

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[1] Since the NBER file only includes information on issued patents, the count of filed patents that the firm had at any point in time only includes patents that were eventually issued.

[2] I define *stronger* patent rights over a technology to mean that there are patent rights covering the technology, as against the situation when the same technology is not protected by patents, or when the technology is covered by more patents, as against the situation when it is protected by fewer patents. By contrast, other researchers and commentators often refer to stronger patent rights when the whole regime of patent protection is stronger (e.g., when the definition of 'patentable subject matter' is extended).

[3] The interviews, discussed in Wakeman (2007), revealed that this is a reason why pharmaceutical firms will not sign a non-disclosure agreement, at least until they are convinced that the technology is novel and interesting.

[4] Patent law distinguishes between "design", "plant", and "utility" patents, but by far the largest category of patents – and the category into which most biotech innovations fall – is utility patents. In order for a utility patent to be valid, an inventor must claim a concept, idea, or item that is useful, novel, and non-obvious. The invention can be a process, a machine, an article of manufacture, or a composition of matter (or an improvement of any of these items).

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[5] The SEC filing rules require that publicly listed firms file anything that may be "material" to the firm's value. The Alliances database currently contains over 19,000 high-level summaries of biotech alliances signed since 1973.

[6] The firm name is standardized across the many variations recorded by the PTO.

[7] Recap identifies each firm as "Biotech, "Device", or "Pharma", although for a number of firms the firm type is not identified. I rely on Recombinant Capital's classification of firms into biotech and pharma. I define a mature biotech firm as a firm that has done at least 10 alliances and has done more alliances as a licensee than as a licensor. Under these criteria, Genentech and Amgen switched from being a start-up technology firm to an established product firm in 1995, and Genzyme in 1996.

[8] In a few cases, Recap has created a record for a biotech firm in order to record their contact details, even though it has no record of any deals by that firm.

[9] I include all firms that Recap classifies as "Pharma" firm in the set of pharmaceutical firms. I also include any "Biotech" firm which (at the date of the alliance) is marketing pharmaceutical products.

[10] Recap classifies each transaction into a range of "types", for which it provides standard definitions. An individual agreement may fall into multiple categories. Using these definitions I determined that the following transaction types involve the transfer of an intellectual property asset: Co-Development, Co-Market, Co-Promotion, Collaboration, Development, License, Research, and Sublicense. Meanwhile, I excluded any transactions that were categorized into the following types: Acquisition, Merger, Settlement, and In-licensed Products (i.e., where the biotech firm in-licenses products or technology from a pharmaceutical firm).

[11] The original NBER patent files are available at the NBER website (http://www.nber.org/patents/) but the most up-to-date data is available at Bronwyn Hall's website (http://elsa.berkeley.edu/~bhhall/bhdata.html).

[12] See Graham & Mowery (2004) for a detailed description of this practice and its role in the patent strategy of software firms.

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[13] I extracted the patent case history for all firms in the dataset. If the patent case history filed in the patent document is empty I interpreted this to mean that there are no other relevant patent applications, so the application date listed on the issued patent is the original filing date. For the remainder, I used a Stata program to parse the case history text into words that look like part of a date, reassembled these to create a list of dates contained in the case history, selected the first application date in time if there was more than one date, and then doubled-checked this date against the text in the patent's case history. However, since Stata SE only handles 244 characters of text, if the case history was longer this method did not produce a complete list of dates. This was the case for 1768 (or 15%) of the 12174 patents assigned to the firms in the dataset. The only way to extract the date of the first application for these patents would be to search each patent record individually on the PTO website, which would be a very time-intensive process. Instead, I left the original application date missing. However, this meant that I was able to the count the filed patents from the original application date only in those cases when I knew the original application date for all patents in the firm's portfolio.

[14] The resulting count of filed patents includes both pending patents (i.e., patents that had been filed but not yet issued) and issued patents. However, I exclude expired patents (i.e., patents more than 17 years after their issue date or 20 years after their application date, depending on the date) from both counts.

[15] Measured by the number of international applications lodged for the patent.

[16] In fact, the USPTO only publishes patent applications after an 18-month lag from their filing date.

[17] There is no general obligation on either the licensee or licensor to disclose a licensing arrangement. In some cases, these patent licenses are disclosed to the SEC under the materiality requirement and hence available on EDGAR (http://sec.gov/edgar.shtml) or databases such as Recap that collect information from EDGAR. In other cases, these licenses are included in datasets of university licensing collected by other researchers (see, e.g., Lowe & Ziedonis, 2006).

[18] The only way to ensure that only relevant patents were counted would be to check each patent individually against the alliance document. For instance, Gans, Hsu, & Stern (2006) searched for a

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match between the key words in the patent and the alliance to establish a relationship. However, since there over 1300 potentially relevant patents, this would involve substantial work.

[19] The number of firms making an IPO or being acquired shown in Table 2 includes firms that do so *after* entering their first deal with a pharmaceutical firm. By contrast, Table 1 shows that 74 firms are acquired *before* they enter into an alliance with a pharmaceutical firm.

[20] The first measure of filed patents counts the number of patents from the filing date listed on the patent that issued. The second measure of filed patents counts from the filing date of the first related patent application listed in the patent's case history.

[21] In just under than half of the observations, both variables are zero.

[22] Since the count of filed patents by this measure begins from the priority date, it is arguably a more accurate measure of the number of filed patents that the firm had at that particular point in time. However, because the time from filing to issue includes continuations and divisions, the share of the patents that have issued may to some extent reflect the tendency to pursue continuations.

[23] In Column (3) the four categories are Discovery, Lead Molecule or Preclinical, Phase I to BLA/NDA filing, and Approved. In Column (4) the categories are Discovery to Preclinical and Phase I to Approved. The omitted variable is Column (3) is the dummy for the "Discovery" stage and in Column (4) is the dummy for Discovery to Preclinical.