IPRs, Economic Performance and the Value of Patents – Five Essays from Different Perspectives

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STRUCTURE

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PREFACE

"Innovation is a powerful explanatory factor behind differences in performance between firms, regions, and countries. Firms that succeed in innovation prosper, at the expense of their less able competitors."

Jan Fagerberg – The Oxford Handbook of Innovation

The Economics of Innovation – A Brief Introduction

The introductory quotation by Jan Fagerberg shows the importance of innovation as a basic factor for economic growth at the micro and at the macro-level, which has at latest been acknowledged within the framework of endogenous growth theory (see for example Romer, 1994). On the foundations of Joseph Schumpeter, who can be seen as the father of innovation research, Michael V. Posner (1961) developed the product cycle model, which states that countries that introduce new goods to a market enjoy economic advantages. New or advanced products, which integrate superior technology will form temporary oligopolistic markets as it takes considerable time and involves costs for a competing country to absorb those technologies and apply them to its own manufacturing processes (see also Dosi and Soete, 1983; 1991; Krugman, 1979; Vernon, 1966; 1979). At the micro level this corresponds to the discussion in the empirical and theoretical literature, which states that the long-term development of market shares is not only driven by price competition, but also by technology and quality competition (Kleinknecht and Oostendorp, 2002; Legler and Krawczyk, 2006; Maskus and Penubarti, 1995; Utterback and Abernathy, 1975).

The successful completion of the innovation process alone, however, is not a sufficient condition to obtain the expected benefits from innovation, since firms also have to be able to appropriate these benefits, i.e. to prevent its competitors from imitating their results (Hanel, 2008). This is due to the nature of innovation, or (technological) knowledge in general. In contrast to traditional goods produced and traded on markets, innovation is characterized by its public good character, meaning that it is non-rival and non-excludable (Schmoch and Grupp, 1990; Stiglitz, 1995). The non-rivalry aspect implies that an increase in the number of users of technological knowledge does not limit the value of this knowledge, since anyone with a given knowledge can achieve potentially equal benefits. Due to the non-excludability element, a new technology can also easily be adopted by other companies. Stated more technically, this leads to a suboptimal supply because the (public) good can subsequently be reproduced at zero marginal cost, implying that initial R&D costs cannot be recouped (Stiglitz, 2008). Thus, innovating firms cannot use their inventions exclusively and transfer them into economic benefits without further institutional arrangements. In other words, due to its public good character, the generation of knowledge and its commodification into an innovation suffers from market failures, i.e. lacking incentives for firms acting under economic rationality to invest in research and development activities. Thus, state intervention and the establishment of appropriate institutional arrangements are needed in order to enable private appropriation of innovation rents and to provide future incentives for (private) innovation efforts.

The Intellectual Property Rights System

The most important institutional arrangement to prevent this market failure and to provide the public good of knowledge generation is the intellectual property rights (IPR) system. It guarantees excludability to the initial inventor and provides the owner of an IPR a mechanism for pursuing infringers for a limited time period (Rammer, 2007). This can be regarded as an incentive for innovators to invest in and generate new knowledge and new technologies. In exchange for this legal protection, IPRs are coupled with a disclosure requirement, meaning that all information covered by the respective IPR has to be disclosed after a given time period, which strengthens the aspect of non-rivalry and leads to a diffusion of knowledge. IPRs thus are a state guaranteed instrument that attempts to balance static efficiency – in the form of monopolistic power to the innovator for a fixed period of time – with a dynamic efficiency by making knowledge available to the public to foster further research (Stiglitz, 1999).

IPRs, like patents, on which this thesis is focussed, can therefore be seen as an output of R&D processes, which at the same time provide an input to future market activities. Especially in technologically relevant markets, patents are the most important visible artefacts of R&D processes and can thus be seen as the most important innovation indicator to assess technological competitiveness at the micro and the macro level (Freeman 1982; Frietsch and Schmoch 2006; Grupp 1997; 1998). However, the existence of the patent system also offers possibilities to exploit patents for strategic purposes. The increase in strategic patenting is a rather recent phenomenon that has been found to be a factor in explaining the massive rise in patent applications during the 1990s, which is known as the patent surge or patent explosion (Blind et al., 2006; Cohen et al., 2002; Frietsch et al., 2010; Harabi, 1995; Sheehan et al., 2003). Several studies have found that the patent system is more intensively used by companies for various other strategic motives and has therefore at least partly uncoupled from the traditional motive of protecting inventions from being imitated (Blind et al., 2009), implying that the use of patents as an indicator of innovative activities becomes limited or at least strategic patenting has to be taken into account. Strategic motives are manifold and include blocking competitors, reducing possible future litigation risks, using patents as bargaining chips in cross-licensing deals, gaining access to financial markets, and preventing key technologies from being invented around (see for example Blind et al., 2009).

Yet, patents are not the only instrument to secure returns on R&D and other innovation activities. Also other IPRs, like trademarks, industry designs, utility models and copyright, grant innovators an exclusive right to use their results from innovation activities (Rammer, 2002; 2007). Taken together, they are commonly referred to as formal appropriation mechanisms, because they are based on state legislation and require a formal application or enforcement before state authorities, at least in the case of a suspected infringement. However, there is also a second category of mechanisms to prevent third parties from imitating, which are referred to as informal appropriation methods. Studies in the USA as well as Germany show that informal mechanisms have gained increased importance in order to secure returns on innovative activities since the 1980s (Cohen et al., 2000; Levin et al., 1987; Rammer, 2002). These mechanisms are not accompanied by an enforcement mechanism and cover different actions firms can undertake to maximize their expected returns on innovation, like keeping inventions secret or benefit from lead-time advantages.

Indicators of Patent Value

As already described, formal appropriation mechanisms, like patents, are not the only - and often not even the preferred - alternative for the protection of technology related knowledge. Keeping in mind that firms do not solely rely on patents – especially against the background of using patents as indicator for the outcome of R&D processes – it is nevertheless important to differentiate between technologically valuable patents and patents that might only be used strategically in technology competition (which does not mean that strategic patents do not have an economic value).

Patent quality or patent value might be viewed differently, depending on the viewer's perspective. According to Frietsch et al. 2010, at least five different concepts of patent value can be identified, which run along two different dimensions. The first dimension targets the benefitting entity (private or social), and the second one targets the modes of value (economic or technological) (for a more detailed overview and discussion on the dimensions of patent value see Frietsch et al. 2010).

According to Frietsch et al. (2010) the first dimension is related to the conceptualization of the patent system itself and ranges from private to social benefits. Private benefits accrue due to the right of excluding others from using protected inventions, therefore generating monopoly rents for a limited amount of time. On the other hand, society will benefit from the advancement of science and technology by increased R&D investments, the disclosure of information on patented inventions and possible technology spill-over effects that foster the generation of enhanced technologies. The second dimension is related to the first and spans from economic to technological value. A patent is economically valuable if it can easily be transferred into economic benefits. Apart from this pure economic value, patents can be technologically valuable, in the sense that research activities of one technology may increase the absorptive capacity of inventors (Cohen and Levinthal 1990) or once again as technology spill-overs, contributing to the development of even more advanced technologies. Along the dimension of economic and technological value, also the strategic potential of patents comes into play. Patents may create strategic benefits for inventors, which can ultimately be transferred into economic benefits (Frietsch et al. 2010).

Since patents can differ from one another both in economic and technological value, counting patents could lead to a distorted picture of the technological base of firms, regions or countries. Therefore, some more advanced patent indicators have been proposed in the literature to correct for the quality or value of patents. These relate, for example, to patent citation measures, the size of inventor teams and even legal events, such as oppositions (see for example Harhoff et al. 2003). The theoretical background as well as the indicators, their meaning and interpretation will be discussed in more detail in the respective chapters.

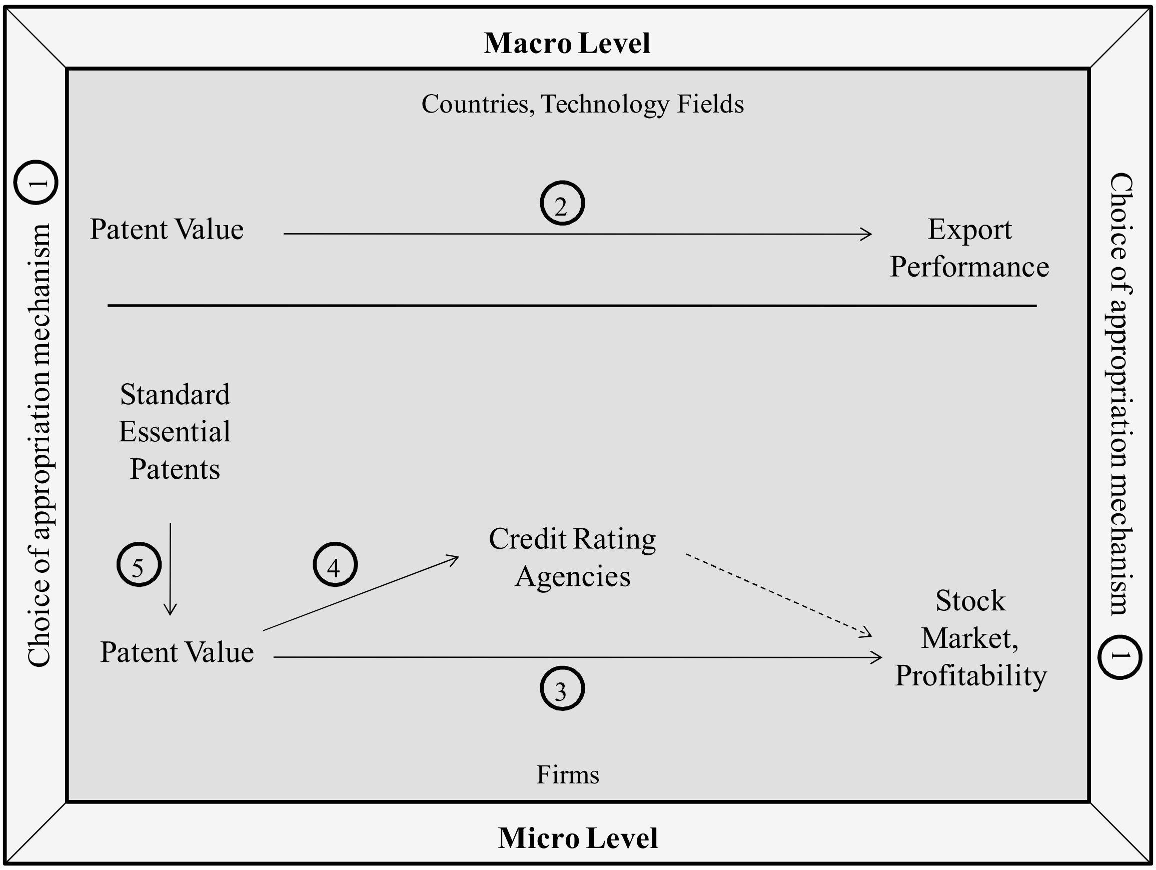
Chapter Overview

In this section, I would like to briefly introduce the topic and the major research questions around which the thesis is centered. It consists of five papers within the context of the economics of patents. More specifically, it is focussed on the patent quality or patent value discussion. Patents carry a certain value that can manifest itself in multiple facets, or along several dimensions, but can hardly be measured directly. Thus, a multitude of indicators, which serve as a proxy or correlate of patent value, has been proposed in the literature. Yet, it is still an open question, which of the proposed indicators is able to serve as a valid estimate of the (economic) value of patents at which level of analysis. In other words, the valuation of patents might work differently at the micro and the macro level. This is the main question that lies at the heart of the thesis. It aims to give evidence on which indicators of patent value are suitable at which level of analysis and to provide some more insight on how the frequently discussed "patent value" ultimately translates itself into economic benefits.

Yet, before we enter the more specific discussion on patent quality, we should get some broader understanding of intellectual property management in general and which (formal as well as informal) mechanisms firms use to appropriate returns on innovative activities. This will be in the focus of the first paper, which can be seen as a common background that is used to integrate all further papers into a broader context. Building on this common background, the second paper starts to dig deeper into the patent value discussion. It deals with the valuation of patents at the macro level, i.e. the level of countries and technology fields. From that point onwards, the analyses are taken down to the micro level. Besides having a closer look at the connection between patent quality and the economic performance of firms in general, the question is analyzed if credit rating agencies – as intermediares between firms and the market – evaluate the innovative performance of firms in terms of quantity and quality, and thus fulfill their information function regarding the technological performance of companies. In a last step, it is analyzed if patents that are declared as being essential to a technology standard reveal significant power in explaining the economic performance of firms and can be used as an indicator of patent quality at the firm level.

An overview of the different papers that are covererd by the thesis is displayed schematically in Figure 1, which presents the very general framework and shows how the papers interrelate. The numbers in the figure represent the respective papers and show to which level of analysis they belong.

Figure 1 The general framework



The discussion on strategic patenting and the increased importance of informal appropriation mechanisms gives rise to "PART I: INTELLECTUAL PROPERTY RIGHTS AND INFORMAL APPROPRIATION MECHANISMS" of the thesis**,** where we find the **first paper** entitled "The Use of Patents and Informal Appropriation Mechanisms - Differences between Sectors and among Companies". The paper deals with the question which firm characteristics foster patenting and which mechanisms firms can employ in order to appropriate their returns on innovation activities and thus shall serve as a common background for the rest of the thesis, against which all further papers – that are focussed on patents only – should be assessed.

On its very basis, it opts to provide a comprehensive overview about the possibilites of firms to appropriate their investments in innovation activities against the background of the rise in strategic patenting. In a second step, the patent activities of firms as well as their preferences for different formal and informal appropriation mechanisms are analyzed. For this purpose, firms are differentiated by several characteristics, e.g. their size, industry sector and their degree of internationalization, to answer the question whether special firm characteristics can influence what is the best appropriation option for the firm.

It can be shown that only a very small percentage of firms evaluate formal appropriation methods as highly important while at the same time giving a low importance to informal methods. Yet, many of the firms state that a combination of appropriation mechanisms is most suitable to generate returns on innovation. This implies that although informal appropriation methods, like secrecy, are an important means to protect one's own technology from being imitated, building and upholding a patent portfolio seems to be required in order to transfer the results of R&D into economic benefits.

We thus have to take into account that patents are by far not the only and often even not the most important appropriation mechanism. There are other options to appropriate returns on innovavation activities, which are used frequently. However, patents remain an important mechanism and seem to be required in order to transfer the results of R&D into economic benefits. The question of how to differentiate patents according to their economic value – preferably already at an early stage of the patent application process – has thus gained increased importance. However, as already been stated, it is still unclear which of the indidcators proposed in the literature is able to serve as a valid estimate of patent value at which level of analysis.

This issue will firstly be adressed in "PART II: THE VALUE OF PATENTS – A MACRO-ECONOMIC PERSPECTIVE", where the macro level will be in the focus. In this section, we find the **second paper** of the thesis, entitled "Patent Indicators for Macroeconomic Growth - The Value of Patents Estimated by Export Volume", which deals with the question, if the value of a patent portfolio of a whole economy can influence its performance on international markets. More specifically, the influence of patent portfolios on the economic performance of countries at the level of technology fields is examined. The analysis attempts to show if exports can be used to evaluate patents and if further indicators of patent value, like patent forward citations or the average family size of a patent portfolio, have any significant effects on the export performance of a country.

In fact, we find that patents and exports are strongly correlated. However, most of the indicators of patent value do not show any significant effects at the country level, although several absolute as well as relative measures of export performance are taken into account. The conclusion is that high-technology patent applications that are targeted towards several markets as such – without any additional indication of value – seem to be a reliable and handy predictor of export activities, especially in high-technology areas. At the aggregate level of countries, the differences in the values of firm's patent portfolios are blurred, implying that a focus on high-technology patents seems to be adequate for the assessment the technological performance at the macro-level. High-technology patent applications already seem to serve as a quality filter in itself.

At this stage, the micro level turns into our focus in "PART III: THE VALUE OF PATENTS – A MICROECONOMIC PERSPECTIVE". It has already been found that the economic value of patents is not determined solely by the characteristics of a single patent, but by various factors of a technology or a firm and its interactions with competitors and markets. This means that the economic or commercial value of individual patents can hardly be derived from the information contained in a single patent document (Schubert, 2011). In addition, the economic benefits of a technological product can hardly be assigned to one single patent, as this product is usually the result of several technologies implemented in one device, machine etc, which is therefore often protected by a large number of patents (Frietsch et al., 2010).

However, several studies have shown that the quality or value of patents is associated with economic performance at the firm level (see for example Bloom and van Reenen, 2002; Hall et al., 2005; Harhoff et al., 2003). This implies that at the level of patent portfolios, indicators of patent quality are needed in order to capture the innovative performance firms. Yet, it is still unclear which of the various indicators of patent value that are proposed in the literature are suitable for the evaluation of patents at the level of patent portfolios and which dimension of economic performance is most affected by quality issues.

This will be in the focus of the **third paper**, entitled "When the Whole is more than the Sum of its Parts: Patent Portfolios and their Impact on Stock and Product Market Performance", which attempts to show how the quality of patents can influence market expectations about a firms' future profitability and its contemporaneous profits. With the help of our analyses it can be shown that innovation and patenting have substantial impact, both on market value and profitability, although patents do not manifest themselves into direct profits but have a temporally delayed effect. At the firm level, the quality of patents actually seems to matter. It can be found that filing a large amount of low-value patents will neither increase profitability nor shareholder value, implying that markets seem to be aware of the quality of patents. However, the design of a patent portfolio is also an important factor. Both, portfolios that consist only of high quality patents and those that consist of only strategic patents are valued lower. It seems to be crucial for firms to uphold a mixed patent portfolio of both types of patents in order to transfer the results of innovation activities into actual revenues.

However, it has to be taken into account that patents only serve as a proxy, measuring the latent construct of innovative performance. Thus, it is not necessarily patents per se, which are rewarded by market particpants with higher market valuations or lead to higher profits for firms. Market participants can use several channels to enlarge their information about companies. One of these information sources is credit rating agencies (CRA). CRA are information intermediares, which retrieve and filter down information for other market participants, thus reducing transaction costs. Taken together with a striking result of the third paper, where it could be shown that price premiums are paid on the stock markets for portfolios that hedge against risks, the question can be posed if innovative performance is also resembled in CRAs credit risk assessments, which will be in the focus of the **fourth paper**. It is entitled "Patent Information and Corporate Credit Ratings: An Empirical Study of Patent Valuation by Credit Rating Agencies" and aims to shed light on the role of patent quantity and quality within the context of credit rating agencies (CRA) credit risk assessments.

The valuation of a credit rating agency goes beyond measures of firm performance like market value or returns on investment, because CRA filter down information to opinions about bond-issuers creditworthiness, in terms of their risk of default. The underlying reasoning of CRA is that the profitability of the firms' business is required for future debt redemptions – i.e. for companies to be able to service its debt there must be prospects of future cash flows. CRA are therefore concerned with evaluating the probability of returns to debt security holders, which in turn depend on the generation of cash flows by the issuer. Ultimately, a firm's creditworthiness thus depends on the firm's ability to amortize its debt and fulfil its interest payments (Standard & Poor's, 2008).

Our findings show that corporate credit ratings, as stock market valuations, reflect the future economic benefits related to patents. It thus can be stated that CRA fullfill their information function regarding the evaluation of the innovative performance of firms. However, patents seem to be valued differently in CRA credit risk assessments than by stock markets. Besides having a larger focus on the patent output of a company in quantitative terms, the patent value indicators suggest that CRA seem to consider patents as insurance against patent lawsuits and do not specifically try to evaluate the technological value of a patent. Although this makes sense with an ever increasing pace of strategic patenting, which has created a litigious patent environment with substantial costs of patent lawsuits (Bessen and Meurer, 2004; 2008a; 2008b), this might have negative implications regarding the financing of innovation via debt. Firms either need to devote substantial financial resources to build and uphold a large patent portfolio as insurance, or they will eventually face higher costs of debt. Hence, companies will experience higher costs of innovation either through increased costs of funding or increased patent portfolio costs, which might be especially troublesome for smaller technology-driven firms.

The management of a patent portfolio is also in the focus in the **final paper**, "Standard essential patents to boost financial returns", which is trying to assess the value of a patent portfolio from a different angle, namely in the standardization process. The basic hypothesis is that patents which are declared by firms as being essential to a technology standard already contain a certain value and thus positively influence a firm's financial performance, controlling for other indicators of patent value.

Standards enable interoperability and communication on a technology platform which is often central to unlocking innovation. A large part of the competition on technology has been moving upwards at the standard setting level. Patents declared as being essential for a certain technology standard might thus serve as a credible signal of technological quality to the market. Yet, when companies declare their patents to a standard, standard setting organizations (SSOs) oblige the patent holder to license the patented technology (Layne-Farrar et al., 2007). This is different for patents on complementary technologies where the patentee is able to block competitors by not licensing out but enforcing the patent. Thus, an optimal level of declaring patents as being essential to a standard is proposed, with "over-declaration" having a negative effect on firm profits from a certain point onwards.

In fact, it can be shown that there is a curvelinear (inverted u-shaped) relationship between patents declared as being essential to a standard and firm profitability. It thus is advantageous for companies to diversify their patent portfolios to balance patenting around standardization. Firms have to strategically position their patents on standard platforms. On the one hand, they need to declare a share of patents to SSOs to freely operate on standardized technology platforms. On the other hand, firms have to maintain a competitive advantage by patenting and not licensing out complementary technologies to be able to block competitors.

In addition to these findings, we do not find any significant effects for the patent output of a company on its profitability. This result points once more to the fact that it is not sufficient to account for a company's technological performance by solely measuring the number of patent filings. We further find only slight effects for the "classical" patent value indicators, which points towards the fact that the patent value effects are captured by the patent declarations themselves, which have been shown to be of higher technological value in the past (Rysman and Simcoe, 2008; Layne-Farrar and Padilla, 2011).

Submission and Publication Record

The paper "The Use of Patents and Informal Appropriation Mechanisms - Differences between Sectors and among Companies" (paper 1) was in a first version accepted for presentation at the 9th Conference of the European Sociological Association (ESA 2009) at the University Institute of Lisbon (ISCTE-IUL), Portugal. After some revisions it was submitted to *Technovation* where it is currently under review.

A previous version of the paper "Patent Indicators for Macroeconomic Growth - The Value of Patents Estimated by Export Volume" (paper 2), co-authored with Rainer Frietsch, Taehyun Jung and Bart van Looy, was presented at the Second International Summer School - S&T and Innovation Development Issues (Higher School of Economics, Moscow) and at the Atlanta Conference on Science and Innovation Policy 2011 at the Georgia Institute of Technolgy in Atlanta, USA. It was then submitted to *Technovation* where it is currently under review.

The paper "When the Whole is more than the Sum of its Parts: Patent Portfolios and their Impact on Stock and Product Market Performance" (paper 3) is co-authored with Rainer Frietsch, Torben Schubert and Knut Blind. In a previous version it was accepted for presentation at the 11th International Conference on STI - Creating Value for Users (Centre for Science and Technology Studies, University of Leiden, The Netherlands) and presented at internal seminars at the Chair for Innovation Economics at the Technical University of Berlin and at the Fraunhofer Institute for Systems and Innovation Research in Karlsruhe, Germany. It is still in an internal revision phase but will be submitted to a journal in the near future.

The paper "Patent Information and Corporate Credit Ratings: An Empirical Study of Patent Valuation by Credit Rating Agencies" (paper 4, co-authored with Carl-Benedikt Frey and Knut Blind), was accepted for presentation at the Patent Statistics for Decision Makers Conference 2011 at the USPTO in Alexandria, Virginia (coorganized by the European Patent Office and the Organisation for Economic Co-operation and Development). After some revisions it is now planned to be submitted to the *Review of Financial Studies*.

A previous version of the paper "Standard essential patents to boost financial returns" (paper 5), co-authored with Knut Blind and Tim Pohlmann was presented at the 6th Annual Conference of the EPIP Association: Fine-Tuning IPR debates (Université libre de Bruxelles, Brussels, Belgium). In addition, it was presented at at internal seminars at the Chair for Innovation Economics at the Technical University of Berlin. It is currently in an internal revision phase but will be submitted to a journal in the near future.

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PART I: INTELLECTUAL PROPERTY RIGHTS AND INFORMAL APPROPRIATION MECHANISMS

1 The Use of Patents and Informal Appropriation Mechanisms – Differences between Sectors and among Companies

Abstract Against the background of the rise in patent applications during the 1990s, the present article tries to explain how different kinds of firms act to appropriate their investments in R&D and other innovation activities under the newly evolving conditions. Thereby, not only the patenting activities of firms, but also their preferences for different formal and informal appropriation mechanisms are analyzed. Firms are differentiated by size, sector, internationalization etc. to answer the question whether special firm characteristics exist that promote or hinder the decision to use formal or informal appropriation methods. For the empirical testing, a large-scale survey of patenting companies in Germany is used, which were responsible for more than 40% of all German patent applications at the EPO or via PCT procedures in the year 1999. Only few firms in the sample stress the importance of formal appropriation methods. Additionally, most factors that one would envisage as being positively linked to a preference for formal mechanims are not. Especially large and internationaized firms significantly add to the number of patent applications, however mostly for strategic purposes. Patents could therefore be seen as a basic requirement to enter foreign markets, with a need to defend market positions by strategic patenting.

1.1 Introduction

The question of how to protect intellectual property has always played a crucial role for companies in securing their returns from technological innovations. During the 1990s, the number of patent applications almost doubled in all OECD countries. Statistical analyses of the European and international patent applications reveal that, especially since the mid 1990s, a massive increase of patent applications, known as the patent surge, was observed, which cannot be explained solely by a corresponding rise in R&D activities, since the R&D expenditures increased only modestly in this period.

Consequently, the patent intensity, defined as the number of patent applications per unit of R&D expenditure, showed a significant increase (Blind et al. 2004). This development is accompanied by a concentration of patent applications in large firms, which thus accounts decisively for the gap between patent applications and R&D activities (Blind et al. 2003). There are several possible explanations for the patent surge phenomenon: an increase in R&D efficiency, i.e. improvements in the research process itself (Janz et al. 2001), a shift to more applied research activities that raises the yield of patentable discoveries (Kortum/Lerner 1999), or the rise of new and strongly growing technology fields like biotechnology or software (Blind et al. 2005; Kortum/Lerner 1999; Thumm 2003). Finally, it is argued that the patent strategies of innovative companies have become broader and more complex, thus resulting in an expansion of patent applications. This reasoning can be confirmed by a number of previous studies (Arundel et al. 1995; Cohen et al. 2002; Schalk et al. 1999). The patent system whose original purpose was to provide a temporally limited protection for technological knowledge, is more intensively used by companies for various other so-called strategic motives, e.g. trying to block competitors or to generate licensing revenues (Blind et al. 2009). If this is true, the patent surge could partly be driven by large firms using patents strategically in technology competition.

Through the increased strategic utilization of patents, the framework conditions for companies have changed radically. They have to take into account not merely the appropriation strategies of competitors, but also blocking strategies etc. Against this background, the present article tries to explain how different kinds of firms – differentiated by the size and their main sector of activity – act to appropriate their investments in R&D and other innovation activities under these newly evolving conditions. In addition to analyzing the patenting activities of firms in general, the data also permit an analysis of the preference for different formal and informal appropriation methods.

The remainder of this paper is organized as follows. Section 1.2 gives a literature review, which introduces the different possibilities to appropriate the returns from innovations, explains how patents can be used as strategic protection mechanisms and presents the theoretical background. Section 1.3 describes the sample, data and the methodology employed for the analyses. In Section 1.4 the descriptive and multivariate results will be presented. Section 1.5 concludes.

1.2 Literature and Theory

1.2.1 Literature Review

The expectation that new or improved products or processes will increase profits leads firms to innovate. The successful completion of the innovation process alone, however, is not a sufficient condition to obtain the expected benefits from innovation. A firm also has to be able to appropriate these benefits, i.e. to prevent its competitors from imitating their results, which can be achieved via various intellectual property rights and other strategies (Hanel 2002).

Several possibilities exist to exclude third parties from the exploitation of one's own innovative endeavors (Rammer 2002), which are commonly grouped into two broad categories. The first are known as formal appropriation methods, e.g. patents, trademarks, industry designs, utility models and copyright, which grant innovators an exclusive right to use their results from innovation activities (Rammer 2002).

These formal instruments can be seen as incentives for innovators to invest in and generate new knowledge, new technologies and foster their diffusion, because the legal system provides the owner a mechanism for pursuing infringers for a limited time period (Rammer 2007). In order to obtain this legal protection, all the information covered by the respective formal instrument has to be disclosed after a given period after application. In the case of patents, for instance, all information has to be disclosed not later than 18 months after application. Patents are probably the most common and widely used formal appropriation method. It can be stated that patents are still mainly used to serve as protection from imitation to secure markets, which can be seen as the traditional motive for patenting (Blind et al. 2003). However, additional strategic groups of motives which are only indirectly connected to the protection of R&D results have gained increased importance.

The second category of mechanisms to prevent third parties from imitating are referred to as informal appropriation methods, which cover different actions firms can undertake maximize their expected returns on innovation. In contrast to formal instruments, they are not accompanied by an enforcement mechanism (Rammer 2002). The most common informal mechanism is secrecy, i.e. keeping the technological knowledge on which the innovation is based confidential until it is ready to be commercialized (Arundel 2001). A second mechanism is trying to commercialize an innovation as fast as possible to benefit from lead-time advantages. A less common form is the complex design of a product that impedes competitors from engaging in reverse engineering or invent-around strategies (Rammer 2007). Studies in the United States and Germany show that by the end of the 1980s informal appropriation mechanisms were in widespread use in securing innovative returns, compared to formal mechanisms (Cohen et al. 2000; Levin et al. 1987).

However, the existence of the patent system offers possibilities to exploit patents for strategic purposes (Blind et al. 2009). According to Arundel and Patel (2003), all motives that go beyond the protection of one's own inventions to appropriate benefits in relevant markets based on this invention are defined as "strategic". The consequence is that the decision to patent has partly uncoupled the technological needs of protection from competitors in the traditional sense, or at least the strategic behavior of other market participants is anticipated and patents serve as new sources of revenue (Blind et al. 2003).

The most common strategic motive is blocking competitors, which can be differentiated in two versions (Blind et al. 2009; Blind et al. 2003). The first is known as the defensive blockade, where firms use patents to avoid their own technological elbowroom being diminished by patents of others. The second version is the offensive blockade, which means that firms only patent to prevent competitors from using technological inventions in the same or adjacent areas of application that are close to one's own inventions, but not identical. So-called patent thickets are built up and firms patent "more broadly" than necessary.

In addition, there is a large bandwidth of further strategic motives (Blind et al. 2009; Blind et al. 2003; Cohen et al. 2000). For example, firms may choose to generate licensing revenues or trade with other firms (cross-licensing), or use patents as bargaining chips in negotiations with other companies to gain access to new technologies, which is especially prominent in sectors like ICT (Hall/Ziedonis 2001). Furthermore, patents can be used for international market extension, standardization, or to increase the firm's reputation or technological image. Another motive can be seen in the use of patents as a measure of internal performance of a firm's R&D personnel that can also be used for motivational purposes. Especially for SMEs (small and medium-sized enterprises), easier access to the capital market can also be regarded as a strategic motive for patenting. Generally, companies' patent portfolios can be seen as a hurdle to deter new potential competitors from entering the market or to establish themselves in a certain sector.

1.2.2 Factors Influencing the Choice of Formal or Informal Appropriation Methods

The choice of an appropriate instrument is often accompanied by a great deal of uncertainty. Over time, and during the innovation process, the information base steadily changes, which makes a permanent re-evaluation by the company management indispensable (Harhoff/Reitzig 2001). In addition, it has to be taken into account that a single economic decision-maker cannot see all business opportunities that result from technological possibilities and manage them in a way that maximizes profits. He thus operates under a scheme of bounded rationality and acts not always under maximizing but "satisficing" rules (Verspagen 2005). However, one can raise the question whether special firm characteristics exist that promote or hinder the decision to use a formal or informal appropriation method.

Literature has already discussed some of those firm characteristics, yet sometimes with contradictory arguments. This paper attempts to summarize the existing discussion and tries to shed some more light on the question which firm characteristics exert the biggest influence on the decision for or against a specific appropriation method. The most important are firm size, research intensity, the sector which a company operates in and its degree of internationalization. Additionally, there are some other firm characteristics, which often are associated with the above mentioned. These are the existence of a patent division and the threat by invent-around strategies and technological opportunity, which will also be discussed in more detail.

Starting with firm size, basically, large companies tend to have more resources at their disposal and virtually possess more market power to enforce their rights than smaller firms. Several assumptions concerning the applicability or preference for different kinds of appropriation methods can be derived from this fact.

First of all, the probability for patents to be litigated by a third party can be assumed to vary by firm size. Larger firms – relatively seen – are less often the target of patent litigation than SMEs (Bessen/Meurer 2005; Cremers 2004). The reason is the higher threat potential of large enterprises that is further increased by the presence of a large patent portfolio, which leads to greater experience or routine in patenting and in the enforcement of rights (Arundel et al. 1997).

Another discrepancy can be found in the probability of using formal instruments strategically. Most of the strategic motives are potentially more beneficial for large enterprises. Blocking competitors, for example, is impossible until a firm has some patents at its disposal and has the (financial) capabilities to patent broadly (Blind et al. 2003). The use of patents for cross-licensing negotiations or trade with other firms also tends to be more useful for large companies, as a larger patent portfolio goes along with such "player strategies" (Cohen et al. 2000; Hall/Ziedonis 2001). The same counts for the use of patents as an internal performance indicator. Larger firms usually employ more R&D personnel and more often possess a special in-house patent department that can be evaluated. On the other hand, some strategic motives, like increasing the reputation or the technological image of a firm by holding a stock of (at best, valuable) patents, can be seen as more beneficial for small companies. Cohen et al. (2000) suggest that small firms, especially in technology industries, are more likely to report this motive than their respective counterparts. Patents can also be used to ease the access to the capital market. Acquiring financing or alliance partners with the help of patents can be seen as a strong motive for small firms to engage in patenting activities.

The costs linked with patenting are a third source of differences between small and large firms. The application of a patent and the associated search for information are significant cost factors, especially for small firms, as application costs in foreign countries are very high (Hanel 2006). Furthermore, the high costs of a potential patent litigation dissuade small firms from patenting (Cohen et al. 2000). This stems from the assumption that large firms are in a better position to spread the fixed costs of applying and defending patents over greater levels of output.

A firm's size can also affect the decision to use informal appropriation methods. Especially the probability of being discovered or outpaced by a competitor can be assumed to differ by the size of a company. Following the arguments of Arundel (2001), large firms could be more reliant on secrecy compared to small firms, because they can use their marketing strength to create lead-time advantages and because they serve larger markets. This increases the financial returns from investment, especially for process innovations, where patents are supposed to be of less value than secrecy (see also Cohen/Klepper 1992; Cohen/Nelson 1998). However, it should be noted that this assumption was tested by Arundel (2001) and found not to be true. Although all firms labelled secrecy to be more important than patents, secrecy was even more important to smaller firms.

Besides firm size, the literature has shown that the decision to use a specific appropriation method varies according to the research intensity of a company. An increase in research intensity could lead to more inventions that meet the requirement for patentability (and possibly more novel inventions) compared to innovations that are developed without R&D. Especially R&D personnel is the major input factor for the R&D process and therefore the R&D output of a company. One could assume that rising research intensity is associated with the necessity to appropriate the returns on R&D activities. Therefore, the importance to appropriate the results of the R&D activities via formal mechanisms increases (Blind et al. 2006). Blind et al. (2006) showed that R&D intensity is positively related to the likelihood to patent for strategic purposes, for example, to increase the exchange potential of the company.

A contradictory argument can be found when looking at patent litigation. The chance for a patent to be litigated increases for firms with higher research intensity, as it can be assumed that more patents with substantial economic benefits (so-called "valuable patents") are generated (Allison et al. 2004). These are more often target of opposition or litigation (Harhoff et al. 2003). Additionally, the costs for a successfully litigated or opposed patent are assumed to be higher for more research-intensive companies, since, relatively seen, more financial resources are lost. The same argument holds regarding the decision to use informal instruments. A higher financial input into R&D also means a greater financial loss when being discovered or outpaced by a competitor. However, these can be regarded as sunk or irreversible costs, which cannot be influenced and therefore should exert no direct effect on the selection of an appropriation mechanism.

Related to research intensity is the sector which a company operates in. Yet some additional arguments regarding the influence of different sectors on the decision to use formal or informal appropriation mechanisms can be found. One of those comes from Arundel and Kabla (1998), who state that patents are of greatest value in those sectors where the cost of copying an innovation is considerably less than the initial cost of invention. Other results show that the differences in patenting behavior between sectors mainly stem from the distinction between discrete and complex product industries (Blind et al. 2009; Cohen et al. 2000; Cohen et al. 2002). Complex product industries, e.g. the electrical engineering and automotive industry, where the number of patents per innovation is large, are assumed to show increased strategic use of patents, than discrete product industries, like the chemical sector, where the number of patents per market-exploitable innovation is considerably smaller. Another point that could be mentioned against this background is also the distinction between discrete and complex products. As Bessen and Meurer (2008) argued, increasingly fuzzy claim descriptions, especially in software and business methods patents, have led to an increase in the number of patents, which is less of a problem for discrete products such as chemicals or fabricated metal products but more for complex products like software (see also Bessen 2009). Therefore, the mere patent output can be assumed to be higher for complex product innovations. On the other hand, one could argue that complex products also increase the usefulness of lead-time advantages because they increase the time required by competitors to copy or imitate the product.

At this point, it is important to mention that differences not only occur between, but also within sectors (Dosi et al. 1988; Dosi 1988). Firms within an industry that use older products and processes may adopt strategies which allow them to survive despite rapid technological change in other parts of the sector (Cooper 1994).

The choice between formal or informal appropriation methods could additionally be assumed to vary according to a company's degree of internationalization. The main difference between highly and lowly internationalized firms is the number of markets they operate in. This is especially important, as the intensity of competition rises with the entry to each new market (Blind et al. 2006). As pointed out by Arundel et al. (1995), the importance of patents increases with the relevance of global markets. The main benefit of using formal instruments for more internationalized firms lies in the possibility of achieving legal protection to generate returns on innovations in several markets, i.e. the traditional motive for patenting is the main focus. Arundel and Kabla (1998) showed that firms which sell products in the US or Japan are more likely to patent a higher percentage of their product innovations than firms that do not sell products in one of those two markets. However, the increased intensity of competition also affects the strategic patenting motives, above all the importance of offensive and especially defensive blockade as the threat of being sued rises. This is even amplified by the increased costs for infringement suits in other countries.

However, some contradictory arguments can also be found at this point. Most important, the concern about disclosing information about an innovation rises with each new country a patent (or other formal instrument) is filed for. Operating in additional markets increases the risk that an innovation is imitated through invent-around or reverse-engineering strategies. Furthermore, patents and other formal instruments are only valid for the country in which they were filed. This leads to an increase in application costs and maintenance fees for granted patents with every additional market that is being secured. The increased costs for litigation also have to be taken into account, as every additional jurisdiction in which a patent is filed is positively correlated with the occurrence of an infringement suit (Cremers 2004).

Internationalization is also important when the alternative of using informal instruments is taken into account. An increase in the intensity of competition leads to a higher chance of being discovered or outpaced by a competitor. This can also be seen as a cost factor, since generating returns on an innovation is then rendered impossible in several markets.

One can think of several other firm characteristics that additionally influence the preference for formal over informal instruments and vice versa. These are often associated with one of the above mentioned characteristics, but are nevertheless worth noting. One of those is the existence of a special in-house patent department, mostly consisting of experienced patent attorneys and specialized R&D personnel. Thereby, the fixed costs for a patent application process, especially the costs for information searches, can be reduced and scale effects can be realized (Hall/Ziedonis 2001). Additionally, the threat potential, especially for litigation suits, rises, due to an increase in experience or routine in patenting and in the enforcement of rights (Arundel et al. 1997).

The degree to which a company's invention is threatened by invent-around or reverse-engineering strategies could also influence the decision in favor of a specific appropriation method. This factor is associated with firm size, as larger firms have better opportunities to use blocking strategies and exert a higher threat potential, especially concerning infringement suits. Additionally, the chances of successfully inventing-around an invention vary by sector. In complex product industries, inventing-around can be assumed to be considerably harder than in discrete product industries, due to the existence of a larger patent thicket. An exception could be the pharmaceutical sector, where patents on key molecules are often surrounded by patent thickets.

The final influencing factor discussed here is technological opportunity, which is associated with research intensity and firm size. Cohen and Keppler (1992) state that a high level of technological opportunity occurs when the cost of developing an invention is low, for instance, when there are already many possible unpatented solutions to a problem. This is more often the case in new sectors, where the concentration of firms is low and a large number of small firms are active. Following this argument, small firms should potentially benefit more from technological opportunities than large firms. Katila and Mang (2003), on the other side, arguedthat a company that discovers an opportunity needs to exploit it as fast as possible before the information reaches potential competitors in the field. This argument implies that quick access to resources is needed, which can be more easily realized by larger firms.

1.3 Data and Methods

1.3.1 Data and Sample

The data is based on a sample of 534 German manufacturing firms that applied for at least three patents at the EPO in the year 1999, which served as a selection criterion. The survey was conducted by the Fraunhofer Institute for Systems and Innovation Research ISI in the year 2002. Initially, 1,570 companies were asked to participate in the survey, which means a response rate of 33.9 percent. The participating companies were responsible for more than 40% of all German patent applications at the EPO or via PCT procedures in the year 1999, thus a high share of large and actively patenting companies is covered. According to the fact that the dataset only covers patenting companies, firms from sectors where patenting is important were more likely to participate in the survey.

In order to fill in some gaps in the questionnaires on the number of employees and the number of patents, the survey data were supplemented by published data from patent and company databases. Data on patent applications at the EPO and via PCT procedures for the year 2001 were extracted from QUESTEL-Orbit (http://www.questel.com) and the "EPO Worldwide Patent Statistical Database" (PATSTAT), which provides information about published patents collected from 81 patent authorities world-wide. The year 2001 was chosen in order to analyze more recent data. The firms in the sample, which met the selection criteria, but did not apply for any patents in the year 2001 were assigned zero patents. This was the case for 28 firms in total. Information on sales and employees was taken from the Hoppenstedt company database (http://www.hoppenstedt.de).

1.3.2 Measurements

Two response variables were created for further analyses. The first is the total number of patent applications for the year 2001, which is used to capture the actual patenting behavior of the companies in the sample. This variable is relevant to find out if a general pattern in firm characteristics exists, which is able to explain the surge of patent applications in the 1990s and if the strategic patenting motives affect the actual patenting behavior of firms. To increase the sample size for this variable, the number of patents was not taken directly from the questionnaire, but from the respective patent database.

To capture the importance for or preference of companies regarding the use of a specific type of appropriation mechanism, data from the questionnaire were employed. Companies were asked to indicate the importance of intellectual property rights and other strategies to appropriate their returns on inventions and innovations on a 5-point Likert scale, where a value of 1 indicates low and a value of 5 high importance. The exact wording of the question was: "Please indicate the importance of the following intellectual property rights and other strategies for the protection of the inventions and innovations of the whole company". As the questionnaire was phrased in German, the question had to be translated for the purpose of this paper.

The items capturing formal instruments in the questionnaire were the importance of domestic and foreign patents, utility models, industry designs, trademarks and copyright. Regarding informal appropriation mechanisms, the items secrecy (including complex product design), lead-time advantage, exclusive customer relations, long-term assignment of personnel and the design of sub-supplier contracts were included.

Three steps were performed to generate a response variable for a multivariate analysis that captures the preference for an appropriation method. First, two index variables were constructed which are supposed to capture the importance of formal and informal mechanisms in general. In order to create the index for formal instruments, the values for the importance of domestic and foreign patents, utility models and industry designs were combined into one variable. Trademarks and copyright were excluded from this index, as they can be seen as inappropriate or irrelevant for the appropriation of technical inventions, which should be the focus of most of the firms in the sample. To construct the index for informal instruments, only the items secrecy and lead-time advantage were chosen. The reason for excluding the other items lies in the nature of the following multivariate model, which assumes discrete choice between given alternatives. Therefore, all appropriation methods must theoretically be appropriate or available for all firms in the sample, which is not the case, for example, for the specific design of sub-supplier contracts or long-term assignment of personnel. As already mentioned, complex product design was subsumed under the item "secrecy" in the wording of the item in the questionnaire, so this informal instrument is implicitly represented in the index variable.

In order to prevent a low sample size and to avoid the situation where companies which did not assign a value to all items are given a lower score on the respective index, the sum of the importance values was divided by the number of actually given answers for each index. This also ensures that the maximum scores for the two indices do not differ. Therefore, both - the index for the importance of formal and informal instruments - range from one to five.

In a second step, both index variables were dichotomized, whereby all values below or equal to three on the variable ranging from one to five were coded as 0 ("low importance") and values above three were coded as 1 ("high importance"). Finally, the two index variables were combined into one variable (Table 1-1).

Table 1-1 Distribution of the variable to measure the importance dimensions of the different appropriation mechanisms

	Informal Mechanisms		
Formal Instruments	Low	High	Total
Low	71	208	279
High	39	209	248
Total	110	417	527

Source: Survey results

Companies that scored zero on both dichotomized index variables were grouped into the category "protection less important". Companies that scored zero on the index for formal instruments and one on the index for informal instruments were grouped into the category "preference for informal instruments" and vice versa for formal instruments. If companies scored one on both indices, they were classified in the "preference for a combination of instruments" category.

Using this variable, it is possible to estimate the effects of different firm characteristics on the preference for one or another appropriation method in one single model, which leads to a comparable basis for interpreting the results. In order to conserve as much specific information as possible, the selected items capturing the importance of appropriation methods are treated separately in the descriptive analyses.

One has to bear in mind that the sample only covers firms that filed at least three patents in the year 1999 which reduces the generalizability of the results. However, this restriction was intentionally introduced into the questionnaire to make sure that the patent option is available to them. Additionally, it can be assumed that the alternatives of using a formal or informal instrument do not need to be mutually exclusive, as often a combination of formal and informal appropriation mechanisms is used, e.g. by trying to keep an invention secret in the first place and filing for a patent afterwards, or by using patents for specific dimensions of a technology, whereas other complementary knowledge components are kept secret. Several possibilities exist to combine appropriation mechanisms effectively. For example, Arora et al. (1997) stated that in the chemical industry it is typical to protect individual compounds of dyestuffs by patents, whereby the composition of the dyestuff is kept secret. Finally, the variable only captures preferences for one instrument or the other. Therefore, a higher score on the index variable does not mean that the preferred instrument is the only alternative for those firms. Hence, the results are still meaningful and reasonable to interpret.

The number of employees (log-transformed) is used to account for size effects in the following analyses. Additionally, in the multivariate analyses, the squared number of employees is introduced into the model to control for non-linear size effects.

Since many firms in the sample did not provide information on their R&D expenditures, the share of R&D personnel in total personnel serves as a measure for the research intensity of a company. Using R&D expenditures would have led to many missing values and a significantly reduced sample size for the following multivariate models. To additionally capture the effects of the firms' efficiency in patenting on the importance of the different appropriation mechanisms, the patent intensity defined as the number of patent applications for the year 2001 per employee is calculated.

Table 1-2 Overview of the variables and summary statistics

Variable	**# Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Response Variables					
Number of patent applications	531	17.62	102.10	0.00	1691.00
Index: importance of protection instruments	527	3.05	1.00	1.00	4.00
Independent Variables					
Size (log number of employees)	521	6.26	2.16	0.69	13.08
Share of R&D personnel on total personnel	464	0.16	0.23	0.00	1.00
Patent intensity	521	0.03	0.08	0.00	1.00
Existence of patent division	524	0.47	0.50	0.00	1.00
Importance of application costs	510	2.73	1.17	1.00	5.00
Importance of "other costs"	509	3.60	1.11	1.00	5.00
Share of foreign sales on total sales	362	0.49	0.25	0.00	0.96
Industry (NACE codes in brackets)					
Construction (10-14)	531	0.09	0.28	0.00	1.00
Consumer goods (15-19, 36)	531	0.04	0.19	0.00	1.00
Metal industries (27)	531	0.09	0.29	0.00	1.00

Motor vehicles (34)	531	0.13	0.33	0.00	1.00
Mechanical engineering (29)	531	0.22	0.42	0.00	1.00
Chemistry (24, 25)	531	0.22	0.41	0.00	1.00
Electrical engineering (30–33)	531	0.21	0.41	0.00	1.00
Importance of appropriation strategies					
Domestic patents	528	4.03	1.02	1.00	5.00
Foreign patents	525	4.14	0.89	1.00	5.00
Utility models	515	2.56	1.27	1.00	5.00
Industry designs	466	1.73	1.14	1.00	5.00
Secrecy	513	3.58	1.24	1.00	5.00
Lead-time advantage	518	4.36	0.78	1.00	5.00
Importance of patent motives					
Imitation	522	4.26	0.93	1.00	5.00
Offensive blockade	516	3.83	1.09	1.00	5.00
Defensive blockade	511	3.95	0.99	1.00	5.00

Source: Survey results, PATSTAT

Furthermore, a set of industry dummy variables identifies seven industry groups according to the self-assessment of the firms in the sample, based on the Statistical Classification of Economic Activities in the European Community (NACE).

In order to differentiate between the degree of internationalization of companies, the share of foreign sales in total sales, ranging from 0 to 1, was calculated. Unfortunately, a better or more refined indication of internationalization, such as, for example, foreign direct investment, is missing in the questionnaire. Therefore this variable serves as the only measure for the degree of internationalization of firms.

Since it can be assumed that the existence of a patent division increases the patent output of companies, this variable was introduced as a dummy, where 0 means "no patent division" and 1 "patent division exists". Additionally, the influence of the importance of costs was captured by two variables which were taken from the questionnaire. Also measured on a 5-point Likert scale, firms were asked to provide information on how important different types of patenting costs are for the company. These were differentiated by patent application costs and other costs (for instance, for employing a patent lawyer) for national and international applications. As the degree of internationalization is reflected in another variable, national and international costs for applications and "other costs" were combined into one index variable ranging from one to five, respectively. Therefore, we have two index variables, one for application costs and one for "other costs". The variables were constructed like the indices for the importance of formal and informal instruments, which means that the sum of the importance values was divided by the number of actually given answers. Therefore, the variables both range from one to five.

To find out if different strategic patenting motives exert an influence on the two response variables, three variables were used that were taken from the questionnaire. Firms were asked to provide information on how important different motives to patent were for the company, again measured on a 5-point Likert scale. As already mentioned, there are many different motives to patent. However, the main motive still is the protection from imitation, which can be seen as the traditional motive. The most widespread strategic motive is blocking competitors, offensively or defensively. Therefore, three variables were included in the models to capture the importance of protection from imitation and offensive or defensive blockade.

1.3.3 Estimation Methods

Two types of multivariate models are calculated. First, a negative binomial regression model on the absolute number of patent applications is fitted. Since the number of patent applications is a count outcome, simply using a standard OLS regression is not suitable. This could lead to inefficient, inconsistent and biased estimates (Long 1997). Several kinds of so-called count models exist to address this problem, with the Poisson and the negative binomial regression model probably being the most prominent. The Poisson distribution, however, assumes that mean and variance of the response variable are the same (Long 1997). If the variance is much larger than the mean, the model underestimates the variance and standard errors of the Poisson regression, leading to overly large z-values. A large difference of the mean and variance of the number of patent applications variable can already be observed in Table 1-2. This so-called overdispersion can be accounted for by a negative binomial regression model, which adds an overdispersion parameter alpha reflecting the unobserved heterogeneity between observations (Long/Freese 2003). A likelihood ratio test on this parameter showed that the negative binomial distribution in this sample is not equivalent to a Poisson distribution and therefore the negative binomial regression model is more suitable for this analysis.

Secondly, a multinomial logit model to account for the different preferences of companies for formal or informal appropriation mechanisms is calculated. The response variable described above, which represents the different preferences, is categorical. Additionally, it can be assumed that the different importance dimensions do not have a natural order. At this point, the advantage of this dependent variable becomes visible. The impacts of different firm characteristics on the preference for an appropriation method can easily be estimated in only one model.

To intepret the coefficients, marginal effects at the means of the independent variables for each category of the dependent variable were calculated. They show how the outcome variable y changes by a one unit change in firm characteristic x. The marginal effects are estimated for one outcome at a time. It is the ratio of the change in the response variable to the change in the independent variable, when the change in the independent variable is infinitely small, holding all other variables constant (Long/Freese 2003). For dummy variables the marginal change is for a discrete change of the dummy variable from 0 to 1. To interpret the effects it is important to note that the marginal effects from a multinomial model cannot be compared across the outcome categories but only within a given category, giving the probability that a firm with characteristic x is in outcome y. Additionally, the marginal effect will likely be much lower for an outcome with a lower number of firms than the marginal effect for a more common outcome, including a larger number of firms.

Both the negative binomial model on the absolute number of patent applications and the multinomial logit model use the same independent variables, with two exceptions. First, in the model on the absolute number of patent applications, the single items capturing the importance of appropriation strategies are added as explanatory variables. Thus, the effects of the importance of the key appropriation methods on the number of patent applications can be estimated. The items used are the same as for the construction of the index variables for the multinomial logit model, namely, the importance of domestic and foreign patents, utility models, industry designs, secrecy and lead-time advantage. Second, the variable on patent intensity is added to the multinomial logit model on the importance of different appropriation strategies to capture the effects of the firms' efficiency in patenting on the importance of the different appropriation mechanisms.

1.4 Results

1.4.1 Descriptive Results

A look at the bivariate associations between the variables reveals that firm size is positively correlated with the number of patent applications. This is also true for the importance of domestic patents and industry designs. It is interesting to note that the size of a firm is not significantly correlated with the importance of foreign patents, implying that there seems to be no difference between SMEs and large firms when it comes to filing foreign patents, whereas size seems to matter when the importance of domestic patents is concerned. The importance of secrecy, however, is negatively correlated with firm size, which is in line with the explanations mentioned in the theoretical part of the paper.

Table 1-3 Pairwise correlations for the total number of patents, the importance of selected formal and informal instruments and firm characteristics

	# Patent App.	**Domestic patents**	**Foreign patents**	**Utility models**	**Industry designs**	**Secrecy**	**Lead-time advantage**
# Patent App.	1.000						
Domestic patents	-0.056	1.000					
Foreign patents	0.011	0.302***	1.000				
Utility models	-0.057	0.278***	0.065	1.000			
Industry designs	0.050	0.098**	0.082*	0.359***	1.000		
Secrecy	-0.032	0.085*	0.216***	0.054	0.065	1.000	
Lead-time advantage	0.040	0.159***	0.271***	0.043	0.063	0.309***	1.000
Size (log number of employees)	0.317***	0.144***	0.043	-0.023	0.085*	-0.101**	-0.046
Share of R&D personnel	-0.019	-0.134***	0.057	-0.266***	-0.153***	0.107**	0.027
Share of foreign sales on total sales	0.092*	-0.1595***	0.2023***	-0.209***	-0.038	0.002	-0.011
Construction (10-14)	-0.034	-0.009	-0.190***	0.092**	0.019	-0.015	-0.054
Consumer goods (15-19, 36)	-0.023	-0.083*	0.014	0.060	0.145***	-0.026	0.016
Metal industries (27)	-0.042	0.049	0.012	0.115***	0.066	0.069	0.007
Motor vehicles (34)	0.087**	0.089**	-0.052	-0.017	-0.040	0.047	0.015

Mechanical engineering (29)	-0.049	-0.010	-0.034	0.013	-0.091*	-0.062	0.047
Chemistry (24, 25)	-0.010	-0.023	0.144***	-0.158***	-0.170***	0.072	0.009
Electrical engineering (30–33)	0.053	-0.028	0.046	-0.012	0.166***	-0.075*	-0.046
Existence of patent division	0.150***	0.121***	0.136***	-0.087*	0.060	0.027	0.020
Importance of application costs	-0.052	0.068	0.012	0.111**	0.065	-0.013	0.050
Importance of "other costs"	-0.017	0.043	-0.016	-0.012	0.034	0.002	-0.075*
Imitation	-0.019	0.343***	0.269***	0.165***	0.140***	0.128***	0.280***
Offensive blockade	-0.067	0.236***	0.247***	0.162***	0.080*	0.125***	0.325***
Defensive blockade	-0.023	0.182***	0.280***	0.097**	0.041	0.197***	0.253***

Source: PATSTAT, Survey Results

The share of R&D personnel in total personnel is not significantly correlated to the number of patent applications and it is negatively related to most of the importance of formal instruments items. However, it is positively associated with the importance of secrecy. It seems to be the case that highly R&D-intensive firms evaluate secrecy as one of the most important instruments for the appropriation of returns on their inventions.

Internationalization is positively correlated with the number of patent applications, meaning that more internationalized firms file a larger number of patent applications than less internationalized firms. The degree of internationalization is also negatively correlated with the importance of domestic patents, but positively related to the importance of foreign patents, which is largely as expected. Additionally, it seems that more internationalized firms concentrate less on filing utility models, as the negative correlation with the importance of utility models shows.

The industry dummies reveal an undifferentiated picture when looking at the bivariate correlations. Regarding the number of patent applications, only the motor vehicles industry shows a significantly positive correlation. Domestic patents seem to be most important for the motor vehicles industry, whereas in the chemical sector foreign patents are the focus. Utility models and industry designs seem to be more important in less research-intensive sectors like consumer goods, construction and the metal industries. When looking at the two informal instruments, a significantly negative correlation can only be observed for the importance of secrecy in the electrical engineering industry.

The existence of a patent division is positively correlated with the number of a firm's patent applications. Additionally, a significantly positive correlation can be found for the importance of domestic and foreign patents. These results are in line with the explanations mentioned in the theory section.

The different motives to patent reveal positively significant correlations with nearly all of the items that measure the importance of formal as well as informal mechanisms, but not with the number of patents itself. Another interesting effect is the positive correlation between patent application costs and the importance of utility models. Utility models seem to be a good alternative to patents when patenting costs are too high for a firm.

1.4.2 Multivariate Results

Several models on the effect of the different firm characteristics on the number of patent applications are calculated (Table 1-4). Thereby, different sets of variables – e.g. degree of internationalization, patenting motives etc. - are added gradually. This is done for two reasons. First, some variables, like the share of foreign sales in total sales, contain many missing values, which considerably lower the sample size for the regressions. Second, it can be observed whether adding new variables increases the explanatory power of the model.

When looking at M3 and M4, it can be observed that the number of patents decreases with firm size. This fact becomes clearer when looking at the squared size effect, where the coefficient is positive. This means that the small and large firms in the sample apply for more patents per employee than medium-sized companies – or in other words, there is a u-shaped relationship between firm size and the patent output of a company, with large firms filing the largest number of patents. Digging a little deeper into these effects by additionally correlating firm size with the motives to patent, a significantly positive correlation to the importance of defensively blocking competitors can be found (0.084*), whereas the other patent motives show no significant correlation. Taking these results together, it seems that firm size is associated with the rise in patent applications in the 1990s, with strategic motives like blocking competitors becoming more and more important with an increase in the number of employees.

As expected, a significantly positive effect for the share of R&D personnel becomes visible, although no significant bivariate correlation could be found (see Table 1-3). However, this effect remains stable over all models. An explanation could be that, although highly R&D-intensive firms evaluate secrecy as one of the most important instruments to appropriate returns on their inventions, as the bivariate correlation shows, they still rely on patents and cannot protect all of their inventions by keeping them secret. Also the existence of a patent division exerts a positive effect on the patent output of a firm, which confirms the results of the correlation analysis and is in line with the theoretical arguments given above. Patent divisions seem to play an important role in increasing a firm's patent output.

Adding the indicator for the degree of internationalization reveals a significantly positive effect in M2 and M3. Therefore, an increase in the share of foreign sales on total sales leads to an increase in the number of patents, keeping all other factors constant. This result, taken together with the high correlation between the degree of internationalization and the importance of patents (domestic and international), largely undermines the result found in previous studies, namely that the importance of patents increases with the relevance of global markets. However, it is interesting to see that this effect loses significance when the variables on the patenting motives are introduced into the model. To analyze this effect in more detail, the degree of internationalization was correlated with the variables on the patenting motives. It can be observed that the degree of internationalization is significantly correlated with the importance of offensive (0.123**) and defensive (0.139***) blockade, but not with the importance of protection from imitation (0.029). This implies that more internationalized firms use patents systematically to block competitors, but not to protect their technology from being imitated which could also be associated with a higher litigation threat on foreign markets. Taken together with the positive effect of the defensive blockade on the absolute patent output of a firm, it seems that the number of patent filings is influenced by an increase in strategic patenting driven by more highly internationalized firms.

Table 1-4 Negative binomial regression models on the absolute number of patent applications

	M1		**M2**		**M3**		**M4**	
Number of patent applications	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Size (log number of employees)	-0.050	0.111	-0.198	0.126	-0.212 *	0.125	-0.344 **	0.141
Size (squared)	0.035 ***	0.009	0.047 ***	0.010	0.048 ***	0.009	0.057 ***	0.010
Share of R&D personnel	0.730 ***	0.229	1.128 ***	0.280	1.117 ***	0.295	1.074 ***	0.297
Industry (NACE codes in brackets)								
Consumer goods (15-19, 36)	-0.150	0.213	-0.390	0.258	-0.377	0.316	-0.421	0.322
Metal industries (27)	0.001	0.213	-0.026	0.245	-0.031	0.244	-0.164	0.229
Motor vehicles (34)	0.226	0.233	-0.150	0.212	-0.220	0.233	-0.220	0.240
Mechanical engineering (29)	0.076	0.157	-0.088	0.194	-0.175	0.214	-0.124	0.226
Chemistry (24, 25)	0.180	0.185	-0.110	0.196	-0.182	0.213	-0.175	0.219
Electrical engineering (30–33)	0.238	0.201	0.077	0.246	0.051	0.265	0.059	0.258
Existence of patent division	0.504 ***	0.129	0.312 **	0.147	0.333 **	0.139	0.381 ***	0.137
Importance of application costs	-0.024	0.054	-0.080	0.056	-0.079	0.058	-0.103 *	0.056
Importance of "other costs"	0.029	0.056	0.081	0.054	0.082	0.056	0.078	0.056
Share of foreign sales on total sales			0.559 ***	0.196	0.472 **	0.232	0.314	0.233
Importance of appropriation strategies								
Domestic patents					-0.012	0.065	-0.048	0.069
Foreign patents					0.101	0.067	0.059	0.070
Utility models					0.032	0.059	0.024	0.055
Industry designs					-0.057	0.050	-0.049	0.049
Secrecy					0.039	0.054	0.009	0.049
Lead-time advantage					-0.061	0.110	-0.098	0.108
Importance of patent motives								
Imitation							-0.050	0.068
Offensive blockade							0.046	0.058
Defensive blockade							0.201 ***	0.069
Constant	0.027	0.443	0.316	0.545	0.210	0.625	0.594	0.662
Number of observations	442		323		284		279	
Wald chi²	469.0		452.3		471.05		484.33	
Prob > chi²	0.000		0.000		0.000		0.000	
R² (McFadden)	0.191		0.214		0.215		0.225	

Significance Level: ***p<0.01, **p<0.05, *p<0.1, robust standard errors
Note: Construction (10-14) is the reference group for industry dummies.

The results of the multinomial regression model on the preference for the different kinds of appropriation methods are depicted in Table 1-5. It shows the marginal effects calculated at the means of the independent variables. The outcome 'Preference for a combination of instruments' serves as the base outcome for the model.

A significantly positive effect of firm size can be observed for the 'protection less important' category. Appropriation mechanisms, either formal or informal, become less important with increasing firm size. The squared size effect, however, shows a negative sign. This means that this relationship is inversely u-shaped. Thus, appropriation methods can be seen as less important, especially for medium-sized firms. This is in line with the results from the negative binomial regression model on the number of patent applications, which showed that medium-sized firms also have a lower patent output compared to small and especially large firms.

Research intensity affects the preference for formal appropriation methods negatively and the preference for informal appropriation mechanisms positively. The first effect implies that an increase in research intensity decreases the preference for formal appropriation mechanisms compared to alternative methods of appropriation. The latter effect even shows that, with a rising share of R&D personnel, informal appropriation mechanisms like secrecy or lead-time advantages gain increased importance. In sum, bearing in mind the results of the correlation analysis and the model on the number of patent applications, it seems that highly R&D-intensive firms evaluate informal mechanisms, especially secrecy, as a very important means to appropriate returns on their inventions. Formal instruments, like patents, seem to play a role of minor importance for highly research-intensive companies. However, they still seem to be reliant on a large patent output, as the model on the number of patent applications shows. At this point, it might be interesting to note that the variable which captures the patent intensity of a firm has no significant effect on any of the outcomes of the dependent variable, implying that the efficiency of a firm of generating patents does not affect its preferences for any of the appropriation methods.

When looking at the share of foreign sales in total sales, one can see that it exerts an influence on the importance of informal instruments and the combination of instruments category. The effect is positive in the case of informal mechanisms, but negative in the case of the combination of instruments, meaning that a higher degree of internationalization increases the probability to attach a high importance to the use of informal appropriation methods, but decreases the probability of a preference for both appropriation methods. These effects require some further clarification, especially in the light of the aforementioned analyses which showed that more internationally active firms file a significantly larger number of patents than their less internationalized counterparts. However, this larger patent output on the part of more internationalized firms seems to consist mostly in strategic patents used to block competitors. Thus, it could be that informal methods (for example, lead-time advantages), provide a crucial edge in securing returns on investments in R&D and other innovation activities in international markets, with the managers of these firms seeing patents as a basic requirement for market entry with a need to defend market positions by strategic patenting, like blocking competitors.

The industry effects provide no evidence for the theoretical assumption that formal instruments are more important in complex product industries, where the number of patents per innovation is large. Significant effects can only be found for the consumer goods industry, the metal, and the motor vehicles industry. In the "protection is less important" category, the consumer goods industry variable shows a negative effect, meaning that the probability to fall into this category is smaller than for firms in the construction sector, which serves as the base category. The dummy variable for the metal industries is negatively related to the preference for formal instruments, which is in line with the theoretical arguments. A contradictory effect, however, can be observed for the motor vehicles industry, where the importance of informal instruments is high. In sum, there seems to be no clear distinction between discrete and complex industries in the importance of different appropriation mechanisms.

Table 1-5 Multinomial-logistic regression on the importance dimensions of appropriation mechanisms by firm characteristics (marginal effects)

Index variable: Importance of instruments	**Protection less important**			**Preference for formal instru-ments**			**Preference for informal instru-ments**			**Preference for a combination of instruments**		
Size (log number of employees)	0.085	***	0.032	-0.010		0.027	-0.046		0.120	-0.029		0.124
Size (squared)	-0.007	***	0.002	0.001		0.002	0.002		0.008	0.004		0.008
Share of R&D personnel	-0.034		0.049	-0.341	***	0.127	0.386	*	0.228	-0.011		0.234
Patent Intensity	-0.016		0.319	0.229		0.363	-1.470		1.338	1.258		1.363
Industry (NACE codes in brackets)												
Consumer goods (15-19, 36)	-0.090	***	0.025	0.028		0.058	-0.036		0.220	0.098		0.220
Metal industries (27)	-0.009		0.026	-0.035	*	0.020	-0.156		0.149	0.200		0.153
Motor vehicles (34)	-0.014		0.022	-0.011		0.028	0.354	***	0.107	-0.329	***	0.096
Mechanical engineering (29)	0.005		0.028	0.014		0.041	0.164		0.131	-0.182		0.126
Chemistry (24, 25)	0.006		0.028	-0.036		0.022	0.190		0.128	-0.159		0.126
Electrical engineering (30–33)	0.002		0.026	0.000		0.030	0.007		0.136	-0.009		0.136
Existence of patent division	-0.013		0.012	-0.061	**	0.028	-0.196	***	0.076	0.269	***	0.077
Importance of application costs	0.001		0.007	0.008		0.010	-0.002		0.039	-0.006		0.039
Importance of "other costs"	-0.003		0.006	0.002		0.011	0.001		0.036	0.001		0.037
Share of foreign sales on total sales	0.036		0.026	-0.022		0.062	0.640	***	0.160	-0.653	***	0.165
Importance of patent motives												
Imitation	-0.012	*	0.007	0.003		0.013	-0.083	*	0.045	0.092	*	0.047
Offensive blockade	-0.017	**	0.007	0.005		0.010	-0.046		0.038	0.058		0.039
Defensive blockade	-0.018	**	0.008	-0.018	*	0.011	-0.048		0.040	0.084	**	0.041
Number of observations	313											
Wald chi²	3300.54											
Prob > chi²	0.000											
Pseudo R²	0.172											

Significance Level: ***p<0.01, **p<0.05, *p<0.1, robust standard errors
Reference group: Model: Preference for a combination of instruments, Industry Dummies: Construction (10-14).
For dummy variables dy/dx is for discrete change of dummy variable from 0 to 1.
Note: Dropping the variable "Share of foreign sales in total sales" to increase sample size did not lead to significantly different results. Therefore, this model is not separately reported here.

The existence of a patent division shows a negative influence on the importance of informal instruments category, which is as expected, but surprisingly, also on the importance of formal instruments. This means that the existence of a patent division decreases the probability of attaching a high importance to the use of formal as well as informal appropriation methods in isolation. However, the effect is positive when the preference for a combination of instruments is regarded. Therefore, keeping all other factors constant, a patent division increases the probability that both formal and informal appropriation mechanisms are seen as important for the firm. It seems that the patent division is not only used by firms to handle the patent application process and to increase the patent output - which was found in the model on the number of patent applications above - but rather to serve as a decision-making mechanism to choose an effective way of protecting an invention. When regarding the influence of the different patenting motives, it can be observed that all of the patenting motives show negative effects in the "protection less important" category, which is largely as expected. Some interesting results, however, can be found when looking at the other categories of the dependent variable. Firms, for which protection from imitation is a highly important motive for patenting have a lower probability to claim a high importance in using informal instruments in isolation. Additionally, firms that evaluate defensive blockade as highly important show a negative effect on the preference for formal instruments. However, the importance of defensive blockade and the importance of protection from imitation have a significantly positive effect on the preference for using a combination of appropriation mechanisms. This means that the probability that the firm uses a variety of appropriation methods is increased by evaluating blocking competitors as highly important, implying that firms which use patents strategically in technology competition do not simply rely on patents, but utilize a variety of methods to appropriate their returns on R&D investments and other innovation activities. The same is true for firms for which protection from imitation is an important patenting motive. Firms seem to utilize more nuanced appropriation strategies than just formal mechanisms when trying to protect their inventions from being imitated.

Combining the results of the models, it can be stated that especially large and internationalized firms seem to contribute to the increase in patent applications during the 1990s. However, many of the firms in the sample do not seem to rely solely on formal mechanisms when it comes to appropriating returns from their innovation activities. Firms seem to have far more refined appropriation strategies, including secrecy and the utilization of lead-time advantages, with a combination of formal and informal mechanisms. These effects are even amplified by employing special in-house patent departments and by using patents strategically in technology competition.

1.5 Conclusions

Against the background of the large increase in patent applications during the 1990s, the main aim of the current study was to assess how different firms act to appropriate their investments in R&D and other innovation activities, and find out if different motives for patenting, like blocking competitors, affect the choice of different appropriation strategies. To pursue this aim, several descriptive and multivariate analyses - based on a sample of 532 German manufacturing firms that applied for at least three patents at the EPO in the year 1999 - were conducted.

The results show that especially large and internationally operating firms significantly add to the number of patent applications. Thus, they can at least partly be seen as a driver of the patent surge during the 1990s. It should nevertheless be emphasized that to some extent also small firms contribute to the rise in patent applications, leaving especially medium-sized ones as the least active in patenting. However, the motives of filing patents seem to differ by firm size and degree of internationalization. Large and more internationally active firms use patents more frequently for strategic purposes, especially blocking competitors.

When looking at the importance of different appropriation mechanisms, some even more interesting patterns can be revealed. It can be shown that only a very small percentage of firms especially stress the importance of formal appropriation methods, while at the same time evaluating informal appropriation methods as being of low importance. On the other side, a large share of firms evaluates informal appropriation methods as being highly important, while formal instruments are of low importance. Most of the firms in the sample emphasize the combination of formal and informal appropriation mechanisms.

Furthermore, most factors that one would envisage as being positively linked to a preference for formal appropriation methods, such as the degree of internationalization or a high share of R&D personnel, are in fact not. With an increase in research intensity, the preference for formal instruments even decreases. And with a rising share of foreign sales in total sales, the importance of informal methods becomes more important. Although internationalized firms file a significantly larger number of patents, they seem to use them rather for strategic purposes than as a mechanism to protect their inventions from being imitated. Against this background, patents could be seen as a basic requirement to enter foreign markets, with a need to defend market positions by strategic patenting like blocking competitors. Informal appropriation mechanisms, on the other hand, seem to provide a crucial edge in securing returns on investments in R&D and other innovation activities in international markets. Besides, one should keep in mind that only German companies, mainly filing their patents at the German Patent and Trademark Office and/or the European Patent Office, are covered by the sample. Both have a high quality of their processes and both patents – once granted – offer a strong protection of the technology. Internationalization beyond Europe might imply filing patents in less reliable systems. Informal mechanisms, among them secrecy, might then be the more suitable strategy, therefore rated relatively more important by internationally oriented companies.

Finally, assigning a high importance to strategic patenting motives, like blocking competitors, as well as the existence of a special in-house patent division, increase the probability that the firm uses a variety of appropriation methods. This implies that strategic patenting is used in parallel to the strategic use of multiple appropriation methods in general. Firms who use patents strategically in technology competition do not simply rely on patents, but utilize more refined methods to appropriate their returns on innovative activities. This also seems to be true for firms that employ a patent division, which do not only increase the patent output, but also serve as a decision-making mechanism to choose an effective way of protecting an invention.

In sum, the results show that firms have far more sophisticated appropriation strategies than relying solely on formal methods, possibly because they are more effective than formal methods only. This bears some important policy implications and implications for the measurement of innovative activities in general. As for the policy side, one could consider shifting the focus away from trying to increase the patent output of firms in general to improving the patent system by limiting the exploitation of the system for strategic purposes (Commission of Experts for Research and Innovation (EFI) 2010; Van Zeebroeck et al. 2008; Van Zeebroeck et al. 2009). This is especially relevant against the background that patent thickets, built and upheld mainly by large and internationalized firms, could prevent small firms from entering markets, leading to less competition in the long run. The European Patent Office already reacted on the patent upsurge with its policy called "raising the bar" that essentially is dedicated to keep the quality of the examination and thereby of the whole patenting process on a high level. One implication of this policy is already visible, namely a decreasing grant rate at the office (EPO 2011).

Furthermore, the findings have some implications for measuring innovative activities. It has to be taken into account that patenting does not seem to be the most important factor for protecting technology-related knowledge and generating returns on R&D and other innovative activities. Other factors, like secrecy or lead-time advantages, are evaluated as being more important by most of the companies in the sample. This implies that measuring innovative activities solely by patents could lead to distorted pictures when trying to assess the innovative activities of companies, since this could only capture a minor part of these activities. In order to draw a complete picture of the innovative activity of firms, various input and output factors have to be taken into account.

However, there are limits to the analyses and the data presented in this paper. For reasons of generalizability, a sample not only of patenting but also of non-patenting firms from the manufacturing sectors could offer additional insights. Additionally, an indicator for the frequency of using informal appropriation mechanisms would lead to more comparable results to the models on the absolute patent output. Moreover, it should be analyzed in more detail whether the number of patent filings, and especially the preferences for different appropriation methods, remain stable or change over time, to obtain more differentiated conclusions about the observed patterns.

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PART II: THE VALUE OF PATENTS – A MACROECONOMIC PERSPECTIVE

2 Patent Indicators for Macroeconomic Growth – The Value of Patents Estimated by Export Volume

Abstract This paper examines the linkage between patenting and export performance for selected countries at the level of technology fields. Some empirical studies show considerable correlation between the patenting behavior of countries and their economic success on international markets. Adding to the existing literature, the aim of this analysis is to assess whether the indicators that are supposed to reflect patent value – like patent citations or family size – have any explanatory power in estimating the export value of countries by technology fields.

For the study, a panel dataset was compiled consisting of annual data (1988-2007) on international trade from the UN-COMTRADE database and patent data from the "EPO Worldwide Patent Statistical Database".

The results show that exports prove to be of good use to act as a valuation of patents. Patents and exports are strongly correlated, although there are visible deviations to this parallelism. The results are ambiguous concerning the meaning and interpretation of the patent value indicators. IPC-classes and inventor counts do not prove to be of relevance in predicting the export value of patents, while family size has restricted predictive power. Especially forward citations are more promising when analyzing patent applications than granted patents.

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2.1 Introduction

This paper examines the linkage between patenting and export performance for selected countries at the level of technology fields. In several empirical studies it was shown that there is a close connection and considerable correlation between patents and the economic success in international markets (Dosi et al. 1990; Gehrke et al. 2007; Grupp et al. 1996; Münt 1996; Porter 1998; Wakelin 1997; Wakelin 1998a; Wakelin 1998b). For example, based on a time series analysis of a set of industrialized countries, Blind and Frietsch (Blind/Frietsch 2006) showed that patents explained export streams, especially in high-tech sectors, but also in low-tech areas. This result corresponds to the discussion in the empirical and theoretical literature which assumes that the long-term development of market shares is not only driven by price competition, but also by technology and quality competition (Kleinknecht/Oostendorp 2002; Legler/Krawczyk 2006; Maskus/Penubarti 1995). Therefore, it can be expected that patents – as they are an output indicator of R&D processes – influence the export performance of countries.

This raises the question whether exports can be used as a means of measuring the value of patents. Even more significantly, one could ask whether patent characteristics which are supposed to indicate a patent's value exert any influence on the relationship between patents and exports. Therefore, the overall aim of this analysis is to show whether different patent quality indicators have any explanatory power in estimating the export value of countries by technology fields.

The economic valuation of patents is one of the biggest challenges in empirical patent value analysis. Renewal fees are one way to assess the value of patents (Bessen 2008; Frietsch et al. 2010) and measuring licensing income is another, even though such data is hard to obtain as neither the licensor nor the licensee have an interest in disclosing it. The most direct way is to survey inventors and ask them for the value of the patent, for instance, on the day of granting (Harhoff et al. 1999). Finally, and this path is pursued here, export data can be used on a macro or meso level of technologies to serve as a measurable value of patents.

For our study, an integrated panel dataset was constructed consisting of annual data of international trade, patenting, and country characteristics for recent years (1988-2007). The panel comprises 18 OECD countries (Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Ireland, Italy, Japan, Korea, the Netherlands, Norway, Sweden, the United States and China). All patent and trade data are aggregated to 35 technology groups for each country for each year. The merger of patents and exports was achieved by applying the definitions of a set of 35 high-technology fields and a residual low-tech area, both in terms of SITC (exports) and IPC (patents). This definition relies on Grupp et al. (2000), as well as Legler and Frietsch (2007).

The remainder of this paper is organized as follows. In Section 2.2, we will give a short account of the literature. Section 2.3 presents more theory and derives the main hypotheses. In Section 2.4 we describe our dataset. Section 2.5 presents the estimation methods and empirical results. Section 2.6 concludes.

2.2 Literature Review

In the mainstream international trade theories, the international trade of goods occurs because of comparative advantage differences in manufacturing goods between two countries. The most widely accepted and tested factor that affects the comparative advantage is factor endowment. The Heckscher-Ohlin (HO) theory predicts that a country abundant in a particular factor relative to other factors will export greater quantities of a good integrating more of that particular factor. For example, according to the Heckscher-Ohlin theory, the United States should export capital-intensive goods and import labor-intensive goods because it is strong in capital relative to labor. However, paradoxically, empirical data revealed the opposite result as first presented by Leontief (1953). As a natural response to this paradox, many alternative explanations and empirical examinations followed[4]. As one of those alternative (or complementary) explanations, some scholars focused on the equal technology assumption in the HO model. The assumption made by the HO theory that production technology is the same across countries is not only unrealistic, but also does not explain the impacts of technological change on international trade.

The "product cycle model" of international trade, alternatively known as the "technology gap model", addresses this gap in the HO trade theory. The product cycle model was first proposed by Posner (1961) and Vernon (1966; 1979) and further elaborated by Krugman (1979) and Dosi and Soete (1983; 1991). In essence, the product cycle model assumes a dynamic change in production technology and that there is a different ability to exploit new technologies between countries. It further assumes the presence of an imitation lag, i.e. it will take time and involve costs for a following country to absorb superior technologies and apply them to manufacturing processes. Under these conditions, new or advanced products integrating superior technology will form temporary oligopolistic markets before followers can catch up. Therefore, firms located in technologically advanced countries will develop new products integrating the superior technology first and will dominate the export markets for these products.

The empirical evidence is largely consistent with the product cycle model. Most empirical studies have tested whether the export performance of a country in a particular sector is positively correlated with technological capability (for example, as measured by stock of patents in that sector). For example, Soete (1981; 1987) showed that there was a positive link for 40 industrial sectors between the export performance of OECD countries in 1977 and the country share of US patents for the past 15 years after controlling for capital-labor ratio, population, and geographic distance from an assumed 'world center'. He obtained similar results for four different measures of export performance such as export market share, revealed comparative advantage (or Balassa index), export-import ratio, and the export-GDP ratio. He also found strong positive associations for most sectors between export performance as measured by exports per capita and technology level as

4 See Deardorff (1985) for a review of the alternative theories and empirical evidence.

measured by granted US patents after controlling for investment per employee and wages on value added (Dosi/Soete 1983). These results, however, also revealed a sectoral heterogeneity of the relationship between technology and exports. This is quite natural given that some products integrate more technology elements than others.

Looking at bilateral trade among 9 OECD countries in 1988, Wakelin (1998b) found that the relative specialization of patents was positively associated with relative export values between two countries for some sectors after controlling for relative investment intensity and relative wage rate. Similar findings are reported for temporal variation of export performance for the UK (Greenhalgh 1990; Greenhalgh et al. 1994). In a study on the bilateral trade of Switzerland, Blind (2001) found that patent applications at the European Patent Office and also the stocks of technical standards are able to explain the export performance of Switzerland. Furthermore, Blind and Jungmittag (2005) analyzed the effects of patents as indicators for innovations and standards on German trade performance and German-British trade in detail and found that Germany's export performance could be explained by its innovative capacity.

Fagerberg (1996) reports interesting sectoral patterns of exports and R&D. For 22 industries in 10 OECD countries he regressed exports in 1985 on three R&D measures: 1) direct R&D investment, 2) indirect R&D investment as defined by purchases of capital goods and intermediate goods, and 3) foreign share of indirect R&D. He controlled for investment in physical capital, wage, size of domestic market, and dummies for country and product groups. He found that the effect of indirect R&D is twice as large as direct R&D overall. More interestingly, while the impact of indirect R&D on exports is high in low R&D-intensive sectors, direct R&D is more influential in high-tech sectors.

Besides sectoral heterogeneity, there is also country heterogeneity. Van Hulst et al. (1991) studied the correlation between the export performance of five industrialized countries and their technology specialization measured by the sectoral share of US patents of a country divided by the sectoral share of US patents of all countries. They found some distinct patterns among the five countries: 1) the Netherlands, Germany, and Sweden show congruence between patenting and exports; 2) there was no relationship between technology and trade for France; and 3) strong sectoral deviance (high dependence of “factor-proportions” products for some industries and technology-driven export for some high-tech industry) for Japan.

In sum, the above cross-sectional studies support the hypothesis that innovation is positively correlated with export performance. However, this does not necessarily establish the fact that innovation causes exports. At the firm level, a study by German researchers addresses the endogeneity of innovation in export regression (Lachenmaier/Wößmann 2006). Using exogenous impulses and barriers to innovation as instrument variables, they were able to show that innovation drives the increase in export shares of German manufacturing firms. Madsen (2007) recently reported the results of analyzing panel data of 18 OECD countries in the period from 1966 to 2000. His findings are consistent with previous studies in that innovative activities explain a large proportion of cross-country variations in export performance. He further finds that patents filed in exporting markets are particularly important in terms of the impacts on exports.

2.3 Theory and Hypotheses

As section 2.2 shows, there is already a body of literature on the links and correlations between patents and export performance. However, to the best of our knowledge, no study has yet made use of exports to assess the predictive power of patent value indicators for the average export value of patents. The focus of this paper is twofold: First, an attempt is made to unravel the complex ties between patents and export volume for different countries and technology fields in order to find out whether exports can be generally applied as a measure of patent value. Second, and even more important, the influence of the value indicators on the assumed relation between patents and exports will be evaluated.

Patents are one of the most important indicators for the output of technology-oriented invention/innovation processes. As has already been established in the literature, apart from quality considerations, the assumption that the number of patent applications positively affects a country's exports is reasonable. A large patent output from a given country indicates greater R&D activities and therefore a higher innovative output, which should in turn increase the export volume of a country. This gives rise to our first hypothesis:

H1: A larger patent output in a technology area increases the exports of a country in that technology area.

Since patents can differ in both economic and technological value, simple patent counts could give a distorted impression of the technological basis of a country. Therefore, the central aim of this analysis is to assess whether the indicators that are supposed to reflect patent value have any explanatory power in estimating the export value of countries by technology field.

Many other indicators have been proposed to correct for the quality or value of patents (for an overview see Frietsch et al. 2010). The indicators we used for our study will be reviewed in the following, both with respect to quantity and quality. For the sake of simplicity, all characteristics that could indicate a patent's value will be referred to as 'value indicators' in the remainder of this paper, although one aim of the article is to find out which of these indicators can be applied to evaluate a country's patent portfolio.

Patent forward citations are one of the most widely-used indicators to assess the value of a patent (Narin et al. 1987; Trajtenberg 1990). It is assumed that the number of forward citations (citations a patent receives) measures the degree to which a patent contributes to further developing advanced technology, thus this can be seen as an indicator of technological significance (Albert et al. 1991; Blind et al. 2009; Carpenter et al. 1981).

H2a: An above-average number of forward citations per patent has a positive effect on the exports of a country.

As some studies show, patent citations can be a noisy signal of patent value (Alcacer et al. 2009; Alcacer/Gittelman 2006; Bessen 2008; Gambardella et al. 2008; Hall/Ziedonis 2001). Therefore, additional measures of patent value are taken into account for the following analysis.

Backward citations refer to previous patents and are mostly used as an indicator of technological breadth or background of an application and indicate the scope of a patent. However, the logic of backward citations is ambiguous (Frietsch et al. 2010). On the one hand, backward citations reflect a patent's scope, as a patent examiner may include more references if the scope of the patent is large. On the other hand, Harhoff et al. (2003) argued that a higher number of backward citations could cause the content of the patent to be more restricted, which could therefore limit its possible value. However, in their analyses they found a positive influence of backward citations on patent value. Therefore, the following hypothesis can be derived:

H2b: An above-average number of backward citations per patent has a positive effect on the exports of a country.

Granted patents could also serve as an indicator of patent value. The interpretation of this indicator is very straightforward as it can be assumed that the value of a patent is determined by the granting process per se. A granted patent can be seen as more valuable than a non-granted patent because it has a higher threat potential and also proves the still valid conviction of the applicant that it is economically applicable (this is the argument of the maintenance fees). Granted patents are able to protect technologies on international markets, while applications are only an option or a potential threat.

H2c: A larger share of granted patent leads to larger export amounts.

Another important patent characteristic which could potentially indicate a patent's value is family size. Family size is determined by the number of countries or patent offices where a patent has been applied for (Adams 2006; Putnam 1996; Schmoch et al. 1988). For each of these countries, application and maintenance fees have to be paid to the respective offices. Therefore, applying for a patent in a foreign country means that the applicant is trying to secure that market to sell his invention and is prepared to bear the additional costs. In this sense, it is assumed that an applicant only files a patent abroad if he expects to make a profit from the sale of the protected technology. Put simply, a large patent family means greater market coverage which is associated with preliminary costs.

H2d: Exports increase with increasing family size.

The above mentioned indicators do not fully reflect the literature on potential indicators for the value of patents. Several other indicators like the number of inventors or the number of IPC-classes have also been discussed. Some of these will be used as control variables in the following multivariate models.

2.4 The Data

The "EPO Worldwide Patent Statistical Database" in its September 2009 version (henceforth, PATSTAT) is used for patent data. The PATSTAT database provides rich information about published patents collected from 81 patent authorities worldwide. For each of the 35 technology fields (Legler/Frietsch 2007), the annual sum of transnational patent applications filed by each country was counted. Transnational patent applications, i.e. patent families with at least one EPO and one international (PCT) application, are used since they are best able to map international markets in adequate relations (Frietsch/Schmoch 2010). For the regressions on patent value indicators, however, we restricted the analyses to European Patent Office (EPO) data in order to focus on a consistent and homogeneous patent system including patent citations. If the EPO search report referred to the PCT document, we also included PCT citations. All patent data reported are dated by their priorities, i.e. the year of worldwide first filing.

Export and import figures were extracted from the United Nations Commodity Trade Statistics Database (henceforth COMTRADE). Because trade data in COMTRADE is aggregated by commodity groups, a concordance table between the technology classification for patents (IPC) and the commodity classification (Standard International Trade Classification Revision 3 or SITC3 for short) was applied according to the definitions in Legler and Frietsch (2007). Additional information was collected from OECD databases (OECD Stats), for example on GDP, inhabitants, exchange rates or purchasing power parities (PPP). To achieve a comparable basis over countries and years, exports and imports were converted to constant US dollars for the year 2000. For further analyses, a set of export intensities – defined as exports per patent application or grant – was calculated, which can be interpreted as the export value of patents.

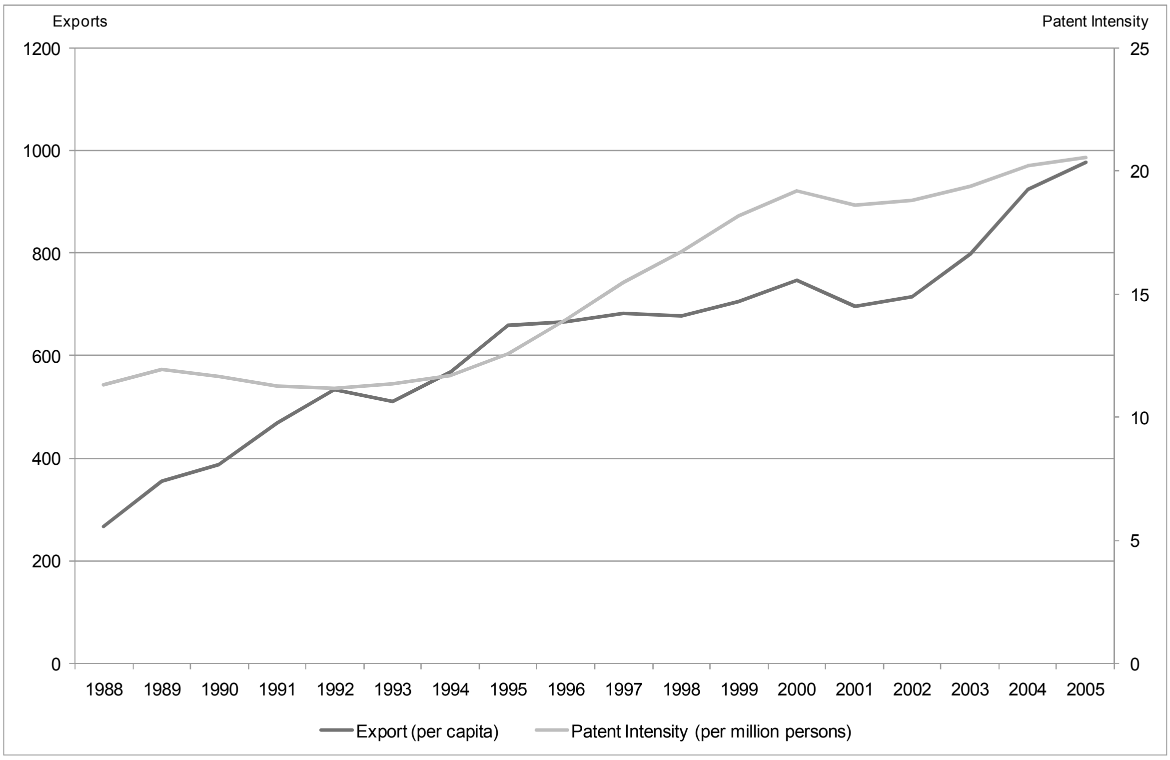
2.5 Results

In this section, first of all the sample characteristics and some descriptive results will be presented. In a second step, the results of the multivariate analysis of the link between patents and exports will be described. Finally, two multivariate analyses are used to estimate the influence of the value indicators on the relationship between patents and exports.

2.5.1 Sample characteristics and descriptive results

Before presenting the multivariate analyses, a brief overview of the sample characteristics and some descriptive statistics are appropriate. Since 1988, the number of EPO patent applications and exports show increasing trends, although not monotonically. The patent upsurge that took place in the second half of the 1990s was not accompanied by a similarly steep increase in worldwide export volumes. However, as can be seen from the two lines in Figure 2-1, a more parallel development occurred after the year 2000, although the economic crisis had a slightly greater impact on the export trend. It should be pointed out that we did not use worldwide filings here but EPO patents, which tend to follow the international trends at a lower level.

Figure 2-1 World export volume per capita and total patent applications per million inhabitants, 1988-2005



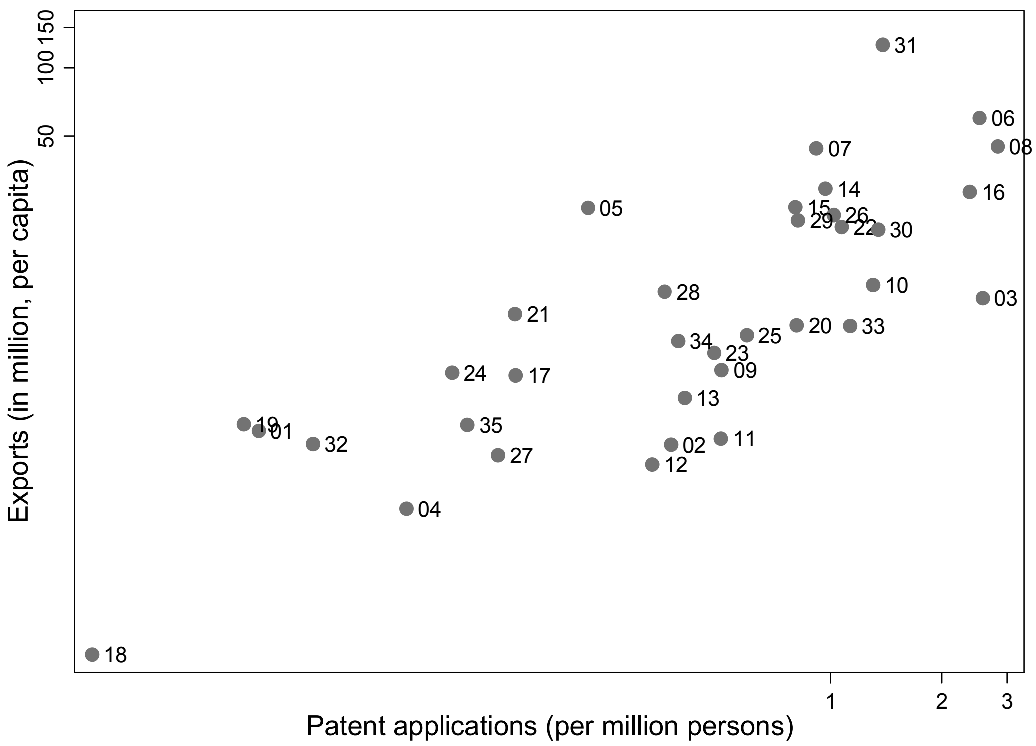
Source: UN-COMTRADE, PATSTAT, own calculations

Plotting the export amount over the number of patent applications by technology shows that technology fields characterized by more patent applications are associated with larger exports– or, to put it in other words, there is a strong correlation between patenting and exports. Computers, communications engineering, and pharmaceuticals are located in the upper right corner of the graph in Figure 2-2 indicating that these fields feature high patent and export activity.

Biotechnology is actively patented but exported only in mediocre amounts. In contrast, automobiles and engines are placed top in terms of exports but ranked fifth in the number of patent applications. Pyrotechnics, photo chemicals, nuclear reactors and radioactive elements, weapons, and rail vehicles are neither exported nor patented at an above-average level.

Next, exports versus the number of patent applications – both in per capita –are plotted for each country examined in the year 2005 (Figure 2-3). Again, this graph shows a positive slope between exports and the number of patent applications, indicating that the more active a country is in patenting, the more it exports. However, in Belgium and Ireland patenting activities do not seem to be related to export performance in the same way as in the other countries. Both countries have considerable imports that relate to exports. In other words, these countries have a low value added and in some areas act as a market hub or trans-shipment center. In the case of Belgium, this is especially obvious in the automobile sector, where it performs even better than Germany in terms of exports per patent.

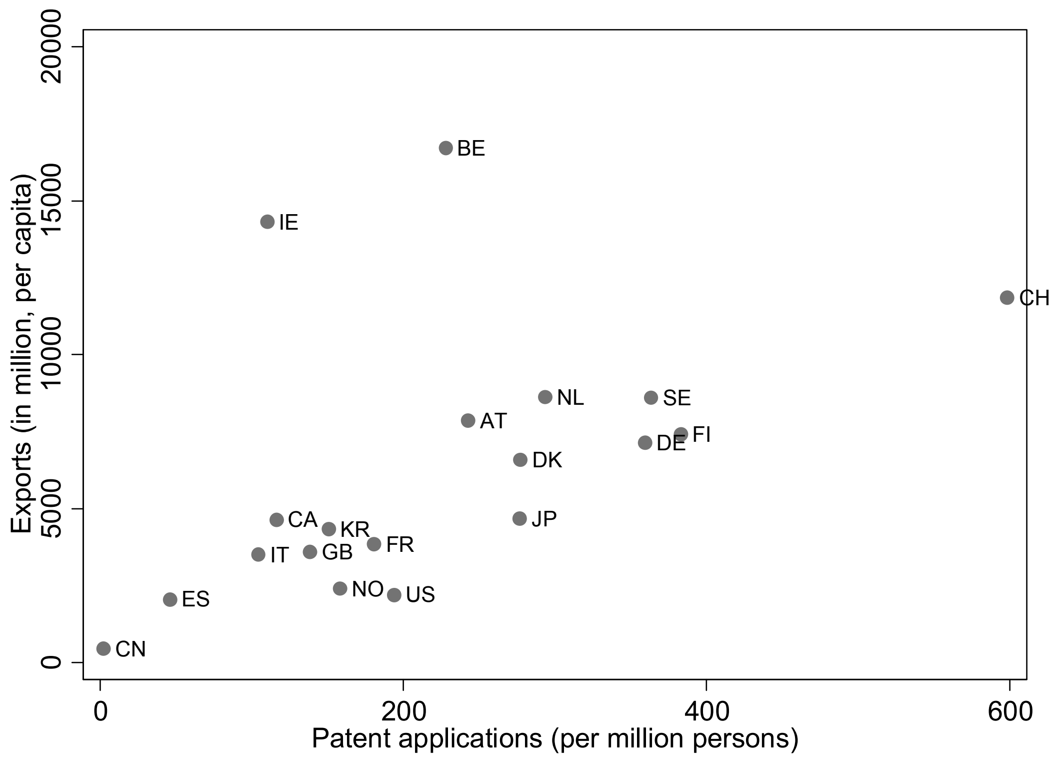
Figure 2-2 Exports and patent applications by technology (over all sampled countries, logarithmic scale), 2005



Note: 1=nuclear reactors and radioactive elements; 2=pesticides; 3=biotechnology and agents; 4=weapons; 5=aeronautics; 6=computer; 7=electronics; 8=communications engineering; 9=electronic medical instruments; 10=optical and electronic measurement technology; 11=optics; 12=dyes and pigments; 13=inorganic basic materials; 14=organic basic materials; 15=polymers; 16=pharmaceuticals; 17=scents and polish; 18=pyrotechnics; 19=photo chemicals; 20=other special chemistry; 21=rubber goods; 22=power machines and engines; 23=air conditioning and filter technology; 24=agricultural machinery; 25=machine tools; 26=special purpose machinery; 27=office machinery; 28=power generation and distribution; 29=lamps, batteries etc.; 30=broadcasting engineering; 31=automobiles and engines; 32=rail vehicles; 33=medical instruments; 34=mechanical measurement technology; 35=optical and photo-optical devices

Source: UN-COMTRADE, PATSTAT, own calculations

Figure 2-3 Exports and patent applications by country (over all technology fields), 2005

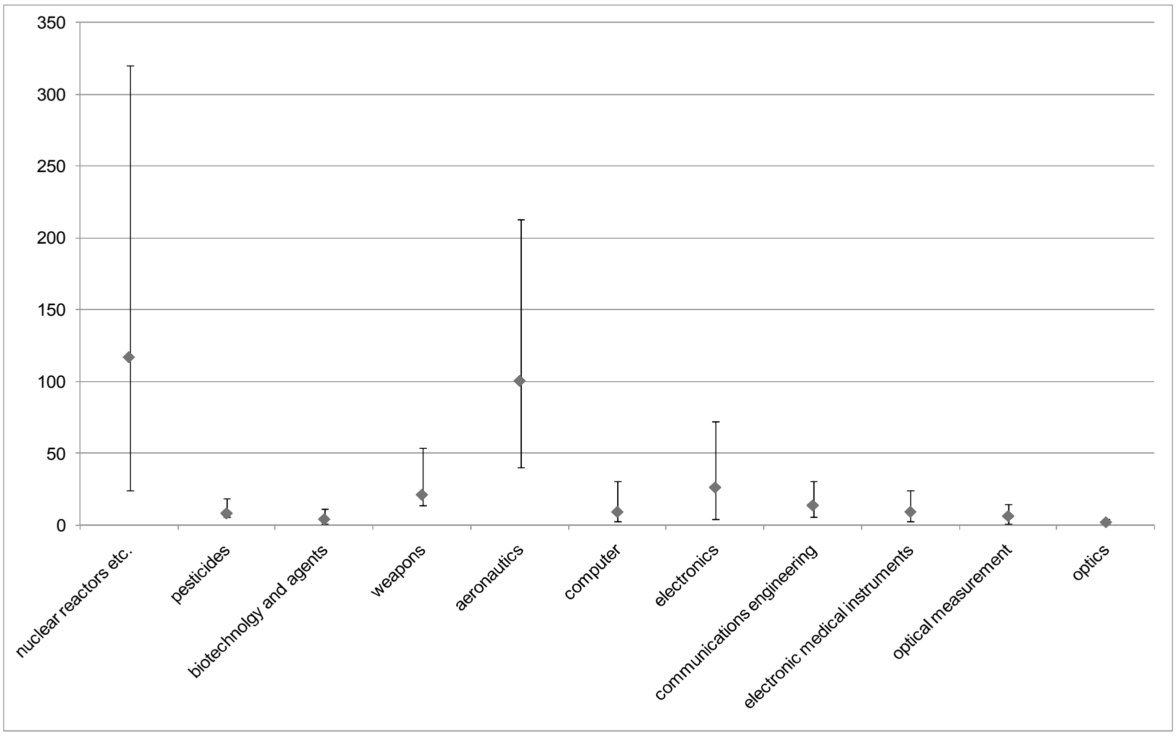


Source: UN-COMTRADE, PATSTAT, own calculations

Figure 2-4 shows the median of export intensities – export volume per patent application – and the 25% and 75% quartiles for each of the 35 technology fields. The median is calculated for each field across all countries for the year 2005. In leading-edge technologies, especially nuclear reactors, but also weapons and aeronautics show an extreme range of values. These fields are rather small in terms of exports and especially in terms of patents, but all three of them are subject to massive government regulation and governance. It is interesting to note that electronics also has rather high variation.

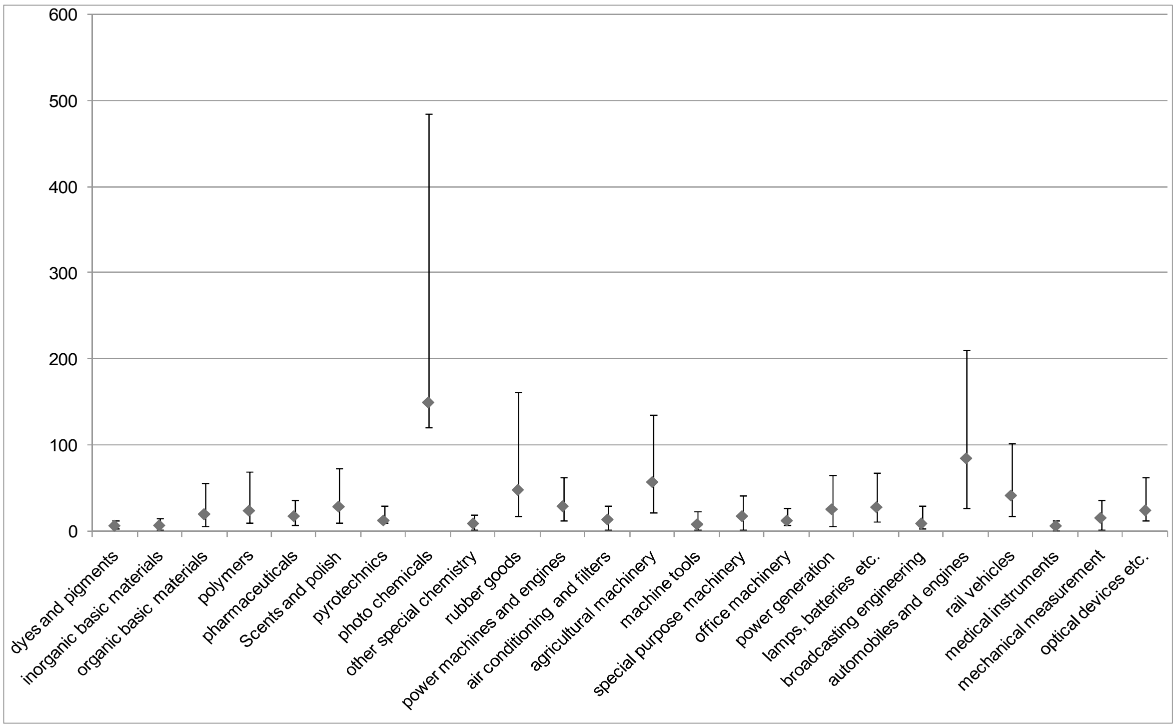
Focusing on the high-level technologies (Figure 2-5), especially photo chemicals, rubber goods, and agricultural machinery deviate considerably from the general pattern, both in terms of the median values and their variations. All of them are rather small technology fields and some of them – especially photo chemicals – have been subject to a considerable decline in relevance. Among the high-level technologies it is interesting to note that automobiles and engines have a high median value and also show great variation. The explanation is more complex in this case. On the one hand, some countries are very patent-active in relation to export activities – among them Germany and Japan. On the other hand, as already mentioned above, countries like Belgium have a high export volume of automobiles and engines, but a low patenting activity. The reason is that they import a large number of cars before they export them again – they act as trans-shipment centers.

Figure 2-4 Median and quartiles (25%, 75%) of export intensities (exports per patent application) in leading-edge technologies, 2005



Source: UN-COMTRADE, PATSTAT, own calculations

Figure 2-5 Median and quartiles (25%, 75%) of export intensities (exports per patent application) in high-level technologies, 2005



Source: UN-COMTRADE, PATSTAT, own calculations

Table 2-1 displays the mean and standard deviations for different kinds of export intensities. The intensities are defined as exports per applications and exports per grants, respectively. For a second set of intensities, not exports but the trade balance – defined as exports minus imports – is used as a numerator. This is done to balance trans-shipment effects, although more than just this aspect is covered by the trade balance.

Table 2-1 Mean and standard deviations for a selected set of export intensities (per patent) by technology, 1988-2005

	Exports per application		**Exports per grant**		**Trade balance per application**		**Trade balance per grant**	
	Mean	**Std.dev.**	**Mean**	**Std.dev.**	**Mean**	**Std.dev.**	**Mean**	**Std.dev.**
nuclear reactors etc.	96.4	9.0	216.7	26.2	-5.9	6.0	-37.9	18.2
Pesticides	7.7	0.4	32.7	4.4	-3.0	0.6	-2.2	3.0
biotechnology and agents	8.2	0.8	54.2	10.4	2.7	0.7	18.1	7.6
Weapons	46.6	4.4	81.0	7.4	3.4	3.7	9.0	6.5
Aeronautics	232.9	16.1	492.2	49.0	-51.9	13.2	-47.9	26.0
Computer	83.5	11.3	276.7	40.5	-33.0	8.2	-127.1	30.1
Electronics	68.9	8.6	303.7	43.1	-28.9	4.3	-62.7	17.0
communications engineer.	24.1	1.5	87.9	14.7	-3.7	1.4	-11.3	11.2
electronic medical instr.	17.9	1.6	59.4	7.2	1.0	1.5	1.1	4.7
optical measurement	10.3	0.6	48.8	6.7	-3.0	1.0	-5.2	4.7
Optics	3.4	0.3	11.2	1.3	-2.1	0.4	-4.5	1.4
dyes and pigments	12.4	1.1	28.9	3.0	-7.4	1.2	-10.6	2.4
inorganic basic materials	12.7	0.9	40.7	5.0	-4.2	0.9	-9.9	2.9
organic basic materials	104.5	24.4	346.7	92.0	56.8	21.8	168.1	80.7
Polymers	32.3	2.1	106.5	15.1	-16.0	2.4	-33.4	9.5
Pharmaceuticals	22.7	3.5	220.7	78.9	8.3	3.1	83.9	65.6
scents and polish	50.9	11.5	129.2	30.3	13.2	9.8	32.4	26.8
Pyrotechnics	14.4	1.6	33.1	6.0	-2.4	1.6	-1.7	3.8
photo chemicals	102.1	12.9	232.1	32.4	-10.4	8.9	24.9	18.0
other special chemistry	14.2	1.9	74.5	13.5	1.5	1.6	13.4	10.2
rubber goods	105.7	12.3	209.0	24.0	-14.5	5.1	-32.3	9.7
power machines	36.9	1.7	95.9	13.3	-9.5	2.2	-28.8	10.6
air conditioning and filters	16.0	0.6	60.5	8.2	1.1	0.7	8.6	3.5
agricultural machinery	67.5	3.4	140.1	11.6	-5.5	4.1	-8.2	10.6
machine tools	15.4	0.8	37.2	3.5	-2.9	0.9	-7.9	3.3
special purpose machinery	24.9	0.6	82.9	10.5	0.8	1.4	7.9	6.0
office machinery	31.6	2.2	80.0	8.2	-15.6	2.2	-32.2	5.8
power generation	42.3	2.6	136.3	13.2	5.0	2.1	13.7	8.7
lamps, batteries etc.	65.6	6.6	166.3	15.8	-26.4	3.8	-65.2	10.3
broadcasting engineering	30.0	3.6	99.5	13.9	-20.1	2.6	-98.5	15.8
automobiles and engines	193.9	17.5	674.7	238.2	-64.4	11.4	-125.4	46.5
rail vehicles	57.8	6.6	114.3	14.2	9.9	5.1	17.5	10.0
medical instruments	14.0	1.9	66.8	21.3	0.0	1.5	16.3	17.6
mechanical measurement	23.7	1.1	76.8	7.0	-5.5	1.3	-17.9	5.9
optical devices etc.	35.5	2.8	93.3	11.1	-13.8	3.6	-27.5	11.2
low-tech	41.1	1.6	133.8	14.2	-2.8	1.1	-19.6	10.1

Source: UN-COMTRADE, PATSTAT, own calculations

The case of automobiles shows that the exports per application, but especially the exports per granted patent reach a huge standard deviation, while in the case of trade-balance-related indicators, the standard deviation (in relation to the mean) is below the average of the other fields. This is yet more proof of what was said above about trans-shipment effects. Similar effects are visible for pharmaceuticals and computers. Both are also trans-shipment areas and, in the case of computers, for example, also also fields in which inputs are imported and assembled before being exported with a restricted added value.

It can also be derived that export intensities vary greatly between the fields. Some of them are more patent-intensive while others are less intensive. One must not forget that we are focusing especially on high-tech fields here, which have – as a matter of fact – higher international orientation and which are more subject to international trade than low-tech goods. However, the great variation in the value of the technologies/goods also has an impact on the intensity indicators, as well as the number of units that are traded. To put it more simply, structure matters and differences between technological fields have to be taken into account.

Table 2-2 shows the average export intensities and standard deviations for each country for the 18 years for which we have reliable data. Some countries have developed considerably within this period – among them Canada and Ireland – so that their high standard deviations can be largely explained by this fact. The fact that the grant rates differ substantially between countries also explains another part of the differences between application- and grant-based indicators here.

To sum up, depending on the perspective, each of these four indicators could provide interesting and relevant information for our discussion of patent values. This is why all of them are taken into account in the following examination. At the same time, Belgium and Ireland are outliers in relation to the patterns found for the other countries, so that we are justified in excluding them from the estimation of the regressions.

Table 2-2 Mean and standard deviations for a selected set of export intensities (per patent) by countries, 1988-2005

	Exports per application		**Exports per grant**		**Trade balance per application**		**Trade balance per grant**	
	Mean	**Std.dev.**	**Mean**	**Std.dev.**	**Mean**	**Std.dev.**	**Mean**	**Std.dev.**
Austria	34.0	2.5	78.2	8.5	-12.6	1.9	-20.7	3.5
Belgium	69.8	7.8	326.3	50.7	4.1	2.4	8.3	9.4
Canada	101.8	10.6	407.1	124.1	-16.0	3.5	-53.1	20.6
Switzerland	25.4	1.0	67.7	6.1	-6.2	1.4	-8.3	4.5
Germany	23.2	1.2	56.6	4.8	5.0	0.4	12.0	1.3
Denmark	44.7	2.8	117.2	9.8	-20.3	3.4	-42.1	11.2
Spain	97.7	8.8	226.0	17.0	-42.5	5.5	-119.4	12.6
Finland	28.1	1.6	84.1	11.4	-20.3	3.2	-31.1	10.0
France	27.8	1.5	67.8	5.3	1.4	0.7	-1.0	1.9
Great Britain	40.6	2.4	123.7	8.8	2.0	1.2	-1.1	4.4
Ireland	191.0	23.6	610.4	105.0	47.9	22.1	248.1	94.2
Italy	41.4	2.8	93.7	6.5	-0.8	1.2	-8.1	3.9
Japan	24.7	1.3	76.5	7.1	8.7	1.7	29.0	6.1
Netherlands	58.1	5.5	155.6	15.0	0.2	2.1	6.7	4.8
Norway	40.1	2.6	78.3	6.2	-54.2	4.6	-111.0	12.7
Sweden	31.2	1.6	91.9	9.2	-7.5	1.3	-12.5	6.2
United States	20.4	1.3	106.5	11.2	-0.2	1.1	-20.4	8.6

Source: UN-COMTRADE, PATSTAT, own calculations

2.5.2 The influence of patents on export volumes

2.5.2.1 Estimation strategy and variables

Our dataset is composed of a panel of 19 countries and covers the period from 1988 to 2007. We further break down exports and patent applications into 35 technology areas to control for technology-specific effects. Therefore, our dataset has 665 units (35 technologies multiplied by 19 countries) for 18 years. There are some missing values for some years for some units so that they constitute an unbalanced panel. The basic econometrical model for the technology-level value of exports to the world of a country is specified as follows:

$$X_{j,t}^{i}=\alpha X_{j,t-1}^{i}+\beta_{pat}Pat_{j,t-1}^{i}+\beta_{PR}PR_{j,t}+\beta_{GDP}GDP_{j,t}+\beta_{Pop}Pop_{j,t}+u_{j}^{i}+v_{j,t}^{i} \qquad (1)$$

where $X_{j,t}^{i}$ is the natural logarithm of the aggregate value of exports of country *j* in technology area *i* in year t (in constant US dollars for the year 2000); $Pat_{j,t-1}^{i}$ is the natural logarithm of the aggregate number of transnational patent applications filed by country *j* in technology area i in year *t-1*; $PR_{j,t}$ is the strength of patent protection of country *j* at time t as compiled by Park (2008); $GDP_{j,t}$ and $Pop_{j,t}$ are the natural logarithms of the gross domestic product per capita in constant US dollars for the year 2000 and the natural logarithm of the population of country *j* in year *t*, respectively; u_{j}^{i} is the errors specific to country *j* in technology *i*; and, finally, $v_{j,t}^{i}$ represents idiosyncratic shocks. The models include the lagged exports $X_{j,t-1}^{i}$ in the regressors because we believe that the shift in exports in a particular technology area of a country in the previous year may persist for some reason not modeled. We estimate the effects of the lagged patents instead of the current number of patents because there is a lag when transforming a newly developed technology into commercial products (Hingley 1997; Kleinknecht/Oostendorp 2002). We control two time-varying country-level variables that may affect the overall exports of the country: GDP per capita as a proxy for the overall level of industry advancement; and population as a measure of the size of the economy and domestic market. Finally, we control for the strength of the IPR regime of the country based on the previous literature (Falvey et al. 2006; 2009; Ivus 2010; Weng et al. 2009; Yang/Huang 2009).

In order to obtain valid estimators, our econometric models must address several issues: 1) dynamic panel bias; 2) fixed technology-country-specific effects; and 3) endogenous regressors. The first-order autoregressive term $X_{j,t-1}^{i}$ in the regressors is correlated with the error terms for unobserved individual heterogeneity u_{j}^{i}, which causes upward bias in α for OLS estimation and downward bias for within-group estimation (Roodman 2009). Moreover, in our models, patent applications are not strictly exogenous because they can be affected by the previous level of exports (Hughes 1986) and thus be related to the idiosyncratic error, $v_{j,t}^{i}$. Arellano-Bond's (1991) generalized method-of-moments (GMM) dynamic panel estimators for the first difference transformation (henceforth, "Difference GMM" estimators) provide consistent estimators by incorporating the lagged endogenous variables as their own instruments. We use xtabond2 command implemented in STATA 11.2

(Roodman 2009). The pairwise correlations of the variables in the pooled panel are presented in Table 2-3. Taking a look at the bivariate associations between the variables reveals that patent applications do exert a positive influence on export value.

Table 2-3 Pairwise correlation analysis (N=12072)

Total	$Pat^i_{j,t}$	$GDP_{j,t}$	$Pop_{j,t}$	$PR_{j,t}$
$X^i_{j,t}$	0.705***	0.019**	0.463***	0.230***
$Pat^i_{j,t}$	1	0.217***	0.393***	0.327***
$GDP_{j,t}$		1	-0.530***	0.603***
$Pop_{j,t}$			1	-0.082***
$PR_{j,t}$				1

Significance level: ***p<0.01, **p<0.05, *p<0.10
Source: UN-COMTRADE, PATSTAT, own calculations

2.5.2.2 Estimation Results

The results of the multivariate analyses are presented in Table 2-4. The first two columns show the results from the OLS regression and the fixed effects panel regression with autoregressive terms (we use xtregar in STATA), respectively.

The third column presents our main estimation using Difference GMM. A series of test statistics shown in the lower panel of the table indicates that our Difference GMM specification is correct. First, there is a significant country-technology unobserved heterogeneity as indicated by significant correlation between u^i_j and β (-0.472, p<0.01). Second, Arellano-Bond tests for autoregression show that the level of exports does correlate significantly with the previous level of exports (p-value for AR(1) test statistic is 0.022) but not with the deeper lags (p-value for AR(2) test statistic is 0.323). Third, the coefficient on the lagged dependent variable α estimated by Difference GMM (0.529) falls between the OLS estimator (0.920) and the fixed effects estimator (0.424). Finally, Hansen tests for the validity of instruments show that both our set of our instruments, GMM-like instruments (the level of imports and the third lag of patent applications, $Pat^i_{j,t-3}$) and exogenous instruments ($GDP_{j,t}$, $Pop_{j,t}$, $PR_{j,t}$, and year dummies), are valid (p-values are 0.457 and 0.895, respectively, indicating that the null hypothesis of instrument exogeneity cannot be rejected).

A look at the estimators of the coefficients from the Difference GMM model reveals that the effects of patents on the export value is positive and significant (β_{pat}=0.122, p<0.01). In other words, a one percent increase in patent applications within a technology area by a country raises the value of that country's exports in that technology area for the following year by 12.2 percent, holding all other variables constant. Interestingly, strengthening the intellectual property protection also increases the export value as indicated by the positive and significant estimation of β_{PR} (0.113, p<0.01). The elasticity of exports with respect to GDP per capita is 0.292. On the other hand, the elasticity of exports with respect to population is -1.051, which indicates that the growth of domestic markets may disincentivize exports.

Table 2-4 Dynamic panel data estimators (DV=$X_{j,t}^{i}$)

	OLS	**Fixed effects**	**Difference GMM**
$\boldsymbol{\alpha}$	0.920***	0.424***	0.529***
	(0.028)	(0.009)	(0.063)
$\boldsymbol{\beta_{pat}}$	0.067***	0.102***	0.122***
	(0.019)	(0.011)	(0.041)
$\boldsymbol{\beta_{PR}}$	0.038*	0.125***	0.113***
	(0.020)	(0.037)	(0.039)
$\boldsymbol{\beta_{GDP}}$	-0.087***	0.528***	0.292**
	(0.012)	(0.096)	(0.127)
$\boldsymbol{\beta_{Pop}}$	0.005	-0.942***	-1.051**
	(0.005)	(0.361)	(0.470)
Year dummies (1990-2007)		Jointly significant	
Constant	2.106***	4.235	-
	(0.527)	(3.617)	-
Observations	12072	11407	11406
F test	0.000		
Number of groups		665	665
Largest group size		18	18
Smallest group size		7	7
R-squared, between		0.043	
R-squared, within		0.358	
R-squared	0.936	0.060	
Correlation between $\boldsymbol{u_j^i}$ and $\boldsymbol{\beta}$		-0.472***	
Number of Instruments			630
Wald chi-squared, p-value			0.000
Sargan test, p-value			0.999
Hansen's test (p-value)			0.545
Arellano-Bond test for AR(1), p-value			0.022
Arellano-Bond test for AR(2), p-value			0.323
Hansen test for GMM-like instruments, p-value			0.457
Hansen test for exogenous instruments, p-value			0.895

Significance levels: *** p<0.01, ** p<0.05, * p<0.10, Standard errors in parentheses
Source: UN-COMTRADE, PATSTAT, own calculations

2.5.3 Patent value indicators and the relationship between patents and exports

Two approaches will be followed to examine the linkage between patent value indicators and export performance. First, models based on intensities (exports and trade balance per application or grant) are calculated as dependent variables. Second, panel regressions based on absolute numbers are applied to see whether the effects remain stable over different kinds of models. The patent value indicators that were used are listed below. Because we use the forward citation indicators in a four year time window, the following analyses are restricted to the years 1988 to 2000. Otherwise some years would contain incomplete data.

Number of patent applications. A count of a company's issued patents per year. Note that this variable is only used in the models for absolute export figures.

Average number of forward citations. The number of forward citations in a four year time window divided by the number of applications with forward citations (also in a 4 year time window). This time window assures that all patents have the same chance to be cited. Not using a time window would lead to higher citation counts for older patents since they would have had a longer time period to be cited, which would cause a systematic bias. When analyzing export intensities based on grants, the number of grants with forward citations is used instead of the average number of forward citations.

Average number of backward citations. The number of backward citations of a country's patents divided by the number of applications with backward citations.

Granted patents as a share of patent applications. The number of granted patents divided by the number of patent applications.

Average family size. The average number of distinct patent offices a country's patents were filed at. For reasons of consistency with the other indicators, this indicator is limited to families in which at least one member is an EPO application.

Average number of IPC-classes. The average number of distinct IPC-classes a patent is classified in.

Average number of inventors. The average number of inventors that are named on the country's patent applications.

The correlations between the four export indicators and the patent value indicator reveal low but mostly significant bivariate connections between the factors. The reasons are that the countries as well as the fields are heterogeneous and show different patterns. The expectation here is that only a multivariate analysis, controlling for country and field idiosyncrasies, might be capable of detecting patterns of co-variation.

Table 2-5 Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Exports per application	6090	46.89	117.02	0.00	2,037.72
Exports per grant	5951	69.79	208.11	0.00	9,867.77
Trade balance per application	6090	-12.82	72.63	-1410.63	755.90
Trade balance per grant	5951	-18.17	104.35	-2045.81	755.90
Nr. of applications	6090	249.60	914.16	1.00	18,727.00
Average Nr. of forward citations	6090	2.42	1.81	0.00	27.60
Average Nr. of backward citations	6090	6.87	3.68	0.00	73.00
Nr. of grants with forward citations	6090	90.86	307.99	0.00	4,568.00
Share of grants	6090	0.65	0.19	0.00	1.00
Average family size	6090	7.06	2.48	0.00	36.00
Average Nr. of inventors	6090	2.43	0.87	1.00	19.40
Average Nr. of IPC classes	6090	9.36	4.59	2.00	115.00

Source: UN-COMTRADE, PATSTAT, own calculations

Note: The reported statistics are based on observations from the following regressions. The lower number of cases in the exports and trade balance per grant result from a higher number of zero counts in the number of grants, which is used to calculate the two shares.

Table 2-6 Pairwise correlations for a selected set of export intensities (per patent) and different patent value indicators

	Exports per appl.	Exports per grant	Trade balance per appl.	Trade balance per grant
exports per application	1			
exports per grant	0.854***	1		
trade balance per application	0.300***	0.273***	1	
trade balance per grant	0.323***	0.321***	0.892***	1
Nr. of applications	-0.064***	-0.054***	0.039***	0.035***
Average Nr. of forward citations	-0.0286**	-0.021*	0.075***	0.042***
Average Nr. of backward citations	0.018	-0.001	0.012	0.007
Nr. of grants with forward citations	-0.067***	-0.058***	0.045***	0.041***
share of grants	0.0207*	-0.073***	0.014	0.025**
Average family size	-0.044***	-0.0573***	0.038***	0.029**
Average Nr. of inventors	-0.019	-0.026**	0.100***	0.088***
Average Nr. of IPC classes	-0.040***	-0.038***	0.075***	0.070***

Significance level: ***$p<0.01$, **$p<0.05$, *$p<0.1$

Source: UN-COMTRADE, PATSTAT, own calculations

In the next step, panel regression estimations are applied to regress the patent value indicators next to the control variables – GDP per capita, field, and country – on export intensity as well as on absolute export volumes or trade balances, respectively. Several models with different independent variables were fitted. Hausman tests were applied to test for unobserved heterogeneity and in all models it was possible to accept the null hypothesis of no difference between the coefficients in the fixed and the random effects model. Therefore, we only report the results of the random effects models.

The average number of IPC-classes in the patents is not a relevant factor in any of the regression models. In none of the models – except if the citation variables are omitted – does the number of IPC-classes significantly add to the explanatory power of the model. The same holds for the average number of inventors per patent. This is the reason why both variables are omitted in the further course of the analyses.

Table 2-7 Panel regression coefficients for different models based on intensities

	Exports per appl.	Exports per grant	Trade balance per appl.	Trade balance per grant
Average Nr. of forward citations	-1.750**	--	1.889***	--
	(0.864)		(0.586)	
Average Nr. of backward citations	-0.244	--	0.154	--
	(0.411)		(0.279)	
Nr. of grants with forward citations	--	-0.001	--	-0.005
		(0.011)		(0.005)
Share of grants	18.465**	-135.771***	8.351*	51.705***
	(7.427)	(16.538)	(5.039)	(8.572)
Average family size	0.700	1.504	-1.026*	-1.704**
	(0.801)	(1.499)	(0.544)	(0.777)
Observations	6090	5951	6090	5951
R-squared within	0.291	0.223	0.153	0.170
R-squared between	0.153	0.008	0.189	0.040
R-squared overall	0.291	0.221	0.153	0.168

Significance levels: *** p<0.01, ** p<0.05, * p<0.1, Standard errors in parentheses, coefficients for country dummies, field dummies and GDP per capita are omitted for simplicity.

Source: UN-COMTRADE, PATSTAT, own calculations

From a theoretical point of view, family size could be a good predictor of export activities. However, neither in the models where the export intensities are analyzed nor in the models where the absolute export performance is examined does the average family size show a significant impact. Therefore, H3d has to be rejected. There are at least two possible explanations for this. On the one hand, technologies have a different propensity to internationalization, e.g. ICT and pharmaceuticals are more internationally oriented – and therefore have a higher average number of family members – than for example machinery or automobiles. Countries with a higher orientation to ICT or pharmaceuticals therefore reach higher average family sizes than engineering-oriented countries. This argument does not hold as a single and exclusive explanation, however, because we controlled for country and technology differences. On the other hand, the individual family members will not all have the same export value. This means that a family consisting of the three most important markets in the world – namely the USA, Japan and Germany – might have a higher export value than a patent that is filed in five European countries like Belgium, Switzerland, Finland, Sweden and Greece, for example. And even if the patent is filed in the USA and Germany as well as in the five additional European countries, these additional countries might not outweigh, for example, Japan. To put it in other words: Not all countries have the same market size and therefore calculating the average family size might not be appropriate for export value analyses. Despite this, we keep the insignificant family variable in the model due to the theoretical arguments, but bear in mind the limitations in the construction of this variable.

It is interesting to note that the forward citation indicators are significant in those models using exports or trade balance per application as a dependent variable, while they are not significant when exports (or trade balance) per grants are analyzed. Furthermore, the sign is negative in the case of exports and positive in the case of the trade balance. As the trade balance might be a better indication of patent value than absolute exports, it seems justifiable from this perspective to use forward citations as a value indicator, but having a negative impact on the balance. It is also interesting to note that backward citations have no predictive power, while the grant rate does.

What we can also see is that especially the model on exports per application has a higher explanatory power than the model on grants. Taken together with the fact that patent applications are available earlier than granted patents, this is a strong argument in favor of using applications instead of granted patents only.

If absolute volumes are taken into account instead of intensities, it is first of all the absolute number of applications that has a significant and strong impact, which effectively is simply a size effect. However, after controlling for this, the citation and family variables do not add any additional predictive power to the models. What can also be seen is that the trade balance models in general have a lower overall fit, which means that – based on the variables in our dataset – the share of explained variance is much lower than in the models where only exports were used. On the one hand, the trade balance is influenced by different factors that we are not able to control. This was already discussed in the descriptive section above. On the other hand, patents reach a much better correlation and therefore have higher predictive power for absolute exports than for the trade balance, which confirm their role as an instrument to develop and structure markets. And even if producing or assembling is the main reason to enter a national market, a patent is still helpful or even necessary to safeguard the intellectual property.

To sum up, H2b and H2d (the effect of backward citations and family size) have to be rejected. Concerning the analyses of patent applications, this is also the case for H2c (positive influence of the share of granted patents). On the other hand, H2a (the positive effect of forward citations) can be confirmed but only when using the trade balance as the dependent variable. The effect of forward citations seems to be dependent on the dimension of the outcome variable and should therefore be applied with care. In general, the findings of the panel regression stress the differing predictive power of citations and thereby their ambivalent use as a value indicator. However, if a value indicator has to be selected from the set of indicators at hand, then forward citations seem to be most promising, especially for patent applications rather than granted patents.

Table 2-8 Panel regression coefficients for different models based on absolute numbers

	including citation indicators		excluding citation indicators	
	Exports absolute	**Trade balance absolute**	**Exports absolute**	**Trade balance absolute**
Nr. of applications	10.607***	-2.243***	10.604***	-2.240***
	(0.157)	(0.155)	(0.157)	(0.155)
Average Nr. of forward citations	-8.115	82.390	--	--
	(73.283)	(72.261)		
Average Nr. of backward citations	-41.287	-15.976	--	--
	(34.857)	(34.372)		
Share of grants	1699.220***	919.459	1707.153***	924.606
	(629.919)	(621.143)	(629.851)	(621.067)
Average family size	-10.656	-16.034	-30.274	-11.973
	(67.929)	(66.983)	(65.824)	(64.906)
Observations	6090	6090	6090	6090
R-squared within	0.746	0.138	0.729	0.130
R-squared between	0.896	0.644	0.810	0.513
R-squared overall	0.747	0.138	0.730	0.130

Significance levels: *** p<0.01, ** p<0.05, * p<0.1, Standard errors in parentheses, coefficients for country dummies, field dummies and GDP per capita are omitted for simplicity.

Source: UN-COMTRADE, PATSTAT, own calculations

2.6 Concluding Remarks

Exports prove to be of good use to act as a valuation of patents, allowing for a meaningful interpretation of the data. The number of patent applications and exports are strongly correlated, although some disturbances to this parallelism are visible, especially as exports are much more extremely affected by the overall economic situation. However, it could be revealed that a one percent increase in patent applications in a technology area by a country raises the value of that country's exports in that technology area by 12.2 percent for the following year.

The results are still ambiguous to some extent concerning the meaning and interpretation of the patent value indicators – namely citations, grant rate, family size, number of IPC-classes, or number of inventors. While IPC-classes and inventor counts do not prove to be of any relevance in predicting the export value of patents, forward citations are especially promising if patent applications rather than granted patents are analyzed. Family size also has a very restricted predictive power which could be explained by the fact that the individual family members cover markets whose value varies widely and therefore each member has a very different export value. A simple summing up of family members does not seem appropriate in the value discussion, at least at the country level.

Furthermore, trans-shipment effects as well as the effects of intermediate inputs to production processes via imports were able to be taken into account using the trade balance instead of exports only. However, the analyses show that patents are much more closely related to exports than to the trade balance – defined as exports minus imports. It was explained that protection of the intellectual property involved is advisable also in the case of trans-shipment and assembly.

To sum up, patent applications as such – without any additional indication of value – are a reliable and handy predictor of export activities, especially in high-technology areas. In addition, in the case of export volumes or export intensities, forward citations are the most promising indicator to predict patent values in terms of exports.

Some potential for further research remains. In particular, it would be good to balance family size, for example, by the size of the market in terms of exports. Yet, this would be tautological for our analyses. However, introducing a weighting factor for this indicator could be helpful.

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PART III: THE VALUE OF PATENTS – A MICROECONOMIC PERSPECTIVE

3 When the Whole is more than the Sum of its Parts: Patent Portfolios and their Impact on Stock and Product Market Performance

Abstract The article analyzes how the results of R&D and its protection – representing the technology base of a firm – can influence market expectations about its future profitability and its contemporaneous profits. We thereby highlight the importance of patent portfolio effects as well as interactions within the set of patents owned by a firm. Using an international panel of large R&D performing firms, we first determine the latent characteristics of patent portfolios with the help of a factor analysis. These are found to be breadth, intensity of strategic patenting, patent quality, and the degree of legal contestability. In a second step we develop a stage model that analyzes the differences between the profitability and market expectations, which we use to construct hypotheses about the influence of the patent indicators, which are then tested. We find strong importance of the portfolio interaction effects in particular with respect to market expectations, where we can show that both breadth mitigating risk and strategic protection of the valuable patents by "patent thickets" are important. With respect to profitability, we find a timely delayed effect, which highlights the role of innovation as an investment, while the reaction of the markets seems to be much prompter.

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3.1 Introduction

The value and competitive advantage of firms depends on a large number of different factors, such as business strategy, knowledge resources, or market position. Increasingly, importance is also attributed to innovative capacity, because it allows firms to constantly renew their products and adapt their production techniques to new developments, not only in a technological sense, but also to new market situations. Innovation therefore has become a self-sustained competition parameter (Damanpour 1991, Porter 1985, Schubert 2010).

In this analysis, we will use patents as its most widely used empirical indicator (Freeman 1982; Frietsch and Schmoch 2006; Grupp 1998), because they represent a resource that is – in Barney's (1991) definition – valuable, rare, inimitable, and hard to substitute. Therefore patents can build the basis for sustained competitive advantage (Markman et al. 2008). However, innovation may also imply threats for the firm, e.g. by inducing both market and technological uncertainty (Abrahamson 1991, Chen and Miller 2007). Thus, from a theoretical point of view, it is not completely clear how innovation activities will affect the financial performance of firms, which points at some gaps in the literature that we will deal with.

First, the diverse patent indicators are usually treated in a "the more the merrier" fashion, leading to hypotheses that patents, forward citations, or other indicators (e.g. number of inventors) uniformly increase value. Yet, it is our contention that it is necessary to really understand what these indicators mean and which information they bear, before we can make any credible claims about their influence on financial performance. Second, patents are usually treated in isolation, neglecting portfolio issues. Third, studies usually use various measures of financial performance. However, to the best of our knowledge, there is no study contrasting actual profitability and market value as distinct measures of financial performance.

With respect to the first issue, we ask what the important drivers of innovation, i.e. the latent characteristics of a patent portfolio are, where we use most of the indicators treated in the patent literature as a basis.

This is related to the question through which mechanism patents create or destroy value. The framework used in this analysis is based on the notion that patents are never isolated items but generate value within a portfolio. In this notion, often blanked out issues such as risk considerations and strategic aspects directly enter the scene (Cooper et al. 2009, Piranfar 2009), which could affect market expectations about future profitability as well as contemporaneous profitability differently.

We intend to propose some insights into these questions by analyzing an international panel dataset of large R&D conducting firms that was constructed on the basis of the DTI-Scoreboard. To this we have added financial data and patent data from the PATSTAT database, which comprises diverse information captured among others by the patent stock, the average number of patent forward citations, the average family size or the average number of inventors.

3.2 Literature Review

Today many disciplines support the idea that innovation is among the most important competitive factors which ultimately affects profitability and market value. Accordingly, we will see that many of the known studies find a positive association between innovation and market value. In the following, we will review some of the works that have related innovation and particularly patent indicators to financial performance.

A notable early work studying the market value of firms was written by Griliches (1981), who found a significant relationship between firm market value and what he calls its 'intangible' capital, proxied by past R&D expenditures and the number of patents, based on data for large U.S. firms. The results of Deng, Lev and Narin (1999) indicate that the number of patents, forward citations and closeness of R&D to basic research are associated with stock returns and market-to-book ratios of companies. Bosworth and Rogers (2001) analyzed the value of large Australian firms. Their findings suggest that R&D and patent activity are positively and significantly associated with market value as measured by Tobin's q. Lanjouw and Schankerman (2004) used an index of patent quality and showed that research productivity at the firm level is negatively related to the patent quality index, but exerts a positive influence on the stock market valuation of patented innovations held by firms. Hall, Jaffe and Trajtenberg (2005) used patents and citations and found firm market value positively related to the ratios of R&D to assets stocks, patents to R&D, and citations to patents. Additionally, Miller (2006) found that technological diversity, measured by citation-weighted patents, positively influences a firm's market value. In a firm dataset from the US pharmaceutical and semiconductor industries, Lee (2008) estimated a Tobin's q equation on the R&D intensity, patent yield of firms, and citations to patents. Interestingly, he discovered that information on patent citations received long after a patent is granted bears significant information about the market value of innovating firms. In more recent studies, Chen and Chang (2010) found that the relative patent position[8] and patent citations of firms were positively associated with corporate market value in the pharmaceutical industry. Additionally, they detected an inversed u-shaped relationship between patent citations and corporate market value.

Regarding current profitability measures, like returns or sales, Narin and Noma (1987) found correlations in the range of 0.6 to 0.9 between an increase in a company's profit and sales and citation frequency, as well as concentration of patents in only a few patent classes. By analyzing a sample of 50 business firms within the German mechanical engineering industry, Ernst (1995) revealed that the number of international patent applications, the rate of valid patents and highly cited patents are positively related to economic performance as measured by sales. In a sample of German machine tool manufacturing firms, he could also show that national patent applications lead to sales

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8 The relative patent position is a measure proposed by Ernst (1998), which compares the patent counts of a company to that of its most active competitor.

increases with a time lag of two to three years after priority filing (Ernst 2001). Also, the stock of patents within a firm is known to be positively associated with sales revenue from new products (Nerkar/Roberts 2004). Furthermore, in an analysis of a sample of German manufacturing firms, Czarnitzki and Kraft (2010) found that the patent stock of a company has a strong and robust effect on profitability. Finally, Hall and MacGarvie (2010) in an analysis of firms in the ICT sector detected slightly higher market values for firms holding software patents compared to those firms with no software patents.

Thus there is some indication that there is a positive relation between innovation respectively patents and financial performance. However, the theoretical insights into why and under which conditions this positive association can be expected are limited, there is definitely a need for a more conceptual approach to the question.

Since we use exploratory factor analysis as a necessary ingredient to derive our hypotheses, we will now present the data and then deal with some of the more conceptual questions afterwards.

3.3 The Data

For the empirical analysis, a panel dataset including 479 firms from 1990 to 2007 based on the DTI-Scoreboard[9] was constructed that contains data on, R&D expenditures, market capitalization, turnover etc. The basis year for the construction of the dataset is 2001 where in total 500 companies were listed in the DTI-Scoreboard. Data on preceding and following years were added to this dataset. If any of the 500 companies had not been listed in the years before or after 2001, the respective observations were treated as missing. Fortunately, in some years the scoreboard provides information on the R&D expenditures for the previous four years. In case this information was available it was used to fill the gaps. Since some observation variables are still missing in some time periods, the panel remains unbalanced.

In the case of mergers and acquisitions (M&A) between companies listed in the DTI-Scoreboard, all data for the respective firms were added up. Using this method, the firms were treated as if they were merged from the beginning of the observation period. This approach was chosen to preserve comparability over time, as no separation of information is possible after the merger.[10] M&A with units not covered by the DTI-Scoreboard had to be left uncontrolled. In any case, since it contains the most important R&D performers, enterprises not listed should be smaller, and distortions should be limited.

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9 For more details on the dataset compare http://www.innovation.gov.uk/rd_scoreboard/

10 Clearly, this treats merged companies as being the sum of their parts, which may be problematic, if mergers and acquisitions caused for example synergy effects.

Table 3-1: The patent indicators

Patent stock of a company	A sum of the company's issued patents in the last five years, depreciated by 15% each year.
Application intensity	Application intensity is defined as the number of patent applications divided by the number of grants of a company in a given year, minus its patent applications divided by grants in the previous year.
Granted patents as a share of patent applications	The sum of granted patents of a company by year divided by total number of patent applications.
Withdrawn patents as a share of patent applications	The sum of withdrawn patents of a company by year, divided by total patent number of applications.
Refused patents as a share of patent applications	The sum of refused patents of a company by year, divided by total number of patent applications.
Opposed patents as a share of patent applications	The sum of opposed patents by company and year divided by total applications.
Average number of forward citations	The number of forward citations in a four-year time window divided by the number of applications with forward citations per year (also in a 4-year time window). With this time window it is assured that all patents have the same amount of time to be cited. Not using a time window would lead to higher citation counts for older patents, as they had a longer time period to be cited, which would cause a systematic bias.
Average number of backward citations	The number of backward citations of a company's patents divided by the number of applications with backward citations.
Average family size	The average number of distinct patent offices where a company's patents were filed.
Average number of inventors	The average number of inventors that are named on the company's patent applications.
Average number of IPC classes	The average number of IPC classes a company's patents are classified in.

The relevant information on patenting behavior and financial indicators were added to this database. The relevant patent data forming the basis for the indicators found in Table 3-1 were extracted from the 'EPO Worldwide Patent Statistical Database' (PATSTAT), which provides information about published patent applications collected from 81 patent authorities worldwide. We restricted the analyses to EPO data, to be able to focus on a consistent and homogeneous patent system. Citations given to the original PCT application were included if the EPO search report makes reference to the PCT document. All patent data reported are dated by their priorities, i.e. the year of world-wide first filing.

The companies were identified via keyword searches, where the keywords also included the names of the companies' subsidiaries, which were held by the parent company with a direct share of at least 25% to keep the patent data comparable with the financial data from the companies' balance sheets. Information on the names of the relevant subsidiaries by company was added from the LexisNexis (http://www.lexisnexis.com) and Creditreform Amadeus (http://www.creditreform.com) databases.

Table 3-2: Overview of the variables and summary statistics

Variable	Mean	Std. Dev.	Min	Max	# Obs.	# Firms
Market expectations	1.23	1.27	-0.11	9.80	3221	446
ROI	0.08	0.09	-0.76	0.50	7635	462
Patent stock (in k)	0.39	0.76	0.00	10.74	4769	417
Application intensity	2.57	17.54	-109.00	465.83	5532	427
Grants/applications	0.46	0.32	0.00	1.00	7185	453
Withdrawals/applications	0.21	0.21	0.00	1.00	7142	453
Refusals/applications	0.02	0.06	0.00	1.00	7142	453
Oppositions/applications	0.03	0.07	0.00	1.00	7142	453
Avg. # FW citations	3.69	2.80	1.00	72.00	6525	452
Avg. # BW citations	6.67	4.26	1.00	198.00	7148	453
Avg. family size	6.18	2.90	2.00	31.89	7158	453
Avg. # inventors	2.87	1.11	0.00	24.03	7185	453
Avg. # IPC classes	1.87	0.59	1.00	7.33	7185	453
(Withdrawals/applications times Avg. # FW (citations)	0.91	1.63	0	72	6523	452
R&D (in m)/sales (in m)	0.07	0.08	0.00	0.99	5342	479
Sales (in m)/employees	0.19	0.13	0.00	0.98	4423	443
Intangible assets/employees	30.32	93.27	0.00	2040.86	5884	454
EBIT/employees	19.49	67.80	-446.25	4553.33	6388	456
Capital expenditures	582.81	1338.09	0.00	20972.41	6241	462
Long-term debt/employees	38.30	103.62	0.00	5726.67	6358	456
Sales (in m)	10902.77	17409.95	5.00	184879.00	5375	479

The financial data for the companies that are needed to calculate the firms' financial performance indicators were added from Standard & Poor's COMPUSTAT Global and COMPUSTAT North America databases. All monetary measures were converted to British pounds (GBP) based on a yearly averaged exchange rate which was taken from COMPUSTAT Global Currency database.

3.4 Theory and Hypotheses

As outlined above, in the first step of our analysis we will analyze the latent characteristics of a firm's patent portfolio, which will help interpreting the indicators themselves. In the second step, we will turn to our measures of financial performance, highlighting communalities but also important differences. After having proposed some suggestions on this, we will link the insights from the patent indicators to the differences in the performance measures and present some hypotheses on how the multiple aspects of the patent portfolio affect the different financial performance measures.

3.4.1 The Informational Content of the Patent Indicators

Today a multitude of patent indicators exist, ranging from the most basic patent counts to more advanced indicators, relating, for example, to forward or backward citations, the number of inventors or even legal events, such as oppositions (see for example Harhoff et al. 2003).

It is interesting to see that all these indicators have been proposed in order to find suitable measures of the value of a patent. As we will see, however, for several indicators the theoretical justifications for treating them as value indicators are rather limited and at best ambiguous. We will also show that several of them are more likely to reflect aspects of the patent portfolios that might even give rise to lower financial performance. Despite these problems, we start by summarizing the discussion from the literature on the indicators used in this paper (see Table 3-1).

Besides quality or relevance considerations, it is usually assumed that the number of patent applications positively affects firms' performance. Large patent portfolios indicate higher innovative output, are strategically useful to block competitors (Blind et al. 2006), increase the chance for licensing agreements or trade with other firms, and can also be used to close markets for new entrants. Furthermore, patent output can be seen as a positive signal to the market. Yet, firms may be tempted to inflate their patent stock also with low value patents. This in turn may reduce the signaling value of this indicator.

Probably the most commonly used indicator for the value of a patent is patent forward citations (Narin/Noma 1987; Trajtenberg 1990). It is assumed that the number of forward citations (citations a patent receives) measures the degree to which a patent contributes to further developing advanced technology rendering them an indicator of technological significance (Albert/Avery/Narin/McAllister 1991; Blind/Cremers/Müller 2009; Carpenter/Narin/Woolf 1981).[11] Despite these findings, several studies show that patent citations are a very noisy signal of patent value (Alcacer/Gittelman/Sampat 2009; Alcacer/Gittelman 2006; Bessen 2008; Hall/Ziedonis 2001, Schubert 2011). Consequently, other measures have also been discussed.

11 In fact at the EPO there are different kinds of citations, among them the so called “killing” XY citations, which destroy an application. However, there such a high correlation between the different types that we sticked with total citations here.

Among these are backward citations (references a patent makes), which refer to previous patents and are often discussed as an indicator of technological breadth. However, the logic of backward citations is ambiguous (Frietsch et al. 2010). On the one hand, backward citations reflect a patent's scope, as a patent examiner may include more references if the scope of the patent is large. On the other hand, Harhoff et al. (2003) argumented, that a higher number of backward citations could cause the content of the patent to be more restricted by other patents, which could therefore limit its possible value. In this context a backward citation may also be a measure of incrementality.

Turning to granted patents, a grant should be a positive signal since a granted patent has at least met the criteria of novelty, technological height and commercial applicability. The alternatives to a grant decision are a deliberate withdrawal by the applicant or a refusal by the patent office. The refusal is clearly a negative signal, because refused patents do not even meet the regular conditions outlined above. A withdrawal, however, can indicate different things. It may be an anticipation of a likely refusal (Harhoff/Wagner 2009). On the contrary, withdrawn patents can also have had a strategic (e.g. blocking) purpose during their lifetime. In this sense, patents are abandoned when they have met their strategic objective. Furthermore, a withdrawal decision can reflect the successful product portfolio management of a firm that gives up products when the commercialization phase has ended or where market acceptance was completely missed (compare Blau et al. 2004).

Next, opposition or litigation history has been well established as an indicator of patent value (Harhoff et al. 2003; Harhoff/Reitzig 2004; van der Drift 1989). The explanation for the use of oppositions as a patent value indicator is twofold. Opposing a patent is subject to significant additional costs, which companies would only be willing to pay if they see a market for one of their inventions that is currently protected by a rival’s patent. In addition, an appeal against a patent means that at least two parties conduct research or at least want to secure some technological elbowroom for a comparable technology. Therefore, the cost and risks associated with the dispute signal the existence of a market for the patented invention (Van Zeebroeck 2009).

A further patent characteristic which has been proposed as an indicator of a patent's value is family size. The family size is the number of patent offices, at which a patent has been applied for (Putnam 1996). For each of these countries, however, application and maintenance fees have to be paid to the respective offices. Therefore, an application for a patent in a foreign country means that the applicant tries to secure that market to sell his invention and is prepared to bear additional costs. In this sense, the family size can also be understood as the breadth of the commercialization strategy.

We conclude our discussion with two indicators that are believed to measure dimensions of breadth. The first is the number of IPC codes, which measures technological breadth, as it should be related to the different technology sources the patent is based on. The second is the number of inventors, which could be seen as a measure of the breadth of the human capital and the knowledge base employed to generate an invention. In this sense, a larger team of inventors should involve a larger set of skills (Van Zeebroeck/Van Pottelsberghe De La Potterie/Guellec 2009, Guellec/van Pottelsberghe de la Potterie 2000).

3.4.2 The Latent Characteristics of Patent Portfolios

At this point of the discussion it may have become clear that while there are a multitude of suggestions on how the indicators could be interpreted, there is also high uncertainty about what these indicators really measure. This is particularly true because of a lack of empirical corroboration of the arguments given above.

At this point we state that a more promising way to treat every patent indicator as a potential signal of value is to understand the informational content of the indicators with respect to the latent dimensions of a company's patent portfolio. The first step in treating patent indicators is therefore the acknowledgement that they are indicators. That means that they do not by themselves represent *clear causal* relationships. However, it is our contention that they may (though not need to) be linked to latent dimensions that are causal. Therefore, if we find patent indicators that unambiguously reflect such causal dimensions, they themselves can be treated as being causal. To keep in line with the parlance of the methodology to be used subsequently, we label these latent dimensions "factors". Although the factors are unobserved, they reveal information about themselves by affecting the values of the observed indicators.

Methodologically, we may determine the link between the causal factors and the patent indicators by a factor analysis. In short, by plugging the patent indicators given in Table 3-1 into a factor model, we may easily derive the factors and the corresponding factor loadings which are necessary to find linkages between indicators and the latent causal characteristics of the patent portfolio. As is well known, there is one subtlety of factor analysis: we have to decide how many factors we want to extract in advance. Several procedures have been proposed, ranging from simple rules of thumb – the most common is probably to extract as many factors as there are associated Eigen-values of correlation matrix that are larger than unity – to more complicated statistical tests.

We decided to perform a statistical Chi-sq test to decide how many factors we want to extract. It is strongly in favour of at least 5 dimensions (p-value<0.0001 for four factors; p-value$=0.61$ for five). Since also the cree-plot as well as the Eigen-value rule were compatible with this specification, we finally decided to extract five factors. The results of the factor analysis can be found in Table 3-3, where, in line with the literature, we plotted only the loadings that exceeded a value of 0.5. Thus, we focus on relationships between factors and indicators that can be considered strong.

The most important factor, explaining 18% of total variance, consists of high loadings of the average family size, the average number of inventors as well as the average number of IPC codes. Although all indicators certainly do measure quite different aspects, as the discussion above has already shown, we should note that there is one aspect common to all of them: all three measure some aspect of breadth. While the number of IPC codes certainly is a measure of the breadth of the technological basis of the invention, the number of inventors is a measure of diversity of the human capital basis. Lastly, the family size could be understood as a measure of geographical breadth or outreach of the patent. In this light, we label the first causal dimension *breadth* (understood in a very general way).

Table 3-3: Factor analysis

Uniqueness:

Grants/ applications	Refusals/ applications	Withdrawals/ applications	Oppositions/ applications	Avg. # FW citations	Avg. # BW citations
0.064	0.812	0.491	0.625	0.005	0.689

Avg. family size	Avg. # IPC classes	Avg. inventors	# Patent stock (in k)
0.480	0.005	0.479	0.962

Loadings:

	Factor1	**Factor2**	**Factor3**	**Factor4**	**Factor5**
Grants/applications		-0.649			
Refusals/applications					
Withdrawals/applications		0.642			
Oppositions/applications				0.582	
Avg. # FW citations			0.910		
Avg. # BW citations					
Avg. family size	0.506				
Avg. # IPC classes	0.938				
Avg. # inventors	0.644				
Patent stock (in k)					
	Factor1	**Factor2**	**Factor3**	**Factor4**	**Factor5**
SS loadings	1.810	1.157	1.082	0.873	0.465
Proportion Var.	0.181	0.116	0.108	0.087	0.046
Cumulative Var.	0.181	0.297	0.405	0.492	0.539
Chi²	3.25				
p-value	0.662				

For the second factor (explaining about 12% of total variance), high loadings can be observed for the indicators relating to the outcome of the application process. In particular, we have a high negative loading of the share of granted patents and a high positive loading of the share of withdrawn patents. Based on the preceding discussions, two possible interpretations seem reasonable. First, we could assume that a withdrawn patent should be interpreted as a failure in the application process, i.e. a withdrawn patent may be an anticipated refused patent. However, if this were true, we would also expect that the share of refused patents loads highly on this factor. But this cannot be observed. Furthermore, both variables should display a reasonably high level of correlation. However, this amounts only to 0.04, which implies that both variables are orthogonal and virtually unrelated, emphasizing that both measure completely different constructs. Therefore, suggesting a second explanation, i.e. that a withdrawn patent can be interpreted as a strategic application (fulfilling for example offensive or defensive blocking strategies) that is often withdrawn just at the moment where renewal fees need to be paid. In this sense, a withdrawal is not a failure to achieve a grant, but is just the opposite: a withdrawal evades the grant just before it is about to happen. Thus, this factor rather reflects the *importance of strategic applications*.

With respect to the third factor (11% of the variance explained), we see that only the forward citations load high. Since the numerous studies reviewed above have shown that patent forward citations are a good indicator of the technological quality of the invention, we would argue that one important latent dimension of a patent portfolio is *technological relevance*.

Furthermore, the fourth factor (9% of the variance explained) is related to the share of legally opposed patents. Thus, we can say that another significant dimension is the *degree of legal contestability*.

Finally, the fifth factor consists of a high number of low-level factor loadings, which do not exceed the threshold of 0.5. Furthermore, since there is no obvious or easily interpretable paradigm, we tend to assume that this factor is already one that captures the left-overs, so to say the "cree". Certainly reflected also in the inconclusiveness of the different selection criteria with respect to the number of factors, we will not interpret this factor any further.

Before we turn to the derivation of hypotheses, we will shortly explain our measures of financial performance.

3.4.3 Elements of a social theory of the differences between profitability and market value and the role of innovation

A variety of different stock-market-based indicators have been used to assess the value of firms. In this analysis we intend to use a measure of market expectations about future profitability that is based on Tobin's q (Brainard/Tobin 1968; Tobin 1969) or to be more precise the market-to-book-value (MBV). We will call this measure the market-expected future value (MEFV). The second measure of contemporaneous profitability is taken as the Return on Assets (ROA).

There is a well know relationship between Tobin's q and the ROA, if there is no uncertainty about the future. In particular, let us assume that a firm operates for T periods and let r be the discount rate (consisting of an appropriate interest rate and possibly time preference), π be profits, V the market capitalization of a firm, R the selling value of the firm and A be the book value of the assets. Then we will have

$$\underbrace{\sum_{t=1}^{T}\frac{\pi_{ti}}{A_{0i}}\frac{1}{(1+r_{ti})^{t}}+\frac{R_{Ti}}{A_{0i}}\frac{1}{(1+r_{Ti})^{T}}}_{MEFV}=\underbrace{\frac{V_{0i}}{A_{0i}}}_{MBV}-\underbrace{\frac{\pi_{0i}}{A_{0i}}}_{ROA} \quad (1)$$

which simply is a rearrangement of the statement that today market value is equal to the sum of all future discounted profits.

The question to be answered in this paper is how patents affect the MEFV as well as the ROA and how these effects differ from each other. There is extent research on the sources that affect competitive advantage and related to that profitability. We will not go into details here, but we acknowledge that innovation and in turn patents as a visible artifact are among the most prominently discussed sources. Therefore, an important aspect of our question is whether innovation is structurally related to today's or future profitability. However, there is more to it.

Let us note for the moment that the ROA and MEFV differ fundamentally in at least two aspects:

- The ROA relates to the present. The MEFV relates to the future.
- The ROA reflects an objectively measurable fact about real events taking place on the market. The MEFV reflects market participants' beliefs about the future profitability of a firm.

Thus, while we may feel confident in hypothesizing that innovation has some predictable and structural impact on the profitability, the relationship between innovation and MEFV is mediated through market participants' perceptions.

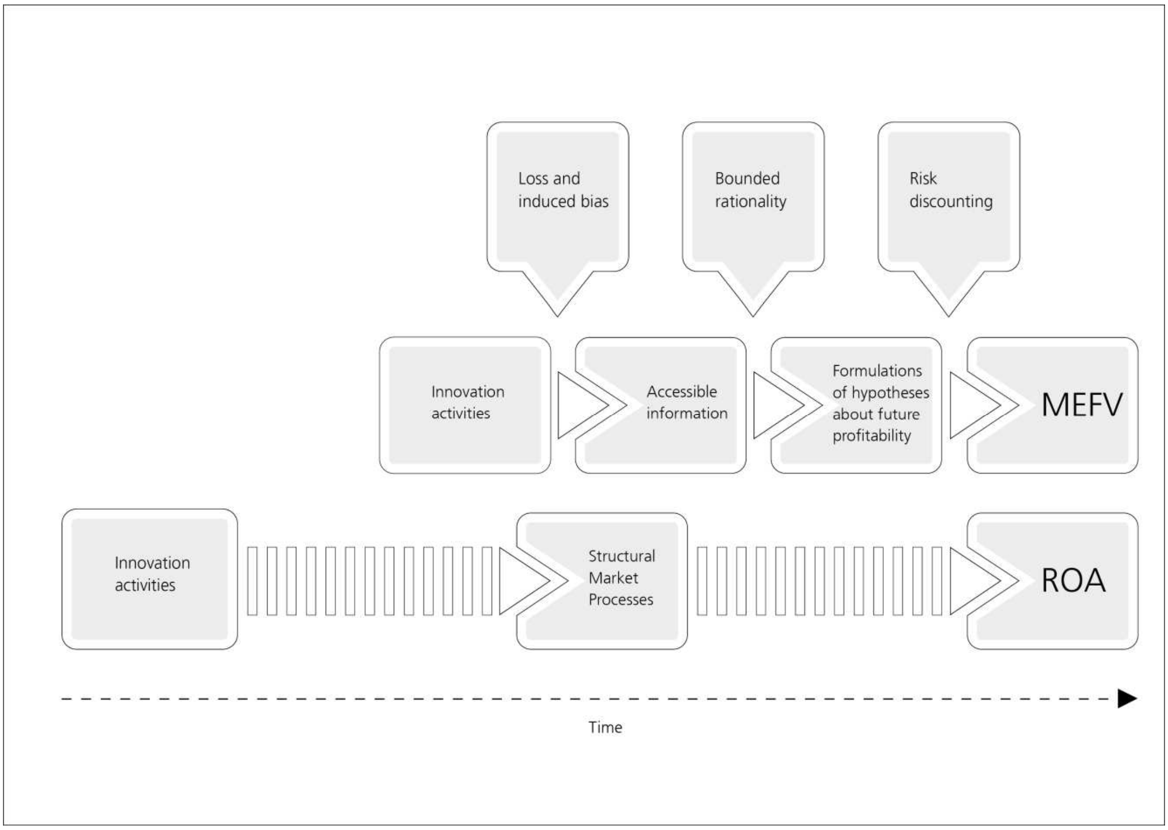
That means that the key to understanding the differences in impacts of innovation on the ROA and the MEFV is to acknowledge that there may be direct impact of innovation on profitability, but with respect to MEFV the impact stems from, amongst others, cognitive processes of the market participants.

In order to understand how market value differs from actual profitability we must understand how this projection process works. We devise a simple stage model here, which is summarized in Figure 3-1.

Primarily dealing with the MEFV, in the first stage the partly unobservable innovation activities are transformed into information that can be used by market participants. This transformation process is likely to be incomplete. In particular, the innovation activities may yield observable patents. But this process will induce loss of information or even bias, e.g. when companies apply for patents that shall signal technological competence but are otherwise worthless.

In the second stage this information needs to be interpreted by the market participants, that is, the information is used to formulate hypotheses about the future profitability. This may lead to further distortions. First, market participants will only use the information available. If important information about the innovation activities is missing and market participants know that, they may give more weight to available patent information that might even exaggerate the importance of patents. So to say, market participants may pay “excess attention” to patents,. Second, formulating hypothesis may only partly be a rational process, which would ideally imply that market participants (try to) calculate a probability distribution of all future states of nature, and determine the expected future profitability.

Figure 3-1: A stage model of the impact of innovation and patents on ROA and MEFV



It is more likely that this ideal process is perturbed by the social framing. Oliver (1997) highlights that practical decisions are always taken in social and institutional context and are often based on subjective beliefs and views. These are not so much influenced by optimizing (i.e. rational) behavior but by the search for social legitimacy leading to isomorphism (Johnson et al, 2003). In simpler words this means that decisions and expectations about the future might be influenced by what is deemed socially acceptable, where behaviors are more likely to be regarded as acceptable the more people adhere to them. Thus, eventually the search for legitimacy leads to isomorphism, implying that one believes what everybody believes, even if the resulting hypotheses differ from those that would result from a process of rational expectation formation. As Nicholson et al. (1990) stated scholars tend to assume that innovation is something good. Thus, engaging in innovation might provide legitimacy and ultimately strongly affect market value, probably more than the profitability: if everybody believes innovation/patents are good, then so do I.

Finally, the estimate of future profitability needs to be transformed into an associated value. Since there is uncertainty associated with patents, this process will depend on the inherent and perceived risk as well as the risk preferences. The more risky an investment is, the higher should be the discount.

Things are more clear for the ROA. Since the latter reflects a direct measure of what currently happens on the product market which is not perturbed by the complex social process on the financial markets, any relationship can be understood as structural. Any effect of patents is therefore in certain sense more pure.

Additionally it should be noted that our stage model highlights that there should be differences in the timing of the effects. The market actors usually try to anticipate economic effects that are to happen, while the ROA refers to these effects in real terms. Thus the effects of patenting should become visible for MEFV much faster than for the ROA.

3.4.4 Deriving Hypotheses

We will combine the stage model and the causal factors breadth, degree of strategic patenting, degree of legal contestability and quality to derive hypotheses about the association between patent indicators (as measures of these latent characteristics) and ROA on the one hand and MEFV on the other.

Starting with the empirically most important factor of breadth, the stage model highlights the importance of risk. If market actors are risk-averse, we expect that they prefer patent portfolios that hedge against risks. Certainly, a portfolio should provide a hedge when it is broad (in a general meaning outlined above). That is why we expect that all indicators loading high on the breadth dimension (IPC counts, family size, number of inventors) are positive for market value as they should reduce the implicit risk premium – an argument already made by Miller (2006). With respect to the profitability, breadth can even have a negative impact, if specialization advantages are forgone. This argument is for example analyzed by George et al. (2008) for the case of biotechnology, which should eventually render the effect on ROA less strong.

H1: The effect of average IPC counts, family size, and the number of inventors is positive on MEFV. The effect on ROA is less pronounced.

With respect to quality of a portfolio the literature on patents is already quite determined and regards citations as an unambiguously positive measure, even if it is admittedly somewhat noisy. Thus we conclude:

H2: Average number of forward citations affects ROA and MEFV positively.

Turning to the issue of the degree of strategic patenting, it is very important for companies to decide whether they intend to secure monopoly rents by their patent (traditional protection motive) or whether they want to use patents as strategic competition tools. We have argued above that withdrawal rates measure the importance of the strategic motive. However, whether grants or withdrawals are positive for financial performance depends on the profit contribution of traditional protection relative to that of strategic patents. We refrain from stating this result as a hypothesis, because we are unable to specify a directed hypothesis in advance.

Even though we were not able to specify an overall contribution of strategic patenting on profitability in advance, there may be valuable interaction portfolio effects between high quality patents and strategic patents. The most prominent argument suggests that companies build up fortresses of secondary patents to protect the few valuable patents from intrusion and from invent-around strategies of the competitors. Such secondary patents can also be used to cloak the valuable patents, in which case we talk about patent thickets. If these strategic motives create valuable interactions with the quality of the patent stock, we expect the following:

H3: The interaction term of the withdrawal rate and the average number of forward citations is positive on both ROA and MEFV.

The last latent dimension is related to degree of legal contestability. Two scenarios on the stock markets are possible. First, the market actors take oppositions as a positive signal, since they signify the existence of a particular valuable patent that is worth risking a trial for. Alternatively, markets take it as a negative signal, because they primarily perceive the threat of a potentially very cost-intensive litigation process. The second scenario is more likely, if markets are able to judge the value of the patent portfolio based also on other indicators or additional information. In this case the positive signal will be rather unimportant, because markets have already correctly anticipated the value of the patent, while only the negative signal remains. There should a positive effect on contemporaneous profits, because the associated effects of the litigation process are likely to become eminent only in future periods.

H4: The effect of the share of opposed patents is negative for MEFV but insignificant for the ROA once the quality indicator "citations" are partialed out.

Based on the stage model we may deduce to further hypotheses that do not directly relate to the latent dimensions of the portfolio. In particular, we may assume that the time lags between the effects differ. As Ernst (2001) has shown the lag is likely to be around three years with respect to sales increases. A similar lag should exist for the ROA. With respect to MEFV the market participants' cognitive process of interpreting patent information is faster (which is quite likely in the age of modern information technology), they will anticipate future returns.

H5: Primarily the lagged patent indicators possess explaining power for the ROA. For the MEFV the contemporaneous variables are more important.

We have argued in the previous section that markets will not act completely rational and will have only limited information. Irrationality could give rise to differences how the MEFV and ROA are impacted. We have hinted both at the fact that innovation is partly unobservable while patents are among the few widely available sources of innovation as well as isomorphism. Both are likely to lead to an exaggeration of the importance of patents on the stock markets.

The argument with respect to the first is clear. If patents are the only widely available source of information about innovation, reactions to changes in them will be large (probably too large relative to the information they bear). Second, Nicholas et al. (1990) highlight that there is a tacit agreement about the importance of innovation, even though the evidence of their impact on profitability is much less convincing (Abrahamson 1991). This paradox can be interpreted as a result of isomorphic tendencies. In summary, patents are treated as a substitute indicator for innovation and markets may pay “excess attention” to them.

H6: The MEFV is more influenced by the patent indicators than the ROA.

3.5 Multivariate Results

Before we proceed to the interpretation of the results, we make some notes on the methodology. In order to test the hypotheses we performed fixed effects (FE) panel regressions, to allow for individual effects to be correlated with the error term. We also used the Arellano-Bond (1991) generalized method-of-moments dynamic panel estimators with lagged values of the explanatory variables as instruments to allow for more complicated models of dynamic feedback and to make sure causality runs from the patent indicators to the financial performance measures and not vice versa. Although the results differ only slightly, the specifications tests of the Arellano-Bond model indicate that the covariance restrictions that allow using lagged values as instruments were not met unambiguously under a variety of alternative specifications. Therefore, we regarded the associated risk of using the IV-based Arellano-Bond estimators as too severe and sticked with the simpler FE regressions.

With respect to potentially confounding firm characteristics, in addition to the patent indicators discussed above, we included several other control variables. First of all, the sales and capital expenditures are included to control for size effects. To account for the firm’s productivity in general, we use sales per employees. To control for productivity of the R&D process, we use R&D intensity (R&D expenditures divided by sales). Additionally, we control for the share of intangible assets, earnings before interest and tax (EBIT, and long-term debt (all per employee). We further control for the change in application intensity (the difference between the share of EPO patent applications on granted patents in a given year and the share of EPO patent applications on granted patents in the preceding year), which simply is a measure of new information available to the market participants. In any case, some experimentation showed that the actual choice of control variables was not overly important for our results regarding the research hypotheses.

Table 3-4: Regression Results I

	MEFV				ROA			
	M1		M2		M3		M4	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Patent stock (in k)	-0.210 ***	0.071	-0.443 **	0.181	-0.003	0.002	-0.004	0.010
Grants/applications	0.006	0.144	0.103	0.147	-0.013	0.008	-0.019 **	0.009
Withdrawals/applications	0.560 ***	0.165	0.561 ***	0.172	0.010	0.009	0.011	0.010
Refusals/applications	0.584	0.862	0.527	0.875	0.010	0.041	0.012	0.044
Oppositions/applications	-0.942 *	0.523	-1.089 **	0.545	0.007	0.026	0.016	0.029
Avg. # FW citations	0.126 ***	0.016	0.094 ***	0.016	0.001 *	0.001	0.000	0.001
Avg. # BW citations	-0.004	0.007	-0.002	0.007	0.000	0.000	0.000	0.000
Avg. family size	0.082 ***	0.013	0.071 ***	0.014	0.001 **	0.001	0.001	0.001
Avg. # inventors	-0.092 ***	0.031	-0.087 ***	0.031	0.000	0.002	0.000	0.002
Avg. # IPC classes	0.122 **	0.056	0.087	0.056	0.003	0.003	0.001	0.003
L1.Patent stock (in k)			0.260	0.166			0.000	0.009
L1.Change application intensity			0.002	0.002			0.000	0.000
L1.Grants/applications			0.196	0.152			0.013	0.009
L1.Withdrawals/applications			0.166	0.165			0.019 **	0.010
L1.Refusals/applications			0.526	0.794			-0.003	0.040
L1.Oppositions/applications			-0.877	0.537			-0.037	0.026
L1.Avg. # FW citations			0.055 ***	0.013			0.002 **	0.001
L1.Avg. # BW citations			-0.015 **	0.007			0.000	0.000
L1.Avg. family size			0.018	0.013			0.002 **	0.001
L1.Avg. # inventors			-0.069 **	0.030			0.000	0.002
L1.Avg. # IPC classes			0.065	0.056			0.007 **	0.003
R&D (in m)/sales (in m)	2.814 ***	0.727	2.917 ***	0.785	-0.159 ***	0.025	-0.153 ***	0.025
Sales (in m)/employees	1.798 ***	0.349	2.050 ***	0.350	-0.037 **	0.016	-0.024	0.017
Intangible assets/employees	-0.003 ***	0.000	-0.003 ***	0.000	-0.101[α] ***	0.000	-0.090[α] ***	0.000
EBIT/employees	0.005 ***	0.001	0.006 ***	0.001	0.002 ***	0.000	0.002 ***	0.000
Capital expenditures	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Long-term debt/employees	-0.004 ***	0.001	-0.005 ***	0.001	-0.241[α] ***	0.000	-0.253[α] ***	0.000
Sales (in m)	-0.015[α] ***	0.000	-0.018[α] ***	0.000	0.000	0.000	0.000	0.000
Change application intensity	0.001 **	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Constant	0.175	0.208	0.038	0.265	0.075 ***	0.012	0.047 ***	0.015
Time-dummies	YES		YES		YES		YES	
Number of companies	339		333		350		339	
Observations	1,816		1,778		2,434		2,283	
R^2 within	0.335		0.363		0.560		0.561	
F	29.19 ***		22.32 ***		100.53 ***		65.87 ***	

Significance level: ***p<0.01, **p<0.05, *p<0.1

[α] Coefficient multiplied by 1,000 to make effects visible.

Notes: The difference in the number of observations can be explained by the fact that we use an unbalanced panel, in which data for some observations in the respective years could be missing. L1 means that the variable is lagged by one year.

Table 3-4 presents the results from the FE regressions on the MEFV and ROA.[12] Since our market expectations measure is only available from the year 2000 onwards, the following models on ROA are also calculated with the restricted dataset.

Although we find significant effects for some of the general control variables (R&D per sales, sales per employees, debt by employees etc.), we will not discuss these effects explicitly, because they do not form the core of this study.

Directly turning to core hypotheses, H1 states the indicators capturing the breadth of a patent portfolio all have significant effects. As expected, the average family size and the average number of IPC classes are both positively related to firm market value. A broad portfolio that hedges against risks should be more valuable for risk-averse market participants. Contrary to our expectations, the average number of inventors, however, is negatively associated with the market value of a firm. The argument that many inventors reflect a broad knowledge pool seems to be unimportant or even a hindrance. The markets may even fear that too many cooks spoil the broth. This is also backed by the assumption that many inventors reflect large, possibly spatially and organizationally distributed teams, inducing additional transaction costs or unintended knowledge spillovers outside the team, which might result from labor mobility. In addition, there might be an "optimal" team size, with the risk of running into problems of free-riding when the number of team members becomes overly large.

Concerning the ROA, only the average family size has a significantly positive effect while the average number of IPC classes and the average number of inventors do not. Eventually, we must state that excessive breadth may also counteract the positive effects of implicit hedges, because specialization advantages may be destroyed. This again meets our expectations, since the risk does not necessarily increase profitability. Family size, however, still exerts a positive effect on profits, since the larger the family, the larger consequently is the coverage of national and regional markets, leading to an increase in contemporaneous profits. In total however, we can corroborate the hypotheses that portfolio breadth insures against risks leading to higher market valuations.

H2 states that quality, measured in terms of forward citations, has a positive effect on MEFV and ROA. This can clearly be confirmed, although the effect on the ROA is less pronounced. Even more so, we find a negative effect of the patent stock for market expectations. Therefore, we conclude that after having partialed out quality, pure size is taken as a negative sign, possibly because the market regards large portfolios as a possible indication of “penny patents”. Thus, it does not make sense trying to fool the markets by filing a large number of low-value patents as a signal of technological competence.

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12 Industry-specific effects are absent from the model, because they are eliminated by using the fixed effects estimator. This does not mean that they remain uncontrolled. Rather, they simply cannot be identified.

Particularly interesting are the effects of the withdrawal rates, which measure the importance of strategic patenting. We observe that at least the stock markets reward strategic patenting. The coefficient is positively significant in both M1 and M2, rendering this result rather robust. Thus, strategic patents should not be confused with "penny patents", even if their immediate commercialization potential may be limited. In any case, the important question is how strategic patents contribute to market value. In this context, H3 states that they may serve to protect valuable patents. Thus, we have added the interaction term of the withdrawal share and the forward citations (Table 3-5). With respect to all variables, the results closely resemble those in Table 3-4. That is why we present only the coefficients on the variables of interest to this hypothesis.

With respect to these, the results indicate that both the contemporaneous and the lagged term on this interaction are positive, while withdrawals and forward citations alone lose significance. This means that neither strategic patenting nor high value patents in isolation really add to market value. We conclude that a healthy mix of strategic patenting and aiming for high quality patents should be implemented.

With respect H4, we identified oppositions as a source of juridical risk. As hypothesized, oppositions influence market value negatively, while they have no effect on the ROA. We have argued that this is because markets primarily perceive the threat of a potentially very cost-intensive litigation process and anticipate the value of the patent portfolio by other indicators, like forward ciations. Comparable results can be found in Häussler, Harhoff and Schirge (2009), where obviously it is true that the markets observe an opposition as a potential threat. With respect to ROA, this effect may be offset because the litigation risk will become eminent only in future periods. Indeed this is what we observe, so H4 can be fully confirmed.

Table 3-5: Regression results II (only relevant variables presented)

	Market Expectations M5		
	Coef.		S.E.
(Withdrawals/applications times Avg. # FW citations)	0.284	***	0.079
Withdrawals/applications	-0.396		0.308
Avg. # FW citations	0.025		0.024
L1.(Withdrawals/applications times Avg. # FW citations)	0.147	**	0.073
L1. Withdrawals/applications	-0.312		0.286
L1.Avg. # FW citations	0.015		0.021

Significance level: ***p<0.01, **p<0.05, *p<0.1
L1 means that the variable is lagged by one year.

Considering H5, we expect the lagged value to be of greater importance in the ROA models, while the markets should react more rapidly, leading to a greater importance of the contemporaneous effects. This can be found in the data. The lagged explanatory variables seem to be of great importance in the ROA models, whereas the contemporaneous variables mostly do not show significant effects.

Lastly turning to H6, it is interesting to note that even after including time lags the MEFV is more strongly influenced by patent indicators than the ROA, as the count of significant variables has shown. As argued, one reason could be that markets are not fully informed and boundedly rational, leading them to use patents as substitute indicators for the unobserved value of the underlying innovation products, which eventually leads to what could be called “excess attention” paid to the patenting indicators.

3.6 Managerial Implications

The above discussed regressions have a variety of management implications. First, we note that in all regressions the patent characteristics have a substantial explanatory power for both the MEFV and ROA. This means that, both in terms of profitability and shareholder value, orientation patenting and innovation have profound effects. Since the effects are even more pronounced for the MEFV patenting activities, this is particularly important for the shareholder value approach.

Second, there is indeed a time lag with respect to profitability, which highlights the role of innovation as an investment, while the reaction of the markets seems to be much prompter. This has an important implication. It seems to be the case that the stock markets are willing to pay instantaneous price premiums for innovation activities, which emphasizes the importance of innovation and patenting as a strategic parameter, because it allows the market valuation and the shareholder value to be increased.

However, the statement that innovation and patenting are important does not mean that firms should simply maximize their patent stock. As can be seen from the results, the unadjusted patent count even has a negative effect, once quality is controlled for. This leads us to suspect that markets are quite aware of the quality and the economic potential of patents, which is also reflected by the observation that forward citations (reflecting the quality dimension) are positively associated with the market expectations.

Additionally, we have hinted at the role of a successful management of patent and innovation portfolios. This concerns, first, risk issues, where the financial markets seem to favor portfolios with an immanent hedging by greater breadth (in terms of targeted markets and as well as technological classes). Second, this relates to the strategic orientation. Here we have pointed out the importance of patenting with strategic motives (as reflected by the withdrawal rate), which is taken as a positive signal on the financial markets. In this context, we were able to show that markets reward a patenting strategy where high quality patents are protected by a ‘thicket’ of strategic patents that either provide sufficient elbowroom or obfuscate the existence of these patents.

3.7 Summary and Conclusion

The main aim of the current study was to shed light on the question of how far the technology base of a firm can influence its financial performance in terms of market expectations about future profitability and returns on assets. For the analysis, a large international firm database was constructed that contains information on financial performance, R&D expenditures, patenting behavior and indicators for the value of the companies' patents.

In summary, we would emphasize five things. First, innovation and patenting have substantial impact, both on market value and profitability. Yet the importance for the stock markets is even greater. We interpret this as a sign that markets pay “excess attention” to patents because they are never fully informed and therefore have to rely on patent statistics, which are at least available.

Second and relativizing the preceding statement, this does not mean that markets are easily fooled by enterprises. Simply filing a large number of low-value patents will increase neither profitability nor shareholder value. On the contrary, markets seem to be aware of the quality of patents.

Third, portfolio issues are important. Price premiums are paid on the stock markets for portfolios that hedge against risks. Likewise, there should be a healthy mix of high quality patents and strategic patents that protect them. Both, portfolios that consist only of high quality patents and those that consist of only strategic patents are valued lower. There should be a healthy mix of both types of patents.

Fourth, we note that innovation and patenting remain activities that need patience. Innovation is an investment that takes time to unfold positive effects and cannot be expected to yield direct payoffs. However, the good news is that markets seem to understand the value of innovation, even if has not yet manifested itself in increased profitability and repays firms today already by higher market values. Thereby disincentives related to innovation that may result from managers’ short-term planning horizons, as suspected by Hill and Hoskisson (1987) or Baysinger and Hoskisson (1989), may be mitigated.

Finally, comprehensive patent portfolio management takes both the impact of patent portfolios for market expectations and for profitability into account. The first is relevant for gaining access to capital markets in general and for reducing the cost of capital, which in turn also has implications for the profitability. Thus, the patent strategy should have both measures in mind, acknowledging the differences in effects patenting may have on each of them.

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4 Patent Information and Corporate Credit Ratings: An Empirical Study of Patent Valuation by Credit Rating Agencies

Abstract The present paper aims to shed light on the role of patent quantity and quality within the context of credit rating agencies (CRA) credit risk assessments. We test this on the basis of a panel dataset, including 191 US firms, which received credit ratings from 1990 to 2001. Our findings show that patents are valued differently in CRA credit risk assessments than by stock markets. CRA seem to consider patents not only in terms of innovation output, but rather as insurance against patent lawsuits. Based on our findings, we derive some theoretical and practical implications for financing technological innovation.

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4.1 Introduction

The theory of corporate finance is commonly derived from Modigliani and Miller (1958), who formalised the capital structure irrelevance proposition. Under the assumption of an efficient market – i.e. without asymmetric information, taxes, etc. – this theory states that the value of a firm is unaffected by its capital structure. Since then, however, empirical research has shown that there is, in fact, asymmetric information between managers and investors, not least with regard to technology-driven companies. For example, Aboody and Lev (2000) find that gains from insider trading are substantially larger in technology-driven firms. They argue that public information fails to directly capture the productivity and value of R&D spending due to asymmetric information regarding firms' research and development (R&D).[15] This leaves investors deprived when assessing the value of these firms (e.g. Chan et al. 2001).

In the presence of asymmetric information, theoretical corporate finance models, such as pecking order theory, suggest that capital structure has an impact on firm value. More specifically, Myers and Majluf (1984) show that under asymmetric information issued equity will be undervalued, diluting shareholder value for the current owners. Equity issues will therefore only be made to resolve financial distress, meaning that it will signal bad news to outside investors. As a result, firms will prefer to issue debt.

Aghion et al. (2004), however, ascertain that firms' use of debt declines with their R&D-intensity. Rather, they find that technology-driven firms issue more equity. Notably, Rajan and Zingales (1995) also show that companies with a higher market to book (M/B) ratio – implying a high proportion of intangible assets – rely less on debt. Altogether, these findings imply that technology-driven firms mainly rely on equity to finance innovation. Still, Eberhardt et al. (2004) find that stock markets consistently undervalue intangible investments although an increase in R&D spending leads to abnormal operating performance within a five year period. This raises the question of why technology-driven firms prefer undervalued equity to debt.

Carpenter and Peterson (2002) argue that this relates to the high attrition rates of R&D projects, leading to highly skewed returns on R&D investments.[16] Such uncertainty is especially problematic in relation to debt contracts, as creditors are only concerned with the bottom tail of the distribution of economic returns because they do not share the upside related to the firm's investments (e.g. Stiglitz (1985)). Hence, since the borrower's returns are highly uncertain, the creditor will want to raise interest rates in order to be compensated. However, Stiglitz and Weiss (1981) suggest that as interest rates rise, the nature of debt contracts can ex post lead to that unmonitored borrower's in-

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15 Insider gains refer to benefits for traders from having information that has not been disclosed to the public domain.

16 For example, Mansfield et al. (1977) show that only 27 percent of R&D projects are financially successful.

vestment in higher-risk projects with potentially higher returns, and thus increase the probability of default without offsetting higher gains to the creditor in case of success. This means that debt financing of R&D projects may increase moral hazard (e.g. Stiglitz 1985). Moreover, asymmetric information related to risk and default probabilities potentially leads to adverse selection and a situation where lenders will ration credit rather than raise interest rates because higher interest rates can prompt low risk borrowers to exit the market (Stiglitz and Weiss 1981).

Equity, on the contrary, does not require any collateral, nor does it cap the upside of investors' returns. Most likely, the low debt levels exhibited by technology-driven companies can at least partly be explained by the fact that investments in research and development typically provide limited inside collateral value for creditors. Financial institutions will therefore constrain lending when the balance sheet of the firm contains too many intangible assets, which cannot be used as collateral (e.g Hall and Lerner 2010). Furthermore, equity finance does not give managers incentives to substitute low risk projects for higher ones because managers themselves most often have tied up their income in compensation according to the firm's performance, mitigating agency problems (e.g. Jensen and Meckling 1976). It has thus been emphasized that the lower the amount of tangible value inside the firm, the more outside investors will want to have control rights, leading to a pecking order in which technology-driven companies prefer equity to debt (Aghion and Bolton 1992; Hart 1995). Finally, some explanations have focused on the costs of default. For example, Opler and Titman (1994) find that R&D-intensive firms with higher leverage suffered more than less R&D-intensive companies by financial distress, implying that technology-driven companies will want to rely less on debt to reduce the risk of bankruptcy.

Although the literature provides several plausible explanations for why technology-driven companies prefer undervalued equity to debt, there is very little empirical evidence on how debt markets value companies' innovation activities. Instead, past research has focused on the valuation of R&D and patents by stock markets (e.g. Hall et al. 2005; Sandner and Block 2011). The objective of the present study is therefore to bridge this research gap, by examining the impact of R&D expenditures and patents on corporate credit ratings.

We also decided to focus on credit ratings to assess the role of credit rating agencies (CRA) in helping technology-driven companies to emerge from the fog of asymmetric information. In short, CRA give opinions on the creditworthiness of corporate debt issuers which are communicated to the public domain.[17] Because CRA gather and process information from various sources, investors can reduce their own research activities and rely more on the information retrieval and analysis of CRA. This suggests that CRA contribute to the informational efficiency of capital markets. For example, Holthausen and Leftwich (1986) as well as Hand et al. (1992) showed that rating down-

17 The debt issuers can range from firms, to governments, to non-governmental organisations (NGO), to special purpose vehicles (SPV). In the present study, however, the focus is on firms issuing debt securities, to which CRA assign ratings – i.e. corporate credit ratings.

grades have an impact on both bond and share prices, and thus provide new information for investors. Since past research shows that patents have a positive impact on firm productivity (e.g. Bloom and van Reenen 2002; Greenhalgh and Longland 2005), contribute to companies' market value (e.g. Hall et al., 2005) and even explain the market value of firms' better than financial information (e.g. Hirschey and Richardson 2001; 2004), credit ratings ought to reflect the value of patents. Should this not be the case, technology-driven firms will most likely pay higher interest rates on their debt or may even be constrained in their ability to tap into debt markets, potentially explaining why they prefer undervalued equity.

To our knowledge, only one study has so far addressed this question by examining the relationship between patents and ratings.[18] In doing so, Czarnitzki and Kraft (2004) studied the impact of R&D expenditures, patents and share of sales with newly developed products on a German rating agency's credit ratings. They find that all of the investigated variables have an inverted U-shaped relationship with credit ratings. However, they do neither differentiate between valuable and low value patents, and thus do not consider the implications of strategic patenting (see Blind et al. 2009; Gambardella et al. 2008), nor do they control for any debt related measurements, which are essential in rating agencies credit risk assessments. Moreover, their sample is limited to German firms covered by a national rating agency. Hence, the consideration of patent information by international CRA, such as Standard Poor's, has as far as we know not yet been assessed.

In short, the present study aims to bridge this research gap by examining whether CRA differentiate between valuable patents and 'lemons', and thereby communicate patent value to debt markets. Thus, it delivers two important contributions to the literature in (a) showing that patents are valued differently by CRA than by stock markets (b) providing an additional explanation why technology-driven firms issue more equity than debt, even under asymmetric information.

4.2 Theory and Hypotheses

In the following section, we will first briefly discuss the corporate credit rating methodology of Standard & Poor's.[19] In addition, a review of the literature on patent value indicators is conducted. Based on both discussions, we derive our hypotheses.

4.2.1 Credit Ratings

CRA retrieve and filter down information to opinions about bond-issuers creditworthiness, in terms of their risk of default. In doing so, they consider three pillars of risk; country risk, industry risk

18 Because credit ratings are mainly a concern of lenders, an assessment of CRA use of patent information takes a debt market perspective.

19 The discussion is limited to Standard & Poor's because the present study only makes use of their ratings. However, other CRA, such as Moody's, follow similar approaches.

and firm risk. Country risks are risks of doing business in a particular country. Such risks can relate to uncertainty about the enforcement of regulations and legal norms, the stability of the financial system or the currency (Standard & Poor's 2008). In general, a firm cannot receive a higher rating than the country in which it mainly operates. For this reason, the rating of the country is often referred to as the *sovereign ceiling* for a firm's rating.

The second pillar is the industry in which the firm operates. An evaluation of the industry is made because the revenues a firm can generate depend on the size of the industry it operates in as well as its growth potential. This involves analyses of the intensity of competition as well as barriers to entry. In addition, industry-related risks, such as regulatory changes, pace of technological innovation, as well as dependence on cyclical economic patterns, are considered. The importance of these factors differs according to the industry (Standard & Poor's 2008). For industrial firms, a review of business fundamentals such as industry prospects for growth and vulnerability to technological change is inevitable.

Finally, a firm-level analysis is conducted. On this level, CRA assess the firms' financials and business prospects by looking at factors of both quantitative and qualitative nature. To determine the firm's rating, each of these factors is given a score. The manner in which these factors are combined to arrive at a specific rating, however, depends on each case (Standard & Poor's 2008). Qualitative factors relate to business-oriented parameters such as the firm's competitiveness within the industry and the competence of the management team. There are assessments that require close collaboration between the firm and the rating agency.

Still, the fundamentals of the firm-level analyses relate to financial risks. The underlying reasoning is that the profitability of the firms' business is required for future debt redemptions – i.e. for companies to be able to service its debt there must be prospects of future cash flows. CRA are therefore concerned with evaluating the probability of returns to debt security holders, which in turn depend on the generation of cash flows by the issuer. Ultimately, a firm's creditworthiness thus depends on the firm's ability to amortize its debt and fulfil its interest payments. If the probability that the firm will not be able to do so increases, the firm's rating will eventually be downgraded (Standard & Poor's 2008).

4.2.2 Patent information and patent value indicators

Past research show that patents have a positive impact on firm productivity (e.g. Bloom and van Reenen 2002; Greenhalgh and Longland 2005) but also contribute to companies' market value (Hall et al. 2005). Although large patent portfolios do not simply lead to more effective appropriation of innovation (e.g. Grindley and Teece 1997; Reitzig 2004) they can be strategically useful. For example, firms rely on patents to block competitors, for licensing purposes or to trade with other firms (e.g. Cohen et al. 2002; Pitkethly 2001). Furthermore, an extensive patent portfolio can send positive signals to the capital market (e.g. Blind et al. 2006). Firms may therefore be tempted to inflate their patent portfolios also with low value patents. This in turn, however, will eventually reduce their signaling effect.

Since patents differ substantially in economic value (e.g. Gambardella et al. 2008), patent counts (or patent stocks) can give a distorted impression of the value of a company's patent portfolio. Also, from a debt market perspective, this means that the potential of patents to be used as collateral for loans diminishes, at least if patents are not valued properly. For this purpose, several patent value indicators have been proposed in the literature (e.g. Frietsch et al. 2010; Reitzig 2002), which can be used for patent valuation purposes.[20]

Probably the most common and widely used indicator for patent value is patent forward citations (Hall et al. 2005; Harhoff et al. 2003; Narin et al. 1987; Trajtenberg 1990). Since forward citations (citations a patent receives) relate to previous prior art, conclusions can be made concerning the inventive step and novelty of the invention. A citation in this sense means that the patent is still relevant since it provides an important part of the prior art. Theoretically, it has therefore been argued that this indicator measures the degree of technological significance related to a patent (Albert et al. 1991; Blind et al. 2009; Carpenter et al. 1981).

However, several studies show that citations provide a noisy signal of patent value (Alcacer et al. 2009; Alcacer and Gittelman 2006; Bessen 2008; Hall and Ziedonis 2001). Therefore, we use an additional indicator of patent value, namely patent family size (e.g. Harhoff et al. 2003; Lerner 1994). The family size of a patent describes the number of countries in which the patent has been filed (Putnam 1996). Applying for patent protection in a foreign country provides an investment, indicating that the company is prepared to bear additional costs for the application and maintenance fees in order to secure an additional market to commercialize its invention. Theoretically, it can therefore be argued that companies only file for patent protection abroad if a corresponding profit is expected from the patent.

4.2.3 Hypotheses

Empirical studies have shown that patents have a negative impact on firms' risk of default, which is ultimately what CRA look to determine. These studies focus on the relationship between patents and firm survival rates after an IPO. For example, on the basis of data from companies' IPO listing particulars, Wilbon (2002) found that companies owning intellectual property rights exhibit higher survival rates over a five year period. In addition, Audretsch and Lehmann (2004) show that the ownership of patents increases the probability of firm survival substantially. A recent study by Helmers and Rogers (2010) also reveals that a higher number of patents is associated with higher firm survival rates with some sectoral differences. Taken together with past research, which shows

20 For the sake of simplicity, all patent characteristics that could indicate patent value will be referred to as value indicators in the remainder of this paper.

that patents have a positive impact on firm productivity (e.g. Bloom and van Reenen 2002; Greenhalgh and Longland 2005) and contribute to companies' market value (Hall et al. 2005), the following hypothesis can be derived:

H1: The larger the number of patents a company files per year, the higher the corporate credit rating it receives.

Since patents differ substantially in economic value, patent counts can give a distorted impression of a company's value (e.g. Gambardella et al. 2008).[21] From a debt market perspective, this means that the potential of patents to be used as collateral for loans diminishes, if patents are not valued properly. In order to do so, Bittelmeyer (2007) shows that patent information can be used to determine firms' default risk, and finds that well established patent value indicators – i.e. patent age and the number of forward citations – have a positive impact on the company survival rate of a company. This suggests that CRA ought to be concerned with these indicators in their credit risk assessments. However, since patent renewal decisions take place about five to eight years after the application is filed, patent age cannot be used as a value indicator for younger patents (e.g. Pakes 1986; Reitzig, 2002). A more promising indicator is therefore family size, which similarly reflects an investment decision, but can also be used for younger patents (e.g. Harhoff et al. 2003; Lerner 1994). Following these findings we derive the two hypotheses below:

H2a: The higher the average number of forward citations associated with a company's patent portfolio, the higher the corporate credit ratings it receives.

H2b: The larger the average family size associated with a company's patent portfolio, the higher the corporate credit ratings it receives.

4.3 Data and Methods

4.3.1 Data and sample statistics

For the empirical study, a panel dataset including 479 firms from 1990 to 2007 based on the DTI-Scoreboard was constructed,[22] containing firm-specific data, on amongst others, R&D expenditures, market capitalization and revenues. As the basis year for the construction of the dataset we

21 Of course, a similar hypothesis has already been formulated by Czarnitzky and Kraft (2004). However, their sample was limited to a German CRA – with a different rating system than the one of Standard & Poor's - and did not account for the influence of companies' debt-related measurements and the value of their patent portfolio.

22 The DTI-Scoreboard is provided annually by the British Department for Innovation, Universities & Skills (DIUS) and the Department for Business, Enterprise & Regulatory Reform (BERR). For the year 2008, it lists the Top 1400 international companies according to their R&D expenditures by industry (the number of companies is smaller in preceding years). In addition to the R&D expenditures, further firm-specific values, such as sales and the number of employees, are shown. http://www.innovation.gov.uk/rd_scoreboard/

chose 2001, where 500 companies were listed on the DTI-Scoreboard. Data on preceding and following years were added from the previous and subsequent DTI-Scoreboards. If any of the 500 companies had not been listed in the years before or after 2001, the respective observations were treated as missing. Since some observations were still missing in some years, the panel is unbalanced.

In case of mergers and acquisition (M&A) related activities between the firms listed on the DTI-Scoreboard, the data for the respective firms were added up in one observation for each year. Using this method, the firms were treated as if they were merged from the beginning of the observation period.[23] This approach was chosen to preserve comparability over time, as a separation of information is not possible after the merger.[24] M&A activities with companies that were not listed in the DTI-Scoreboard had to be left uncontrolled. However, since the DTI-Scoreboard already contains the most important R&D performers, most firms should be listed, and thus distortions should be limited. These procedures left us with a sample of 479 companies.

In a second step, the patent data and various key financials were added to the sample. Corporate credit ratings as well as additional financial indicators were extracted from Standard & Poor's COMPUSTAT North America database. All financial indicators were converted to British pounds (GBP) based on a yearly averaged exchange rate – which was taken from COMPUSTAT Global Currency database – in order to make the data comparable to the DTI-Scoreboard data. Since the information on credit rating was found to be available only for North American companies, firms from other countries had to be excluded from the sample. This reduced our sample size to 3438 observations from 191 US companies.

The relevant patent data were extracted from the EPO Worldwide Patent Statistical Database (PATSTAT), which provides published patent information from 81 patent offices worldwide. The companies were identified via keyword searches. The keywords also included the names of subsidiaries, which were directly held to at least 25 percent. This was done to make the patent data comparable to the financial data. Information about the names of the relevant subsidiaries by firm was derived from LexisNexis (http://www.lexisnexis.com) and Creditreform Amadeus (http://www.creditreform.com). The patent data include the annual number of patent applications filed by each firm as well as granted patents by the United States Patent Office (USPTO). Furthermore, the patent value indicators forward citations and average family size were added to the dataset. The priority date – i.e. the year of first filing world-wide – was used for all patent data. Since the data on corporate credit rating was only available for US firms, we restricted the analysis to USPTO data. This was done to be able to focus on one patent system and thereby ensure the consistency and homogeneity of the sample. However, due to a legal change in the US patent system,

23 For details of this method of dataset construction, see Frietsch (2006).

24 Clearly, this treats merged companies as the sum of its parts, which may be problematic, if mergers and acquisitions caused, for example, synergy effects.

the USPTO publishes patent applications instead of granted patents from 2001 onwards. This leads to systematic distortions when comparing the information provided by the USPTO before and after 2001. We therefore decided to restrict our analysis to granted patents at the USPTO from the years 1990 to 2001. This left us with a final sample of 2292 observations from 191 US companies.

4.3.2 Operationalisation

4.3.2.1 The Dependent Variable

Standard & Poor's employs a rating system ranging from A+ (highest rating) to D (lowest rating) (see Table 4-1).[25] On the basis of this rating scale we specify our dependent variable. As Czarnitzky and Kraft (2004) we do so with a one period lead, which is used to ensure that causality runs from the value indicators to the credit rating and not vice versa. Furthermore, Ernst (2001) has shown that it takes up to three years after a patent application has been filed before a technology is commercialised and revenues are generated. Taking together this argument with the fact that it takes some time for a patent at the USPTO to be granted[26] and the fact that the CRA do not adjust ratings immediately to changes in firm activities (Standard & Poor's 2008), our specification of the dependent variable seems reasonable.

Table 4-1: Detailed summary of the dependent variable

Corporate Credit Rating	**Category**	**Frequency**	**Percent**
D	1	12	1.9
C	2	78	12.34
B-	3	65	10.28
B	4	145	22.94
B+	5	154	24.37
A-	6	60	9.49
A	7	44	6.96
A+	8	74	11.71

Source: Own calculations
Note: Only the number of cases that are used in the multivariate regressions are reported.

25 Ratings from A+ to B+ are considered as investment class bonds.

26 The average time until a decision upon a patent application was made was slightly above two years at the USPTO in the year 2001 (USPTO 2002).

4.3.2.2 The Independent Variables

The above derived hypotheses were operationalized on the basis of the following indicators. In doing so we draw upon several past studies, examining the value of patents (e.g. Harhoff et al. 2003; Lerner 1994; Narin et al. 1987; Reitzig 2002; Trajtenberg 1990).

Number of patents: The number of granted patents at the USPTO by company and priority year (in thousands). By including this variable we account for the possibility that older patents will already be reflected in the firms rating. On the contrary, newly issued patents are more likely to provide new information.

Average number of forward citations: The number of forward citations of a company at the USPTO in a four-year time window divided by the number of the company's granted patents with forward citations (also in a four-year time window). We use this time window to assure that all patents have the same amount of time to be cited. Not using this restriction would lead to higher citation counts for older patents, as they would have had a longer time period to be cited, causing a systematic bias.

Average family size: The average number of distinct patent offices a company's patents were filed at. A prerequisite, however, was that one of the filing offices was the USPTO, as we focus on companies operating in the US. Additionally, for this calculation we excluded the "singletons" (Martinez 2010), which are patent families that consist of only one family member, to focus solely on patent families with at least one member in another country.

4.3.2.3 The Control Variables

In determining the control variables, we draw upon an extensive base of past research (e.g. Horrigan 1966; Pogue and Soldofsky 1969; Pinches and Mingo 1973; Kaplan and Urwitz 1979; Ashbough et al. 2004; Kim 2005), as well as the rating framework of Standard & Poor's. The following indicators are controlled for (see also Table 4-2):

Firm size (annual revenue): Firm size enters the empirical model in term of sales (in billions). This is because past research shows that larger firms exhibit a lower risk of default and thus usually receive a higher rating. For example, Ashbough et al. (2004) employ total assets as an indicator for firm size and finds a strong positive impact on corporate ratings (see also Horrigan 1966; Kaplan and Urwitz 1979; Kim 2005). In our model, however, firms' size in terms of sales is used, following Czarnitzki and Kraft (2004).

ROA (earning before interest and tax (EBIT)/total assets): As indicated by Standard & Poor's (2008), profitability provides a litmus test for a firms rating. Return on assets (ROA) provides a widely used measurement for the profitability of a company, in terms of its ability to generate revenue on its assets. Past studies also show that ROA has a significant positive impact on firms' ratings (e.g. Ashbough et al. 2004). For this reason, ROA is controlled in the model (see also Pogue and Soldofksky 1969; Pinches and Mingo 1973; Kaplan and Urwitz 1979; Kim 2005).

Leverage (total debt/total assets): Firms with higher debt-to-assets are more leveraged, imposing a risk that the company will not be able to service its debt. For example, Ashbough et al. (2004) find that leverage has a significant negative impact on firms' ratings. Accordingly, CRA employ leverage ratios to determine a firm's leverage (Standard & Poor's 2008). Debt-to-assets therefore enters the model as a control variable (see also Horrigan 1966; Pogue and Soldofsky 1969; Pinches and Mingo 1973; Kaplan and Urwitz 1979; Kim 2005).

Cash flow adequacy (net debt/EBIT): A main concern of CRA is whether a firm will be able to service its debt. To assess this, CRA look at the payback period over which a company will be able amortize its debt (Standard & Poor's 2008). Taking EBIT over the firm's total debt provides an indicator for how many years the company needs to do so. If a firm, however, holds significant amounts of cash, calculations on a net basis are essential (Standard & Poor's 2008).[27] This is done by taking the firm's total debt and subtracting cash or cash equivalents. Accordingly, net debt over EBIT enters the model.

Subordinated debt (dummy variable): Subordinated debt ranks after other debt instruments in case of liquidation during bankruptcy. This means that subordinated debt is associated with higher risks being imposed on lenders, as subordinated debt-holders have claims on the firm's assets only after senior debt holders while lacking the upside potential of shareholders. Not surprisingly, Ashbough et al. (2004) find that subordinated debt has a significant negative impact on firms' rating. For this reason, a dummy variable controls for subordinated debt in our model (see also Horrigan 1966; Pinches and Mingo 1973).

Interest rate (net interest/total debt): We also control for the interest a firm pays on its debt. This is because if the risk of default related to a debt issuer increases lenders will want a premium to compensate for the higher risk, usually in terms of higher interest (e.g. Stiglitz and Weiss 1981). While ratings are shown to have an impact on the interest a firm pays when refinancing its debt (e.g. Hand et al. 1992), CRA consider the interest that is currently being paid by an issuer in their assessments through various measurements (Standard & Poor's 2008).

Short term debt (debt due in one year/total debt): Debt that is almost due indicates a need for a firm to refinance itself. This imposes a risk on firms to fail to do so, or doing so at a higher cost of capital (Standard & Poor's 2010). We control for this risk by taking the share of a firm's total debt that is due within a year into the model.

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27 This is because the firm could use its cash to immediately amortize a part of its debt, and thus reduce its debt burden.

R&D expenditures: Following past research, annual R&D expenditures (in billions) enters the empirical model (Czarnitzki and Kraft 2004). This is because new R&D expenditures indicate future growth potentials that might not already be reflected in a firm's rating.

Table 4-2: Overview of the variables and summary statistics

Variable	Mean	Std. Dev.	Min	Max	# Obs.	# Firms
Corporate Credit Rating (1 year lead)	4.70	1.84	1.00	8.00	632	129
Return on assets (ROA)	0.13	0.09	-0.36	0.34	632	129
Total debt/Total assets	0.17	0.13	0.00	1.14	632	129
Net debt/EBIT	0.92	19.87	-365.49	152.68	632	129
Subordinated debt dummy	0.09	0.29	0.00	1.00	632	129
Debt due in 1 year/Total debt	0.10	0.13	0.00	1.00	632	129
Net Interest/Total Debt	0.14	0.27	0.00	4.01	632	129
Sales (in billions)	9.95	15.54	0.06	137.96	632	129
R&D expenditures	0.54	0.77	0.04	5.65	632	129
Number of patents	0.28	0.47	0.00	4.58	632	129
Average family size	6.57	3.42	2.00	28.03	632	129
Average # of forward citations	7.31	3.32	1.00	23.86	632	129

Source: Own calculations
Note: The summary statistics are only reported for the number of cases that are used in the multivariate regressions.

4.3.3 Estimation Methods

Corporate credit rating is an ordinally scaled variable, since credit ratings can be ranked ordered, but uniform differences in categories cannot be assumed.

As ordinal dependent variables violate the assumptions of the linear regression model (OLS), models that avoid the assumption of equal distances between the categories provide a better choice (Long and Freese 2003). Therefore, we employ ordered probit models with maximum likelihood (ML) estimation to assess the effects of the patent indicators on corporate credit ratings. Ordered probit models start from a latent variable model with

$$y_i^* = x_i\beta + \varepsilon_i \text{ with } \varepsilon_i \sim N(0,1) \qquad (1)$$

where y_i^* is the unobserved, latent dependent variable, x_i is a vector of explanatory variables, β is a coefficient vector and ε_i the normally distributed error term. The dependent variable is limited by thresholds μ with

$$y_i = \begin{cases} 0, & \text{if } -\infty < y_i^* \le \mu_0 \\ 1, & \text{if } \mu_0 < y_i^* \le \mu_1 \\ \vdots & \\ J & \text{if } \mu_{J-1} < y_i^* \le \infty \end{cases} \quad \text{with } i = 1, 2, \ldots n \qquad (2)$$

where y_i is the observed categorical corporate credit rating variable, which takes on values of 0 to J, where J=8 is the last of our estimates since the corporate credit rating variable consists of eight categories.

As we use a panel dataset for our analyses, we are able to specify to which group each observation belongs and that we use data with repeated observations on firms. In other words, we can cluster the ordered probit model by companies, and thus use heteroscedasticity-consistent standard errors (White 1980). This allows us to control for unobserved heterogeneity in our models. In addition, we add time- and industry-dummies to the models to account for period- and industry-specific effects.

The coefficients of the ML estimation can be interpreted insofar that a positive sign of the coefficients means that it belongs to a higher rating category, whereas a negative sign means that it belong to a lower category, respectively.

4.4 Empirical Findings

4.4.1 Descriptive Statistics

The bivariate analysis of the variables in Table 4-3 already reveals several interesting insights.[28] First, as we expected, there is a positive and significant correlation between ROA and companies credit rating. This is also true for our firm size indicator (sales), which along with past findings shows that larger firms exhibit a lower risk of default and therefore usually receive a higher rating. Moreover, in conformity with previous studies we find a significant negative correlation between our dummy for subordinated debt and the credit rating variable.

On a bivariate level, the number of US patents does not show a significant correlation with corporate credit ratings. The patent value indicator family size, however, is significant and positively correlated to the rating variable. Hence, a larger average patent family size is associated with a higher rating. Theoretically, this could be explained by the fact that a larger family size indicates broader patent protection, and thus exclusivity in the appropriation of economic returns, for a greater geographical market. Surprisingly, however, patent forward citations are negatively correlated with ratings. This is a finding that requires a more profound explanation and will be analyzed in more detail in the multivariate analyses.

28 For the bivariate analysis we also use polyserial correlations, which use maximum likelihood estimation. These can be used to correlate discrete and continuous variables if the discrete variable measures an underlying continuous latent variable (see for example Olsson et al. 1982). As can be seen in Table III, however, the results only change slightly when calculating the in this case more accurate polyserial correlations.

Table 4-3: Pairwise correlations for the corporate credit rating measures and innovation indicators

	Pairwise correlation	Pairwise polyserial correlation	
		Rho	S.E.
Return on assets (ROA)	0.22***	0.30	0.04
Total debt/total assets	0.01	0.00	0.05
Net debt/EBIT	0.06	0.13	0.10
Subordinated debt dummy	-0.17***	-0.29	0.06
Debt due in 1 year/Total debt	0.04	0.05	0.06
Net Interest/Total Debt	-0.02	-0.01	0.03
Sales	0.12***	0.14	0.07
R&D expenditures	0.03	0.02	0.04
Number of patents	0.05	0.02	0.03
Average family size	0.19***	0.19	0.04
Average # of forward citations	-0.23***	-0.37	0.05

Source: Own calculations
Significance Level: ***p<0.01, **p<0.05, *p<0.1
Notes: Correlation coefficients are only calculated for the observations used in the multivariate regressions. Significance levels are not available for the polyserial correlation coefficients. Therefore only the standard errors are reported. In case of the subordinated debt variable, the correlation coefficient is polychoric rather than polyserial since both variables are categorical.

4.4.2 Results of the Multivariate Analyses

Turning to the multivariate analyses, Table 4-4 shows the estimates on corporate credit ratings that result from the ordered probit regressions. Starting from a model without innovation indicators (M1), several models have been calculated in which the variables for R&D expenditures, the number of patents and the patent value indicators were added gradually. This approach was chosen because it allows us to assess whether the effects remain stable over different models. In addition, it enables us to observe if the added innovation and patent value indicators increase the explanatory power of the models compared to the initial model.

A first look at the innovation indicators reveals that R&D expenditures do not to significantly influence the corporate credit rating. There are at least three potential explanations for this finding. A first and very straightforward argument would be that CRA do not have any particularity knowledge about the evaluation of R&D expenditures and therefore do not explicitly consider these. For example, in a study among Italian banks, Ughetto (2007) finds that intangibles are not taken into account in a systematic way in corporate credit risk assessments. The majority of the respondents did not even consider intangible assets as a meaningful determinant for credit risk. A more refined explanation stems from past research, which shows that financial analysts find technology-driven firms more difficult to value (e.g Amir 1999). Contrary to assets, such as commercial properties, which share common characteristics across firms and thus are easy to compare, R&D projects are very specific. In addition, Kothari et al. (2002) find that the variance of earnings associated with R&D is substantially higher compared to the variability of earnings related to tangible assets. It could therefore well be that CRA are reluctant to explicitly consider the value potential of R&D as a consequence of valuation difficulties stemming from the high uncertainty attached to related returns. Finally, in conformity with accounting standards, R&D investments are, at least partly, instantaneous costs,[29] reducing profits in the short-term and potentially pay-off at a later stage. It could therefore well be that the positive and negative effects that are reflected in the R&D indicator balance out, resulting in a non-significant effect.

The size of the patent portfolio, measured by the number of patents, shows a significant and positive effect on credit rating, also when the patent value indicators are included in the model. Therefore, it can be concluded that companies with a higher annual patent activity receive a higher credit rating than their respective counterparts with a lower patent activity. This finding strongly supports H1, where we stated that a larger number of patents per firm is associated with a higher rating and therefore a lower credit risk. We find two potential explanations for this. First, it could be that CRA view patents as innovative output and thus evaluate more innovative firms more positively. We hold against this argument that no such impact was found for R&D expenditures, which after all provide investments in technological innovation. However, although they do not perceive the growth potential of investments in innovation, at least in the short-term, it might be that they perceive future economic benefits related to a large innovative output, as there is some proof of concept and a higher probability of future returns. Second, it can well be that CRA view patents not just as innovative output per se, but as competitive weapons (e.g. Rivette and Kline 2000; Reitzig 2007). This result is in slight contrast to the findings of Czarnitzky and Kraft (2004), revealing an inverse u-shaped relationship between their innovation indicators and the credit rating variable. However, at least in our sample, there is no effect suggesting that too much innovation could negatively affect a company's credit rating. This is something we controlled by including the squared terms of our innovation variables. In doing so, we did not find any significant effects suggesting a non-linear relationship.

Clearly, past research has shown how companies use patents strategically in order to build a stronger competitive position (e.g. Blind et al. 2006; Cohen et al. 2002; Pitkethly 2001), and to reduce risks of lawsuits (e.g. Lanjouw and Schankerman 2001). Accordingly, Lanjouw and Schankerman (2001) argue that portfolio size effects exist, meaning that firms with a larger patent portfolio are more able to settle disputes through cross-licensing agreements, without resorting to patent lawsuits. Since the costs of a patent lawsuit can threaten the existence of a firm from one day to the next, it is likely that CRA consider patents from this point of view.

In line with H2b, the average family size of a company's patent portfolio shows a significantly positive impact on the rating variable. Hence, firms that have secured exclusivity for a larger number of markets receive higher ratings. Theoretically, it seems plausible that a larger average family

29 IAS 38 states that only development costs can be capitalized while research activities are to be treated as expenditures.

size is associated with higher future cash flows, as exclusivity may have been obtained for more markets. As shown, cash flow adequacy is a main concern for CRA in their credit risk assessments, providing a theoretical foundation for its positive impact. Still, the impact of the family size variable is lower compared to the patent counts variable, although we have to keep in mind that the two variables are measured on a different scale. Therefore we also calculated the standardized coefficients for all of the variables in the model. It can be shown, that the standardized coefficient for the number of patents still is higher than the one for the average family size (0.155** compared to 0.127* in M3), yet the difference between the two has become smaller. It should also be noted that our findings do not tell us whether CRA explicitly assess the average family size of a firm's patent portfolio, or if the positive impact is indirect, for example as a consequence of a larger family size which is associated with firms that operate more globally.

In contrast to H2a, the patent forward citations variable has a significant, but negative impact on corporate credit ratings, which has already been found in the bivariate analysis. This is surprising since Hall et al. (2000) show that one forward citation represents a value of 210.000 USD. Hence, one would expect forward citations to be associated with a higher rating. However, Lanjouw and Schankerman (2001) also find a positive relationship between forward citations and the probability of patent infringement as well as invalidity lawsuits. Similarly, Harhoff et al. (2003) show, that more valuable patents are more often a target of opposition or litigation. These findings could explain the negative relationship between forward citations and the credit rating variable.

The costs of patent litigation can be devastating to any firm. Bessen and Meurer (2008) argue that the total costs of patent lawsuits are substantially large compared to legal costs, R&D expenditures, and even patent value. This is because patent lawsuits are associated with additional indirect costs such as distractions of management and loss of market share. For example, pending litigation can shut down production, sales and marketing, and even without a preliminary injunction consumers may stop to purchase the product. Additional costs can be related to managerial distractions, but also a greater risk of bankruptcy. Measuring the loss of wealth based on Tobin's q, they find costs of lawsuits for alleged infringers to be about 28.7 million USD in the mean and 2.9 million USD in the median,[30] but also the costs for patent owners were found to be substantial.

A theoretical reason for the negative relationship between forward citations and ratings accordingly could be that, although forward citations are associated with future economic benefits, CRA still discount for the associated legal risks. We find this argument to be likely, not only because forward citations provide an indicator for patent value. This is also true for family size, which shows a positive impact on the dependent variable. Rather, we argue that because forward citations indicate subsequent research investments, and hence potential competition in R&D, they are associated with a higher probability of lawsuits. It is therefore only logical to discount for forward citations when

30 This was measured in 1992 years USD.

assessing risk, as well as credit risk. Yet, since we have no data available on litigation at the firm level, this explanation can only be grounded on previous findings in the literature.

Finally, it shall again be noted that the patent value indicators have a smaller effect on the dependent variable, compared to the number of patents, which is shown by the values of the standardized coefficients.[31] This finding contradicts past research showing that these indicators have a stronger impact on stock market valuations than the mere patent output (e.g. Sandner and Block 2011). As past research shows a surge in strategic patenting (e.g. Cohen 2005), leading to a relatively high share of low value patents (e.g. Blind et al. 2009), CRA should be concerned with differentiating the valuable ones from the lemons. This is because if the value of a patent relates to a strategic motive – for example its purpose is to increase the firms bargaining power before cross-licensing negotiations (e.g. Hall et al. 2005) – the patent is likely to have no economic value to other third parties. The patent therefore has no potential to be used as collateral or to be commercialized to resolve financial distress. On the contrary, if the patent can be used to protect a product that generates income, it will have an impact on the default risk related to a firm. However, we find that CRA have a different perspective when it comes to patents, namely again the perspective of litigation risks. We argue that the relatively low impact of the family size indicator, compared to the patent flows indicator, might indicate that CRA are more concerned with the size of the firm's patent portfolio than its geographical scope or technological value in terms of the number of forward citations. As argued by Lanjouw and Schankerman (2001), it thus seems likely that portfolio size effects exist, meaning that firms with a larger patent portfolio are better able to settle disputes through cross-licensing agreements, without resorting to patent lawsuits. Together with the negative impact of the citations indicator, this suggests that the credit risk perspective – related to patent lawsuits – is predominant. Hence, the risks of litigation outweigh the potential benefits related to valuable patents. These effects, however, will be analyzed in more detail below, when looking at the marginal effects computed at the means of the independent variables.

A look at the coefficients of the control variables reveals that ROA exerts a significantly positive effect on the credit rating variable, which is consistent over all three models (M1-M3). This finding is also consistent with past research (e.g. Ashbough et al. 2004; Kim 2005). Hence, as expected, more profitable firms exhibit a higher rating. In conformity with previous studies, we also find that the dummy variable for subordinated debt has a strong negative impact on firms' rating (e.g. Ashbough et al. 2004; Pinches and Mingo 1973). We therefore conclude that the riskiness of subordinated debt is reflected in corporate credit ratings. A similar effect can be observed for the interest rate variable, although only in the first model. To our knowledge, this control variable has not been used in past research on the determinants of ratings. However, as elaborated, there are good theoretical reasons for its inclusion. Firms that exhibit higher interest on their debt have a more difficult financial situation in terms of covering their interest payments as they need to generate

31 The standardized coefficient for the average number of forward citations is -0.11*.

higher operating profits than firms paying less interest to do so. Accordingly, they face a higher risk of default. Finally, we find that the sales indicator has a consistent positive effect on the dependent variable, which again supports the argument that larger firms with more mature business models generally face a lower risk of default, and thus also receive higher ratings.

Table 4-4: Results of the ordered probit models

dV = Corporate Credit Rating	**M1**			**M2**			**M3**		
	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.
Return on assets	3.616	***	1.104	3.545	***	1.132	3.414	***	1.134
Total debt/Total assets	0.720		0.724	0.514		0.717	0.448		0.719
Net debt/EBIT	0.003		0.002	0.003		0.002	0.002		0.002
Subordinated debt dummy	-0.956	***	0.255	-0.894	***	0.232	-0.902	***	0.231
Debt due in 1 year/Total debt	0.647		0.549	0.543		0.550	0.654		0.540
Net Interest/Total Debt	-0.323		0.226	-0.317		0.236	-0.324		0.218
Sales (in billions)	0.022	*	0.011	0.020	***	0.008	0.020	***	0.008
R&D expenditures				-0.100		0.138	0.000		0.000
Number of patents				0.429	**	0.191	0.491	**	0.193
Average family size							0.055	*	0.032
Average # of forward citations							-0.049	*	0.028
Time Dummies	YES			YES			YES		
Industry Dummies	YES			YES			YES		
Nr. of observations	632			632			632		
Nr. of companies	129			129			129		
Pseudo R^2	0.179			0.185			0.192		
AIC	2054.21			2044.14			2032.46		
BIC	2218.82			2217.64			2214.86		

Source: Own calculations
Significance Level: ***p<0.01, **p<0.05, *p<0.1
Note: The number of observations in each model was adjusted to the model with the fewest observations (M3) in order to conserve comparability of the effects over all models. To test for multicollinearity between the explanatory variables, Variance Inflation Factors (VIFs) based on an OLS model with "corporate credit rating" as the dependent variable were calculated. R&D flows had the highest VIF (2.69). The mean VIF for the model was 1.50. Hence, we find no multicollinearity concerns (O'Brien 2007).

Turning our attention to the overall explanatory power of the models, i.e. the R^2 values, it can be observed that adding the innovation and patent value indicators increase the explanatory power of the model. Hence, the innovation indicators explain some additional variance in the corporate credit rating variable. Furthermore, we measure the overall fit of the models, using the Bayesion Information Criterion (BIC). The difference in BIC between two models shows which one is better able to explain the variance in the dependent variable. For example, BIC(M1) – BIC(M2)>0 leads to a preference of M2 (Long and Freese 2001). As we can see in Table 4-4, BIC takes a lower value when adding the innovation and the patent value indicators to the model, implying that M3 is best able to explain the variance in credit rating.[32]

In order to control for timely limited effects of the innovation indicators – i.e. R&D expenditures, the number of patents, average family size and the average number of forward citations – on corporate credit rating, in a final step, we specified all of the innovation related explanatory variables with a one, two and three period lag, respectively, and re-calculated M3 only with the lagged explanatory variables. The results show that our findings remain robust up to a time lag of two years. As in the original specification, R&D expenditures have no significant effect, no matter if a one, two or three years lag is used. The effects of the number of patent applications, average family size and the average number of forward citations become slightly stronger pronounced. The significance remains the same as in the original specification. After a lag of two years, the average family size and the average number of forward citations loose significance. This shows that the the number of patents as well as the patent value indicators have a timely lasting effect on the corporate credit rating, which is consistent up to a time lag of two years for all of the three variables.[33]

In order to analyze the effects of the innovation and patent value indicators more in detail, Wald-Tests for the single coefficients for M3 were conducted (see Table 4-5). The tests show that the coefficients for R&D and patents are not equal to zero, meaning that we find a significant influence for a combination of both indicators on the credit rating variable. The same is true, when we add the patent value indicators to the Wald-Test.

Table 4-5: Wald-Tests for the innovation and patent value indicators

R&D expenditures, Number of patents = 0	Chi^2	6.60
	$Prob > Chi^2$	0.04
R&D expenditures, Number of patents, Average family size, Average # of forward citations = 0	Chi^2	9.47
	$Prob > Chi^2$	0.05

Source: Own calculations
Note: The Wald-Tests are based on the results of M3.

Finally, we analyze the effects of R&D, patents and our patent value indicators on the corporate credit rating variable in more detail across the categories of the dependent variable. This is done by calculating the marginal effects at the means of the independent variables (see Table 4-6).

The results show that patents are best able to explain the variance in corporate credit rating in the medium ranges of the dependent variable, i.e. from rating "C" to rating "A". In the lowest and highest category of the rating variable, the patent flows do not play a significant role. An explana-

32 The same is true for Akaike's Information Criterion (AIC), which is a similar measure as BIC. All else being equal, the model with the smaller value of AIC can be considered as the model with the better overall fit (Long and Freese 2001).

33 Since the results of these models only slightly differ to our original specification, they are not shown in detail here. However, the detailed results are available upon request.

tion could be that in the lowest category of the credit rating, other factors affect credit risk more substantially. When evaluating distressed debt this has to be seen as highly likely as the immediate question will be whether the company can become more profitable in the short-term to avoid bankruptcy. Profits related to innovation, however, usually lie further ahead and will therefore probably be seen as of less relevance in such situations. In the upper regions of the rating, where the top-performing firms are found, 'ceiling effects' could be at work. This finding is also logical, since firms with many assets-in-place – i.e. assets that already generate economic returns – can be assessed on the basis of their current cash flows, rather than future profit potentials. A similar result can be found for the patent value indicators, although they influence the credit rating in an even narrower window of categories of the dependent variable. The effect of the average family size turns positive from category B to B+, and thus significantly influences the rating only in these two categories.

The forward citations indicator, which had a negative cumulative impact on the dependent variable, has a positive impact in the lower rating categories, namely B- and B, yet does not show a significantly negative effect in the upper regions of the rating. This is reflected in a negative effect of the average number of forward citations in total (M3).

To sum up, we can state that the number of patents does not only have a larger influence on corporate credit rating, but also significantly affects a broader region of rating. This again supports our argument that rating agencies rather look at the size of a patent portfolio when evaluating the credit risk of a company, whereas the value of the patent portfolio is of less importance for their assessment.

Finally, we have to point out, that it need not be that CRA actually explicitly consider patents or related value indicators when evaluating credit risk. What we can state is that their credit risk assessments seem to reflect patent quantity rather than quality.

Table 4-6: Marginal Effects calculated at the means of the independent variables (M3)

dV = Corporate Credit Rating	**Rating D**		**Rating C**		**Rating B-**		**Rating B**		**Rating B+**		**Rating A-**		**Rating A**		**Rating A+**	
	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.
Return on assets	-0.016	0.016	-0.331 **	0.169	-0.395 ***	0.160	-0.612 ***	0.243	0.464 *	0.247	0.374 **	0.175	0.237 **	0.119	0.280	0.187
Total debt/Total assets	-0.002	0.004	-0.044	0.071	-0.052	0.084	-0.080	0.131	0.061	0.103	0.049	0.082	0.031	0.052	0.037	0.057
Net debt/EBIT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Subordinated debt dummy	0.014	0.013	0.146 **	0.066	0.110 ***	0.039	0.066 *	0.038	-0.176 ***	0.056	-0.078 ***	0.029	-0.042 **	0.021	-0.040	0.029
Debt due in 1 year/Total debt	-0.003	0.004	-0.063	0.056	-0.076	0.067	-0.117	0.100	0.089	0.077	0.072	0.064	0.045	0.043	0.054	0.057
Net Interest/Total Debt	0.002	0.002	0.031	0.023	0.038	0.027	0.058	0.042	-0.044	0.033	-0.035	0.026	-0.023	0.018	-0.027	0.026
Sales	0.000	0.000	-0.002 **	0.001	-0.002 **	0.001	-0.004 **	0.002	0.003 *	0.002	0.002 *	0.001	0.001 *	0.001	0.002 *	0.001
R&D expenditures	0.001	0.000	0.011	0.000	0.013	0.000	0.020	0.000	-0.015	0.000	-0.012	0.000	-0.008	0.000	-0.009	0.000
Number of patents	-0.002	0.002	-0.048 **	0.025	-0.057 **	0.027	-0.088 **	0.040	0.067 *	0.036	0.054 *	0.029	0.034 *	0.020	0.040	0.027
Average family size	0.000	0.000	-0.005	0.004	-0.006	0.004	-0.010 *	0.006	0.008 *	0.005	0.006	0.004	0.004	0.003	0.005	0.004
Average # of forward citations	0.000	0.000	0.005	0.003	0.006 *	0.004	0.009 *	0.005	-0.007	0.004	-0.005	0.004	-0.003	0.002	-0.004	0.003
Time Dummies	YES		YES		YES		YES		YES		YES		YES		YES	
Industry Dummies	YES		YES		YES		YES		YES		YES		YES		YES	
Nr. of observations	632															
Nr. of companies	129															
Pseudo R^2	0.192															
AIC	2032.46															
BIC	2214.86															

Source: Own calculations

Significance Level: ***p<0.01, **p<0.05, *p<0.1

Note: Marginal Effects are calculated on the base of M3. For dummy variables, dy/dx is for a discrete change of dummy variable from 0 to 1.

4.5 Conclusions and theoretical implications

The present study goes beyond past research in examining the contribution of CRA to the informational efficiency of capital markets, in terms of communicating patent value through their credit risk assessments. Our findings give a mixed picture. Corporate credit ratings, as stock market valuations, reflect the future economic benefits related to patents, which supports our first hypothesis that a larger number of patents leads to a higher credit rating. In addition, we find a positively significant impact of the patent portfolios' average patent family size on credit ratings, supporting H2b. This finding indicates that CRA at least partially differentiate between valuable patents and lemons. They also seem to account for forward citations, but not in the positive manner that we expected. Instead, we find a significant negative impact on the rating variable and thus have to reject H2a. This finding shows that stock markets and CRA value forward citations differently.

However, this is not overly surprising when taking into account that stock market valuations and credit risk assessments are fundamentally different. While stock markets look to determine the future economic benefits of an investment, credit risk assessments focus more on the downside, which is of less interest to speculative stock markets. This is because of the different nature of debt and equity contracts. While a shareholder participates on the upside, creditors do not share upside gains related to a firm's investments, and thus are mainly interested in the bottom tail of the distribution of economic returns (e.g. Stiglitz, 1985). For this reason, compared to shareholders, creditors are more concerned with determining the risks of an investment rather than the present value of potential future economic benefits (e.g. Standard & Poor's 2008). Still, past research shows that patents as well as related value indicators are also associated with higher company survival rates, meaning lower risks of default (e.g. Bittelmeyer 2007). Moreover, valuable patents can provide collateral for creditors (e.g. Amable et al. 2008). Theoretically, the absence of collateral could lead to moral hazard complications, and thus credit rationing (e.g. Stiglitz and Weiss (1981)). As most debt funding is given only on a secured basis (e.g. Berger and Udell 1998), it is essential for innovative firms with only few tangible assets to be able to provide some sort of collateral, and thereby enhance their creditworthiness, to finance innovation through debt. To assess whether an asset can properly serve as collateral, however, in terms of whether its value covers the secured debt, a valuation of the asset needs to be conducted (Standard & Poor's 2006). This means that if intangible assets, such as patents, are not valued properly in credit risk assessments, creditors are likely to develop a distorted picture of the risks related to an investment. Hence, there are strong theoretical as well as practical reasons for CRA to assess the value of a company's patents.

However, there is also another side of the patent coin – i.e. the risk of patent lawsuits. The total costs related to such risks go well beyond legal costs, and can increase a firm's cost of capital as a consequence of a higher risk of insolvency (e.g. Bessen and Meurer 2008). Because patents of higher value are more likely to be subject to lawsuits (e.g. Lanjouw and Schankerman 2001; Harhoff 2003), CRA need to make constant trade-offs between the potential future benefits related to patents and the risk of lawsuits. Theoretically, from a creditor's perspective, risks associated with patent lawsuits will generally outweigh potential economic benefits as creditors do not share the upside related to the firm's investments. At first sight, this may seem contradictory to our findings, showing that the number of patents is associated with higher credit ratings. However, as Lanjouw and Schankerman (2001), we argue that portfolio size effects exist, meaning that firms with a larger patent portfolio are better able to settle disputes through cross-licensing agreements, without resorting to patent lawsuits. Accordingly, we arrive at the conclusion that patents do contribute to higher credit ratings, not in terms of growth opportunities, but as insurance.

We believe this mainly for two reasons. First, we find that R&D flows do not contribute to higher ratings, implying that CRA do not explicitly consider innovation activity as a determinant of credit risk, at least in the short-term. Second, we find that the impacts of both patent value indicators are smaller compared to the impact of patent flows. Our findings show that inflationary corporate patent policies under present conditions make it easier for firms to obtain debt funding, although most patents are of relatively low value and do not provide any substantial collateral.

The relationship between our patent value indicators and corporate credit ratings can also be explained from the perspective of tradeoffs between the economic benefits of patents and the risk of lawsuits. We argue that CRA perceive the benefits related to family size to be relatively high, while the benefits related to the forward citations are comparatively low. Our theoretical argument is that while family size indicates exclusivity on a wider range of markets, forward citations not only indicate technological significance, but also the degree of R&D competition between firms, making patent lawsuits more likely.

Turning to the theoretical implications, our findings provide a potential explanation why R&D-intensive firms prefer equity (Aghion et al. 2004), although the pecking order theory shows that in the presence of asymmetric information, companies will rely on debt rather than issuing undervalued equity (e.g. Myers and Majluf 1984). As argued by Lemley and Shapiro (2004): *"Under patent law, a patent is no guarantee of exclusion but more precisely a legal right to try to exclude".* Together with an ever increasing pace of strategic patenting (e.g. Blind et al. 2004; Cohen 2005; Hall and Ziedonis 2001), this has created a litigious patent environment with substantial costs of patent lawsuits (Bessen and Meurer 2007). As creditors do not share upside gains related to the firm's investments, they are mainly interested in the bottom tail of the distribution of economic returns (e.g. Stiglitz 1985). Accordingly, we find that the credit risk perspective – related to patent lawsuits – is predominant for any upside benefits of patent protection. Our findings suggest that firms need to devote substantial financial resources to build and uphold a large patent portfolio as insurance, or they will eventually face higher costs of debt. Hence, companies will experience higher costs of innovation either through increased costs of funding or increased patent portfolio costs – a finding that is especially troublesome to smaller technology-driven firms, not least since smaller technology-driven firms rely less on strategic patenting (Blind et al. 2006), and most often do not have the financial means to uphold a larger patent portfolio. We conclude that the financing of technological innovation through debt will be expensive either way, which is probably why R&D-intensive companies tend to prefer even undervalued equity. For smaller technology-driven firms, the market for venture capital is one response to this funding problem. However, Sahlman (1990) show that venture capital comes at a high cost of capital. Moreover, venture capitalists react to information provided by public stock market (Gompers et al. 2008), and try to time IPO decisions by making an exit, when stock markets valuations are higher. Hence, Black and Gilson (1998) argue that information efficient stock markets are important for venture capital funding, meaning that technology-driven firms will also face relatively high costs of venture capital.

While a funding gap for technological innovation is difficult to establish, it has been suggested by several research scholars (e.g. Hall 2002; Hall and Lerner 2010; Harhoff 1998). The literature shows that it can, at its best, be argued that smaller technology-driven companies only suffer from unjustifiably high costs of capital, much due to asymmetric information. Accordingly, certain NPV positive innovation projects, which would be profitable if financing costs were lower, may not be undertaken. Considering the importance of efficient capital markets and technological innovation to productivity a funding gap for technological innovation could certainly be argued to provide constraints, also to economic growth.

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5 Standard essential patents to boost financial returns

Abstract This article investigates how patents, that are essential to a technology standard, influence firms' financial performance. Standards enable interoperability and communication on a technology platform. In practice, most innovative applications build upon interoperable standardized technologies. In recent years, a large part of the competition on technology has been moving upwards at the standard setting level. Especially in ICT (information and communication technology) where innovation is often cumulative, it is crucial to own essential patents to maintain market positions. We test the influence of declaring a patent to a standard on financial performance using a rich dataset of firms active in ICT standard setting. Our results indicate a curvilinear (inverse U-shaped) relationship of patent declarations on firms' return on assets (ROA). This effect lasts for one year, while the incremental effect is higher for patents declared to informal SSOs (standard setting organizations) when comparing declarations to formal SSOs. We further estimate the optimal number of patent declarations and find a higher optimal level of financial return for declaring patents to formal standards. The curvilinear relationship suggests that firms should balance their patent portfolio by introducing a share of patents into standards and by holding a share of patents on standard constructive technologies. Our results indicate that the effects of patenting around standardization depend on the standardizing SSOs as well as the level of patenting. In order to realize an optimal level of financial returns, we suggest firms to evaluate their patent portfolio before selecting a standard setting forum. Valuable patent portfolios generate higher incremental returns in informal SSOs, while larger patent portfolios reach higher optimal return levels in formal SSOs.

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5.1 Introduction

A firm's innovative capacity is crucial to maintaining competitive advantages in knowledge resources, technology advances, price competitions and market positions. In recent years scholars have increased their investigations of intellectual property rights (IPRs) and their influence on firms' financial performance (Hall et al., 2005; Reitzig and Puranam, 2009). While most of the research examines different factors of patent value, only few analyses have been conducted that shed light on the positioning of patents, such as a patent's essentiality to a technology standard. The commercialization of a technology in ICT (information and communication technology) markets often requires licensing agreements among multiple patentees (Shapiro, 2000; Graevenitz et al., 2011). In this context, ICT standardization has developed to be much more demanding in terms of R&D and now represents a key strategic stake for companies to foster the value of their (patented) technology by having it approved as part of an industry-wide standard. Patents that would necessarily be infringed by any implementation or adoption of a standard are called essential patents (Bekkers et al., 2001; Simcoe, 2007). The essentiality of a patent has an indispensable character in the adoption of standardized technologies. Patents incorporated into standards can hold-up the use of a whole technology, even if the patent only protects a minor component (Farrell et al., 2007). The empirical analysis of Bekkers et al. (2002, 2011) have shown that standard essential patents qualify firms to control market positions in network industries.

Yet, there is only little research that examines the impact of standard setting on a company's financial performance. Waguespack and Fleming (2009) show that participation in SSOs increases the likelihood of a buy-out of start-ups, yet without analyzing performance measurements. Aggarwal et al. (2011) provide empirical evidence of a positive relationship of a companies' participation in standard setting and returns on stock markets.

The aim of this article is to extent the current analyses by examining the impact of standard essential patents on a company's financial performance measured by ROA. While applying measurements of patent value, such as the average number of forward citations and the average patent family size of a company's patent portfolio (Narin and Noma, 1987; Trajtenberg, 1990), we focus on information of a patents' declaration to a standard. We therefore compiled over 65,000 patent declarations by formal SSOs[36] (Standard Setting Organizations) and informal SSOs[37]. Patent declaration statements provide information on the patent number, the patent holder and the timing of declaration. To control for a company's licensing strategy we further added information on firms' patent pool memberships connected to essential patents. We

[36] ISO, IEC, JTC1-a joint committee of ISO and IEC, CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE.

[37] IETF, TIA, OASIS, OMA, the Broadband Forum and the MSF Forum.

created a data panel built upon company level and gathered information on the total amount of sales, R&D expenditure, number of employees and return on assets per year and per company between 2000 and 2007.

To assess the impact of essential patents on a company's financial performance, we conducted bivariate as well as multivariate analyses, using return on assets (ROA) as our explained variable. Our results provide evidence that declaring essential patents to formal and informal SSOs has a curvilinear (inverted U-shaped) effect on financial returns. When comparing the coefficients of our explanatory variables, we further find the incremental impact of essential patents declared to informal SSOs to be stronger compared to patents declared to formal SSOs. We employed additional analyses to identify the optimal level of patent declarations which is higher for formal standards. Patents declared to informal standards in comparison may even have negative effects on ROA beyond an optimal level of patent declaration. To also assess the lasting effects we further tested models with time lags. The effect of patent declarations remains robust up to a time lag of one year. Essential patents start to have no significant impact when lagged by two years or more.

The curvilinear relationship of a firm's patent declaration and ROA suggests that firms need to balance their patent portfolio by introducing patents into standards not beyond an optimal level. Depending on the quality and size of a firm's patent portfolio firms should further select the most beneficial forum of standard setting. Our results show that incremental returns are higher for declaring patents to informal SSOs, while the optimal level of patent declaration that generates positive returns is higher for formal SSOs. We thus suggest firms with large scale patent portfolios to declare to formal SSOs, while high quality patents should be introduced to informal SSOs where patents gain higher returns.

The remainder of this paper is structured as follows. In our theoretical section we discuss the measurement of patent value indicators as well as the role of patents in standard setting and indicators of financial performance. We then motivate our hypothesis, describe our database and define our methodological approach. Subsequently we run regression models to test our hypothesis. We conduct further robustness tests and finally conclude in our last section.

5.2 Literature and Theory

The influence of a company's technology assets on its financial performance has been studied extensively. Analyses by Griliches (1981) and Narin and Noma (1987) were among the first to measure different indicators of patents to influence a company's sales, profits or market value. In the following we will discuss several indicators of patent value, patent essentiality to standards as well as the measurement of financial performance.

5.2.1 Patents and Patent Value Indicators

Patent applications and patent grants are probably the most important indicators for the technological output of innovation processes within companies. Especially in high-tech areas, such as ICT and software, the number of patents can be assumed to exert a positive influence on the financial performance of a company (e.g. Hall et al., 2007; Hall and MacGarvie, 2010). Large patent portfolios reflect increased R&D efforts and thus greater innovative output, which has been shown to influence a firm’s performance in various ways. A large patent output can be seen as a positive market signal (e.g. Hall et al. 2005) also affecting firms' profitability (Bloom and van Reenen, 2002, Ernst, 2001). Large patent portfolios are also strategically useful, for example to block other market participants' innovative endeavors, to displace smaller competitors in relevant markets, to increase the chances for license or commercial agreements, ease the access to the capital market and increase a company's reputation (Blind et al., 2006).

Since patents, however, differ from one another both in economic and technological value, just counting patents could lead to a distorted picture of a company's technological base. Therefore, some additional indicators have been proposed to correct for the quality or value of patents. The most common and widely used indicator to determine patent quality is patent forward citations (Narin and Noma, 1987; Trajtenberg, 1990). The number of forward citations (citations a patent receives from subsequent patents) is assumed to measure the degree to which a patent contributes to further developing advanced technology. Thus, forward citations can be regarded as an indicator of the technological significance of a patent (Albert et al., 1991; Blind et al., 2009; Hall and Ziedonis, 2001), although it has been evaluated to be rather noisy indicator (Alcacer et al., 2009; Alcacer and Gittelman, 2006; Hall and Ziedonis, 2001).

Another patent value indicator is family size. It is determined by the number of countries or patent offices, where a patent has been filed (Putnam 1996), and can therefore be seen as a measure of patented market coverage. This patented market coverage, however, is associated with additional expenses for patent application, information search, translation, examination etc., which are even amplified when patenting in foreign jurisdictions (Hanel 2006). Thus, it can be assumed that a patentee only files a patent abroad, if he expects a corresponding return on the sale of the protected technology that outweighs the patenting costs.

This article extends the analyses on patent counts and patent value indicators to the measurement of the positioning of patents to be essential for standardized technologies. In particular, we use information on the essentiality of a patent to ICT standards.

5.2.2 Essential Patents and Standard Setting

The goal of standard setting is to commonly agree on the specifications of a technology (Lyytinen and King, 2006; Markus et al, 2006). This is often crucial to enabling interoperability and to unlocking innovation in complex technologies based on various components provided by different suppliers. However, the process of setting a standard can be very costly for participating firms, since standard development seizes employee workforce and creates traveling expenses for regular meetings and presentations around the world.[38] Firms' benefits from standard setting are versatile, such as the facilitation of technology and products (Weitzel et al., 2006; Peek, 2010), reinforcing user confidence and user acceptance (Brynjolfsson and Kemerer, 1996; Blind et al., 2010) and consequently the emergence of new and the growth of already existing markets (Blind, 2004). Due to the public good character of a standard, these benefits may accrue to all market participants. While some companies provide their R&D outputs for standard setting, others do not. Introducing essential patents to a standard is a practice to recoup a company's investments in standards setting (Farrell and Saloner, 1985).

Essential patents are those that a company would necessarily infringe when adopting or implementing a technology standard. Especially in the field of ICT, standards may incorporate technology components which are protected by a large number of patents (e.g. GSM, UMTS, Wi-Fi, MPEG)[39]. While standards have to ensure interoperability and should be open to all interested stakeholders, granted patents provide its holders with a temporally limited monopoly right on a technology. In the field of standard setting, companies have to declare patents that might affect the standardized technology and agree to license their rights under fair, reasonable and non-discriminatory (F/RAND) conditions. These F/RAND agreements are still far from conclusive and there is an ongoing discussion about what a reasonable license for an essential patent should be (Layne-Farrar et. al, 2007). It is still a common belief that essential patent owning companies are able to exploit their positions of technology ownership, when standards are commercialized. The decision to include a patent in a standard is a consensus decision and a validation of a patent's technological merit. Recent literature findings show that patents increase in value, when they are included in a standard (Rysman and Simcoe, 2008; Layne-Farrar and Padilla, 2011). Bekkers et al. (2001) give further evidence that a company's position in a particular network market strongly depends on the number of essential patents declared. Firms seem to have strong incentives to introduce patents to standards, as an empirical study by Goodman and Myers (2005) illustrates over-declaring of essential patents in the field of 3G technologies. Berger et al. (2012) show that firms even apply strategic behaviors in the patent application process to adjust their patent claims to the standardized technology.

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38 Chiao et al. (2007) interviewed practitioners in standard setting and retrieved information on IBM which spent more than 500 USD million on standard setting expenses, representing almost 8.5% of their R&D budget in 2005.

39 GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System), Wi-Fi (The Standard for Wireless Fidelity), MPEG (Moving Picture Experts Group)

5.2.3 The Return on Assets

To assess the value of a company, a large number of indicators have been used up to now. Within this analysis we intend to focus on the return on assets (ROA) as a measure of the financial performance of companies. ROA is a measure of contemporaneous profitability, or in other words, present day profits. It is formally defined as earnings before interest and taxes π divided by the total assets A of a company. Assuming that a company will live indefinitely and there is no uncertainty, the following relationship is expected to hold for any company i:

$$ROA_{0i} = \pi_{0i} / A_{0i} \qquad (1)$$

ROA is one of the most widely used measures for the financial success of a company that is subsumed under the expression return on investment (ROI) or rate of return (ROR).

5.2.4 Theory and Hypotheses

Previous studies have shown that owning patents in ICT markets (Hall. et al., 2007; Hall and MacGarvie, 2010) and participating in standard setting (Aggarwal et al., 2011) may increase the financial performance of firms. When declaring a patent as essential to a standard, patent owning companies may be in the position to control whole markets that are based upon standardized technology to thus increase their financial performance. However, including patents in a standard is always a result of consensus agreements on a standardized technology. Decision making is only feasible, when all involved participants face the same benefits. If possible, side payments are solutions to reach common agreements. These payments might resolve e.g. royalty fees from essential IPR (Farrell and Saloner, 1985). In consensus decision making, it seems plausible that side payments increase with a higher number of essential patents. This would in turn negatively affect firms' financial performance. Bekkers et al., (2011) show that firms which declare too many patents seem to declare patents of lower quality. If "over-declaring" increases side payments and is subject to a decreasing patent quality, we predict that the effect on a firm's financial performance also decreases with the number of patents declared.

Aggarwal et al. (2011) state that coordination in standard setting leads to homogeneity of knowledge distribution among participants and thus may reduce a firm's competitive advantage. When companies declare their patents to a standard, SSOs oblige the patent holder to license the patented technology (Layne-Farrar et. al, 2007). This is different for patents outside standardization where the patentee is able to block competitors by not licensing out but enforcing the patent. In order to maintain competitive advantage it thus appears to be advantageous for a company to balance their patent portfolio. We predict that it is beneficial to introduce a certain share of patents into standards to guarantee freedom to operate and increase bargaining positions in cross licensing agreements (Blind et al., 2011), while the remaining share of a company's patent portfolio should be placed to secure differentiation of product designs and complementary applications. Over-declaring would thus not only decrease marginal returns e.g. by side payments, but further decrease the competitive advantage in a market. Firms' R&D decisions are thus always subject to the trade-off between investing in technologies for standard platforms and investing in constructive components. Based on these considerations, we derive the hypothesis that there is a positive incremental effect of essential patents on a firm's ROA up to a certain level. Beyond an optimal level of patent declaration we assume a decreasing effect. We thus derive our first hypothesis:

H1: The declaration of standard essential patents has a curvilinear effect on a company's financial performance, with a slope positive effect at low and moderate levels and a negative incremental effect at high levels.

Patents may be essential to formal or informal standards. Lerner and Tirole (2006) first introduced the option of SSO selection as a concession parameter in relation to technology ownership. An owner of a strong technology will select an SSO aiming to capture much of users' welfare via collecting licensing revenues. In the case of a weak technology or the existence of strong alternatives, the technology owner has to make concessions to users, e.g. by signing a royalty free agreement for his patents included in a standard. Chiao et al. (2007) provide empirical evidence for the hypotheses derived from the model on the decision parameters of SSO selection. Companies may thus choose to introduce their technologies to standards in formal or informal SSOs in view of the most beneficial financial returns.

The standard setting arena is divided into formal and informal SSOs that generally work on complementary technologies (Blind & Gauch, 2008). Estimations claim that over 60% of all standards in the ICT sector are developed in informal SSOs (Tapia, 2010). Formal and informal SSOs pursue different standardization processes but also differ in their IPR rules. While technology selection in formal standardization is a result of consensus agreement, informal SSOs mostly only demand majority voting. Formal standardization is open to all interested stakeholders, while informal SSO membership is more exclusive (e.g. by demanding rather high membership fees). Due to these differences, formal standardization is often seen to be more bureaucratic and thus slower in the decision making processes, while informal SSOs often face shorter standardization processes (Cargill, 2002). In formal SSOs, licensing fees for essential patents are restricted by F/RAND commitments. Informal SSOs allow less restrictive licensing agreements. When considering these differences and the findings of Lerner and Tirole (2006), we conclude that companies with strong technologies would rather choose informal SSOs, where majority voting might help to push technology proposals without agreeing to concessions, e.g. resolving royalties. Furthermore, informal SSOs' less restrictive licensing cap might result in higher royalty fees. We thus predict that the impact of essential patents on a firm's financial performance is stronger in informal SSOs compared to formal SSOs and derive our second hypothesis:

H2: The declaration of essential patents to informal standards has a stronger incremental effect on companies' financial performance compared to patent declarations to formal standards.

Patents in the field of ICT may have a strong effect on a company's financial performance (Hall et al., 2007; Hall and MacGarvie, 2010). Griliches (1990) also predicts a positive lagged correlation of patents and firm performance. Bloom and Von Reenen (2002) provide further evidence that effects of patents on financial performance may have immediate, but also lagged effects. Furthermore, Ernst (2001) found that patents have a lasting effect on a company's amount of sales of up to 3 years after priority year. We believe that declaring a patent to be essential to a standard might also have a lasting effect on a firm's financial performance. However, we assume this effect to decrease over time. This is due to the fact that ICT markets are usually subject to short product lifecycles and the survival of technologies is often at pace. Evidence for this fast pace can be found when analyzing patent data in ICT sectors. In particular, the technology cycle time (TCT) can be used to measure the speed of innovation (Deng et al., 1999; Narin 1993). It is calculated as the median age of cited patent references in a company's patent portfolio. Companies with shorter cycle times than their competitors advance more quickly from prior to current technology. The literature suggests that the cycle time ranges from about three to five years in electronics (Narin, 1993).[40] Since technology life cycles are rather short in electronics and firms declare their patents in average four to six years after priority date (Blind et al., 2011), we believe that declaring a patent to be relevant to the standard is limited in time and has a yearly decreasing effect on a firm's performance. Thus, we derive our third hypothesis:

H3: The effect of essential patents, declared to formal as well as informal standards, is limited in time and has a yearly decreasing effect on companies' financial performance.

5.3 Methodology

5.3.1 The Model Setup

In order to test our hypotheses we set up a mathematical model that we can estimate by regression techniques. In particular, we regress a firm's ROA on formal and informal patent declarations, including its squared terms to test for non-linearity, the number of pool membership seats,

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40 In order to get the most recent data on the TCT we calculated it again using the EPO Worldwide Patent Statistical Database (PATSTAT). It can be shown that the TCT ranges between four and five years in ICT sectors, such as computers and communication engineering, as well as in pharmaceuticals. On average, patents declared essential are between four to six years old (as to the application year).

the number of patent filings and patent quality indictors as well as other innovation and financial performance related control variables, i.e. sales per employee, R&D intensity as well as company size. In addition, we include the one year lagged ROA into our model to account for autocorrelation and endogeneity issues, since it can be assumed that the ROA in a given year is influenced by the ROA in the previous year. By doing so, we seek to isolate the causal effects of formal and informal patent declarations on a firm's ROA. Our benchmark model, which is suitable for H1 and H2, can be described as follows:

$$\begin{aligned} ROA = {} & \alpha_1 ROA_{t-1} + \alpha_2 PDC + \alpha_3 PDC^2 + \alpha_4 CDC + \alpha_5 CDC^2 \\ & + \alpha_6 PLS + \alpha_7 PAT + \alpha_8 CIT + \alpha_9 FAM + x'\beta + c + u \end{aligned} \tag{2}$$

where ROA denotes the Return on Assets, PDC and CDC are formal and informal patent declarations, respectively, PLS is the number of pool membership seats, PAT is the total number of patent applications, CIT and FAM are the average number of total forward citations to a company's patent portfolio and the average family size of the respective patent portfolio. Furthermore, x is a vector of control variables, c is a company-specific effect and u idiosyncratic errors. We omitted time subscripts for the sake of simplicity. In our multivariate analysis we estimate several models by including and excluding different control variables. By doing this, we try to capture the influence of companies' varying investments (R&D expenditures), assets (patent applications, employees) or performance (sales).

With respect to H3, we expand our model by including timely lagged effects of the PDC and CDC variables, including the squared terms. The equation looks similar to equation (2), with the extension of the lagged effects of PDC and CDC as well as the lagged squared terms:

$$\begin{aligned} ROA = {} & \alpha_1 ROA_{t-1} + \alpha_2 PDC + \alpha_{2'} PDC_{t-v} + \alpha_3 PDC^2 + \alpha_{3'} (PDC^2)_{t-v} \\ & + \alpha_4 CDC + \alpha_{4'} CDC_{t-v} + \alpha_5 CDC^2 + \alpha_{5'} (CDC^2)_{t-v} \\ & + \alpha_6 PLS + \alpha_7 PAT + \alpha_8 CIT + \alpha_9 FAM \\ & + x'\beta + c + u \end{aligned} \tag{3}$$

where t is a time subscript and v denotes the annual lag for each additional lagged variable in the model for PDC and CDC starting at a value of $v = 0$, ranging from $v = 0, \ldots, n$. We include each of the lagged variables as well as the contemporaneous variable into one model to calculate the yearly influence of informal and formal patent declarations controlling for the influence of the other years' declarations respectively. This way we can model the hypothesized yearly decreasing effect on ROA and are also able to make sure causality runs from patent declarations to the ROA.

5.3.2 Definition of the hypothesized effect on ROA

Equation (2) shows that H1 is defined in terms of the signs associated with the baseline coefficients $\alpha_2,...,\alpha_5$. These measure the impact of formal and informal patent declarations on ROA. H1 predicts that patent declarations have a curvilinear (inverted u-shaped) effect on the ROA. This implies that the coefficients of PDC as well as CDC, α_2 and α_4, must have a positive sign in order to support our hypothesis, whereas at the same time the coefficients of the squared effects of both variables α_3 and α_5 are expected to have a negative sign. H2 postulates that the effect of informal declarations on ROA is higher than the impact of formal declarations. This does not target the signs of the coefficients, but rather indicates that the value of coefficient α_4 has to be higher than the value of coefficient α_2 in order to confirm our H2.

Table 5-1: Summary of the hypotheses

	H1	H2	H3
ROA	$\alpha_2 > 0$ $\alpha_3 < 0$ $\alpha_4 > 0$ $\alpha_5 < 0$	$\alpha_4 > \alpha_2$	$\alpha_2 > \alpha_{2't-1}$ $\alpha_{2't-1} > \alpha_{2't-2}$ $\vdots$ $\alpha_{2't-p} > \alpha_{2't-v}$ *and* *with* $p < v$, $\alpha_4 > \alpha_{4't-1}$ $\alpha_3...\alpha_{3't-v} < 0$ $\alpha_{4't-1} > \alpha_{4't-2}$ *and* $\alpha_5...\alpha_{5't-v} < 0$ $\vdots$ $\alpha_{4't-p} > \alpha_{4't-v}$

Regarding H3, we need to look at Equation (3). We hypothesize that essential patents, formal as well as informal, have a limited, lasting effect on the financial performance of companies in terms of ROA, which decreases over time. This again targets the strength of the coefficients compared to the coefficients of its lagged versions, implying that the contemporaneous effect of the coefficients is larger than the effect with a one, two or three year lag. In order to support H3 for formal patent declarations, α_2 has to be larger than $\alpha_{2't-1}$, $\alpha_{2't-1}$ has to be larger than $\alpha_{2't-2}$, etc. up to $\alpha_{2't-p}$, which has to be larger than $\alpha_{2't-v}$. For informal declarations, the same assumptions hold for α_4. Since we have no theoretical reason to believe that the assumed decrease in the slope of PDC and CDC that we stated in H1, is more or less strongly pronounced with additional time lags, we do not make any further assumptions about the strength of the coefficients in the lagged specifications. However, as in H1, we assume that they have a negative sign meaning that $\alpha_3...\alpha_{3't-v} < 0$ and $\alpha_5...\alpha_{5't-v} < 0$. In addition, as we do not know how long the effect of PDC and CDC on ROA might last, this approach remains exploratory and we will let the empirical model decide up to which time lag significant results can be found. A summary of the formal modeling of our hypotheses is shown in Table 5-1.

5.3.3 Estimation Method

Since the data used for our analysis is in the form of a company-level panel, the econometric specifications have to take account of the peculiarities of this data structure. Our model can be estimated by a fixed effects regression model, i.e. a within estimator, that eliminates the fixed effects by centering each variable on its individual-specific mean, taking into account potentially endogenous individual effects. In order to control for non-constancy in the residual variance of the variables in our regression model, we employ cluster robust standard errors by company, which are heteroscedasticity-consistent (White, 1980).

If models are subject to unobserved heterogeneity, which is correlated with the explanatory variables, simple pooled OLS estimators are asymptotically biased. To account for this problem, linear panel-data models are used in order to eliminate time constant unobserved heterogeneity. To decide between fixed or random-effects, we additionally employed a Hausman-Test, which showed that the random-effects assumption (that explanatory variables are uncorrelated with company-specific effects) is violated. This would lead to systematically biased coefficients as well as standard errors. Therefore, only a fixed-effects estimator results in unbiased estimates. In particular, the linear panel-data model is as follows:

$$y_{it} = x_{it}\beta + c_i + u_{it} \qquad i = 1,\dots,n \qquad t = 1,\dots T$$

where y_{it} is the explained variable of unit i in period t, x_{it} is a vector of explanatory variables, β is a coefficient vector, c_i is a company-specific effect and u_{it} idiosyncratic errors. In order to test the influence of each of the individual explanatory variables on ROA, we calculate several models and add the respective variables gradually.

5.3.4 The Data

The construction of the dataset is based on the DTI-Scoreboard from the year 2001, in which a total of 500 companies were listed. Data on previous and following years were added. If one of the 500 companies was not listed in the DTI-Scoreboard in the years before or after 2001, we treated the respective observations as missing. In the case that mergers or acquisitions between the companies listed in the DTI-Scoreboard occurred in a given year, all data for the respective companies was summarized. Thus, the companies were treated as if they were already merged at the beginning of the observation period.[41]

In a second step, we added the relevant information on patenting behavior to this database. Relevant patent data was extracted from the "EPO Worldwide Patent Statistical Database" (PATSTAT). The annual sum of patent applications filed by each company in a given year at the European Patent Office (EPO) was calculated. The same was done for the patent value indicators, i.e. for patent forward citations and family size. All patent data from the PATSTAT database are dated by their priorities, i.e. the year of world-wide first filing. We believe that our restriction to analyze value indicators of EPO patents only is sufficient, since over 90% of the essential patents are also filed at the EPO. The priority dates of our data also take into account worldwide offices.

To identify the companies listed in the DTI-Scoreboard in PATSTAT, we employed keyword searches. The keywords included not only the company names[42] in different spellings but also the names of the companies' subsidiaries held by the parent company with a direct share of at least 25%. This assures comparability of patent data with the financial data from the companies' balance sheets.

In a next step, we added financial data of the companies – such as total assets or earnings before interest and tax – that are needed to calculate the company's ROA from Standard & Poor's COMPUSTAT Global and COMPUSTAT North America databases.

Then we added information about a patents' inclusion in a standard. In total, we extracted over 65,000 patent declarations by formal SSOs such as ISO, IEC, JTC1 – a joint committee of ISO and IEC, CEN/CENELEC, ITU-T, ITU-R, ETSI, IEEE. In addition, we added patent declarations by informal SSOs such as IETF, TIA, OASIS, OMA, the Broadband Forum and the MSF Forum. All of the listed SSOs provide public databases about patent number, declaration date and company of declaration.[43] To ensure that each company in our final sample is active in standard setting and is thus able to include their patents in a standard, we only included members of the above mentioned SSOs.[44]

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41 We chose this approach to preserve comparability over time, as the separation of the individual company information is no longer possible after a merger (compare Frietsch, 2006).

42 Information about the names of the relevant subsidiaries by company was added from the LexisNexis (lexisnexis.com) and Creditreform Amadeus (creditreform.com) databases.

43 For example www.iso.org/patents or: http://ipr.etsi.org/ or: https://datatracker.ietf.org/ipr/search/

44 We employed membership information from the SSO's web pages. If the membership information was not at hand, we added information of attendee lists of conferences organized by the respective SSOs.

We further added information on a company's participation in a patent pool. This is important to account for specific licensing strategies of firms. As to Layne-Farrar and Lerner (2011) pool participation is not automatic and firms only join pools when it fits to their specific licensing business model. Our data includes all pool memberships since 1999. Patent pool administrators state which standards are affected by the patent pool. In combination to our data on patent declarations we precisely differentiate between companies that license their patents individually and companies that pool their patents. Patenting on standards increased in the late nineties when the licensing of essential patents became a new challenge to standard setting (Simcoe, 2005). Regarding this rather recent development and to ensure data conformity in our sample we limited our observations to the years between 2000 and 2007.

Due to these limitations and the fact that we use an unbalanced panel, in which data for some observations in the respective years may be missing, we calculate our models for 817 observations of 134 companies in total. All further analyses in the study are based on this final sample.

5.3.5 Variables and Summary Statistics

In this section we briefly discuss the variables used in the following regression models. The summary statistics of these variables are presented in Table 5-2. Following the theoretical discussion from Section 5.2.3, we use the ROA as a measure of a firm's financial performance, which is also added as an explanatory variable with a lagged specification in our models to minimize autocorrelation and account for endogeneity issues.

The number of formal and informal patent declarations per year (both in thousands), as well as the respective squared terms, are our main explanatory variables. A patent declaration is a statement by a company to own patents that are essential to a standard. This statement is not mandatory and in some cases made after a standard has already been released. In most cases the issue of essentiality is not tested by objective authorities (only in the case of a patent pool). However, research on evolutionary technology development (Bekkers et al., 2011; Bekkers and Martinelli, 2012) as well as research on patent filing (Berger et al., 2012) or patent value (Rysman and Simcoe, 2008) have proven that data on patent declaration is a valuable indicator for a patent's essentiality. One patent can be declared to be essential to several standards. The number of patent declarations is therefore by far higher than the number of essential patents.

We further add data on patent pool memberships. In patent pools IPR owners pool their patents to agree on a single license. Patents in patent pools have to pass a test of essentiality concerning a standardized technology. Since license agreements as well as patent declaration behavior change when companies enter a patent pool (Simcoe, 2007), we matched the membership data of 54 patent pools to the companies of our sample. Companies may be a member of more than one pool depending on the standardized technology. Our patent pool variable differentiates the company of observation into pool member and pool outsider.

The number of patent applications at the EPO (in thousands) is a count of a company's issued patents per year. The average number of forward citations is calculated as the number of forward citations in a four year time window divided by the number of applications with forward citations (also in a 4 year time window). The time window assures that all patents have the same amount of time to be cited. The average family size is the average number of distinct patent offices where a company's patents were filed.

Table 5-2: Summary statistics of sample variables

Variable	Mean	Std. Dev.	Min	Max	# Obs.	# Firms
ROA	0.068	0.081	-0.520	0.387	817	134
# patent declarations (in thousands)	0.048	0.513	0.000	11.413	817	134
# consortia declarations (in thousands)	0.001	0.005	0.000	0.065	817	134
# pool licensor seats (in thousands)	0.001	0.002	0.000	0.018	817	134
# patent applications (in thousands)	0.224	0.373	0.001	3.084	817	134
R&D (in m)/sales (in m)	0.074	0.065	0.002	0.708	817	134
Sales (in m)/employees	0.189	0.108	0.042	0.974	817	134
# employees (in thousands)	78.912	88.616	1.030	484.000	817	134
Avg. # FW-Citations	2.391	1.223	1.000	14.861	817	134
Avg. Family Size	5.179	1.671	2.000	14.000	817	134

Note: *The summary statistics are only reported for the number of cases that are used in the multivariate regressions.*

With respect to potentially confounding firm characteristics, we include further control variables. We include the number of employees (in thousands) to control for size effects. The share of sales (in millions) by employee is introduced as a proxy of how efficiently a firm generates sales. In addition, we use R&D intensity (R&D expenditures (in millions) divided by sales (in millions)) in our models, which can be regarded as a proxy of how well a firm converts results of R&D processes into revenues. R&D intensity is supposed to affect firm profitability, especially in our sample of relatively large, R&D performing firms. Finally, we use time dummies to account for confounding level effects that occur over our panel period.

5.4 Empirical Results

5.4.1 Bivariate Analyses

As a first step to assess the influence of formal and informal patent declarations on a company's financial performance in terms of ROA, we run a pair wise correlation analysis, which allows us to assess correlations among variables of our sample. As hypothesized, we find no significant linear correlation between the ROA and formal and informal patent declarations. Furthermore, no significant correlation of a company's patent applications with the ROA can be observed, whereas the patent value indicators and ROA correlate. A significantly positive correlation between the average family size and the ROA can be observed, yet the average number of forward citations shows a rather small, but significantly negative correlation with ROA. The number of employees is also negatively connected to ROA, implying that smaller companies in terms of the number of employees have a lower ROA compared to larger ones. Also our R&D intensity measure is negatively correlated to ROA. This could be interpreted insofar, as R&D expenditures first of all are a significant cost factor and therefore have a negative influence on ROA. The sales per employees measure on the other hand shows a significant positive correlation with financial performance.

Table 5-3: Pair-wise correlation matrix of sample variables

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1 ROA	1								
2 # formal declarations	0.05	1							
3 # informal declarations	0.05	0.21***	1						
4 # pool licensor seats	-0.01	0.02	0.03	1					
5 # patent applications	-0.03	0.11***	0.09***	0.41***	1				
6 R&D/sales	-0.15***	0.10***	0.24***	-0.07*	0.05	1			
7 Sales/ Employees	0.09**	0.06*	0.14***	-0.01	-0.04	0.01	1		
8 # employees	-0.06*	0.00	-0.01	0.27***	0.53***	-0.25***	-0.09***	1	
9 Avg. # FW-Citations	-0.06*	-0.01	0.00	-0.12***	0.01	0.04	0.02	-0.07**	1
10 Avg. family size	0.13***	0.04	-0.03	-0.09**	-0.04	-0.03	-0.01	-0.10***	0.35***

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*
***Note**: The correlation analysis is based on the number of cases that are used in the multivariate regressions.*

In order to extend the analysis of our bivariate effects and to model the hypothesized curvilinear effect of patent declarations on ROA, we need to conduct a multivariate analysis to obtain conclusive results.

5.4.2 Multivariate Analyses

The results of our first multivariate analysis are presented in Table 5-4. As stated in Section 5.3.3, we estimated several models and added the respective variables gradually up to our final model that corresponds to Equation (2).

In all our models (M1-M6) we are able to show that patent declarations in formal and informal SSOs, ceteris paribus, have a curvilinear relationship (inverted U-shape) with a firm's ROA. Therefore, we are able to confirm our first hypothesis H1: Companies' patent declarations significantly increase their ROA up to a certain point. We further confirm that there is a maximum in this relation, which is modeled by the negative squared effects of formal and informal declarations. From this maximum point onwards, the incremental effect of declaring patents on ROA becomes negative. These results support the assumption of an over-declaration effect, where declaring a too high number of standard essential patents decreases firm performance.

Our empirical findings further confirm our second hypothesis H2. The incremental impact of declaring essential patents related to informal standards has a stronger effect on companies' financial performance compared to patent declarations on formal standards. Companies are able to choose to participate in different SSOs depending on the strength of their technology and assumptions of technology returns (Lerner and Tirole, 2006). We argue that the return on essential patents is higher for standards released by informal SSOs. Our results indicate that a company with strong technology assets rather declares its patents to informal SSOs.

The effects of our explanatory variables also hold when adding the number of pool licensor seats of a company as a control variable to our models. Compared to other patent owning firms, a firm that is a member of a patent pool does not individually license its patents. Patent pool memberships indicate a certain licensing strategy of a firm (Layne-Farrar and Lerner, 2011). However, our results show that different licensing strategies do not influence a firm's financial performance. Goals to include patents into standards are not necessarily connected to revenues from licensing.[45] Furthermore firms' licensing strategies are also subject to different IP policies of SSOs. Our differentiation into formal and informal patent declarations might thus already capture the licensing effect. Similar assumptions can be derived for the rest of our control variables, which are added in M5 and M6. When controlling for size effects, increased R&D intensity, patent applications and the value of the patent portfolio, our results remain consistently significant. However, it can be shown that the firm-specific as well as the innovation related indicators strongly increase the R^2 of the models, implying that the chosen indicators also affect firm performance. The statistical tests show that R&D intensity (R&D expenditures/sales) has a

45 Shapiro and Variant (1999) describe the case of the HDTV standard, where Zenith spend enormous effort to get their technology and patents in the standard even though cross-licensing agreement were already fixed before.

significant negative influence on ROA. This negative effect, can be explained by the characteristics of our variable. R&D investments are costs which might pay off several years later. For example, a company invests in new innovative processes or technologies. Yet, it is unsure whether or not these investments are successful and contribute to a company's performance. Therefore, at least from a short-term point of view, R&D investments are first of all costs which consequently have a negative effect on the ROA.

Our variable of labor productivity (sales by employees) does not show any significant results in M5 and M6. The same holds for the number of patent applications, for which we also do not find any significant effects. This result points once more to the fact that it is not sufficient to account for a company's technological performance by solely measuring the number of patent filings. We therefore include patent value indicators in our final model (M6). However, in our estimation the patent family size has no effect on ROA and the number of forward citations even shows a negative effect on our explained variable, although this effect is rather small. There has been evidence in the literature stating that patents, which are essential to a standard have a higher number of forward citations (Rysman and Simcoe 2008; Layne-Farrar and Padilla, 2011). We thus believe that the patent value effects are captured by our main explanatory variables: formal and informal patent declarations.

Table 5-4: Results of the fixed-effects panel regression models

dV: ROA	**M1**			**M2**			**M3**			**M4**			**M5**			**M6**		
	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.
L1.ROA	0.322	***	0.061	0.327	***	0.061	0.326	***	0.061	0.325	***	0.061	0.216	***	0.071	0.216	***	0.071
# patent declarations	0.013	*	0.008				0.014	**	0.006	0.014	**	0.007	0.022	***	0.007	0.023	***	0.008
# patent declarations sq[1]	-0.001		0.001				-0.001	*	0.001	-0.001	*	0.001	-0.002	***	0.001	-0.002	***	0.001
# consortia declarations				2.355	*	1.343	2.360	*	1.334	2.253		1.366	2.816	**	1.178	2.663	**	1.110
# consortia declarations sq				-0.052	**	0.021	-0.053	**	0.020	-0.051	**	0.020	-0.056	***	0.019	-0.052	***	0.018
# pool licensor seats										1.251		1.744	-0.320		1.891	-0.415		1.979
# patent applications[1]													1.617		13.195	-0.420		13.617
R&D/sales													-0.610	***	0.095	-0.614	***	0.094
Sales/employees													0.106		0.074	0.109		0.072
# employees[1]													-0.043		0.186	-0.034		0.182
Avg. # FW-Citations																-0.005	**	0.002
Avg. Family Size																0.002		0.002
Constant	0.054	***	0.008	0.052	***	0.008	0.052	***	0.008	0.051	***	0.008	0.093	***	0.032	0.088	***	0.031
Time Dummies	YES			YES			YES			YES			YES			YES		
Number of companies	134			134			134			134			134			134		
Observations	817			817			817			817			817			817		
R^2 within	0.259			0.262			0.263			0.263			0.357			0.363		
F	13.667			14.436			12.404			11.888			12.604			12.135		

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*

Note: [1] Coefficient multiplied by 1,000 to make effects visible. L1. means that the variable is lagged by one year. The number of observations in each model was adjusted to the model with the fewest observations (M6) in order to conserve comparability of the effects over all models.

In our theoretical section we have also argued that owning essential patents may enable a company to control markets. Thus, we expect the consequence of patent declarations to also have a timely lasting effect on the financial performance of firms, which has been shown for several other innovation related indicators in the literature (Bloom, Van Reenen, 2002; Ernst, 2001; Griliches, 1990). However, we assume that this effect would decrease over time, since ICT markets in particular are subject to short product lifecycles (Narin, 1993). Consequently, we stated in our H3 that essential patents declared in formal as well as informal standards have a limited lasting and yearly decreasing effect on companies' financial performance. The formal modeling can be found in Equation (3).

In M6-1 we add the lagged number of formal and informal patent declarations as well as squared effects to the model (Table 5-5) [46]. By doing so, we regard the yearly effects of patent declarations. From a four year time lag onwards we find no more significant effects of our explanatory variables on ROA, which is why we added the variables in their lagged specifications only up to four years.

Our results still show that the hypothesized curvilinear effect of patent declarations in formal and informal SSOs on ROA holds. Results up to a significance level of 5% remain robust up to a time lag of one year for both SSO types. However, in the dynamic comparison we can observe that the coefficient decreases in the case of formal SSOs and increases in the case of informal SSOs up to a lag of one year. Therefore, we can only partly confirm our H3.

The hypothesized lasting, timely decreasing effect can only be observed for formal declarations, while it is increasing in the case of informal declarations at least in the one year time lag. This effect might occur because declarations related to formal standards generally occur at a later point in time than declarations linked to informal standards. On average, declared patents to standards released by formal SSOs are older (in average 6 years from the priority year) than patent declarations to standards published by informal SSOs (on average 4 years from the priority year). These dynamic differences are connected to different standardization processes, because informal SSOs are expected to standardize technology in earlier stages (Cargill, 2011). Patents might thus still increase in their value while the technology is yet emerging. Our results provide indications of such an effect related to the influence on financial returns. In the case of declarations to formal standards, the effect becomes insignificant from a two years time lag onwards (although the squared effect is still significant in the two year lag specification).

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46 We are aware of the fact that models including several lagged versions of one variable might become instable and therefore difficult to interpret due to multicollinearity issues. Although this approach remains exploratory, we believe that the chosen specification including the lagged versions of the PDC and CDC variables - up to the time lag where the variables become insignificant - serves as an indication of the lasting effect of patent declarations on ROA.

In the case of declarations in informal SSOs, the effect becomes insignificant in a two years lag, but again appears in the three years lag specification. At first sight, this is a puzzling result. However, the timing of patent declaration is often very volatile and can also be subject to policy shocks in the different SSOs.

Table 5-5: Results of the fixed-effects panel regression models with lagged explanatory variables

dV: ROA	**M6-1**		
	Coef.		S.E.
L1.ROA	0.200	***	0.075
# patent declarations			
L0	0.032	**	0.015
L1	0.027	**	0.012
L2	-0.004		0.009
L3	-0.023		0.014
L4	-0.041		0.029
# patent declarations sq			
L0[1]	-0.003	*	0.001
L1[1]	-0.002	*	0.001
L2[1]	0.001		0.001
L3[1]	0.002	**	0.001
L4[1]	0.004		0.003
# consortia declarations			
L0	1.882	***	0.655
L1	3.170	**	1.275
L2	4.384		3.268
L3	3.140	*	1.805
L4	-0.656		1.100
# consortia declarations sq			
L0	-0.047	***	0.014
L1	-0.078	***	0.026
L2	-0.095		0.058
L3	-0.060	*	0.034
L4	0.022		0.017
# pool licensor seats	-1.974		1.916
# patent applications	-0.013		0.015
R&D/sales	-0.595	***	0.092
Sales/employees	0.125	*	0.067
# employees[1]	0.017		0.162
Avg. # FW-Citations	-0.004	*	0.002
Avg. Family Size	0.003		0.003
Constant	0.081	***	0.028
Time Dummies	YES		
Number of companies	134		
Observations	817		
R^2 within	0.397		
F	3272.027		

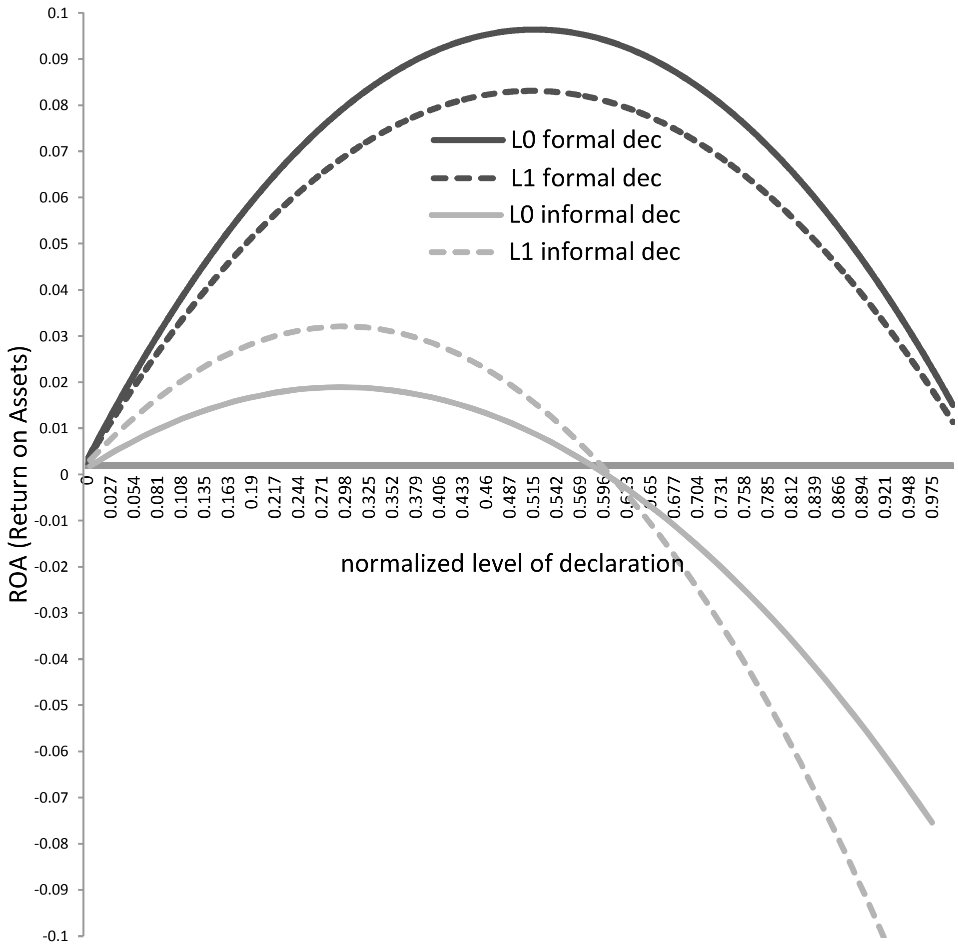
Note: *[1] Coefficient multiplied by 1,000 to make effects visible. L. stands for the lagged versions of the variables. L0 is the contemporaneous effect, L1 means that the variable is lagged by one year etc. Significance Level: ***p<0.01, **p<0.05, *p<0.*

Our multivariate results support our predictions related to the effect of essential patents and illustrate a curvilinear correlation with a firm's ROA. However, our analysis has not yet provided specific information on an optimal level of declaration. We therefore multiply the coefficients of our last model (M6-1) with patent declarations to formal and informal SSOs and plot the distribution over the normalized number of total declarations per firm. We graph the normalized number of total declarations and compare the optimal level of declaring to either a formal or informal SSO. Our empirical models have shown that the incremental effect of one declaration is higher for informal SSOs compared to formal SSOs. However, graph 1 illustrates that the optimal level of patent declaration is higher for formal SSOs, meaning that firms are able to introduce a higher number of patents to formal standards until the incremental effect on ROA turns negative. While the optimal level of patent declarations to formal SSOs has a lower level after a lag of one year, it is reversed in the case of informal SSOs. For both cases the correlation of patents and ROA shows a comparable distribution for lagged periods. While in the case of formal SSOs the effect of patents on ROA decreases, but stays positive after the optimum, patents introduced to informal standards may also have a negative effect beyond the optimum.

The analysis of an optimal level of patent declarations should be interpreted cautiously, indicating a general tendency rather than precise effects and benchmarks. Firms participate in very specialized standard working groups, where they work on technical problems that may differ strongly among SSOs. Since we plot aggregated results of our sample of companies, Figure 5-1 especially illustrates different effects depending on the SSOs and the level of patenting.

The reason why formal standardization allows a higher number of patented contributions in general (Blind et al, 2011) and a higher optimal level in our estimation, can be explained by the different technological specialization of SSOs. Informal SSOs mostly concentrate on IT standardization, while formal SSOs specialize in telecommunication technologies. Standards in the field of telecommunication (e.g. GSM, UMTS, WiFi, etc.) are subject to very complex technologies that are often standardized on a specific physical layer. These standards have to be very precise in e.g. specifying protocols for communication (Bekkers et al., 2001). In comparison, IT standards are rather focused on application layers and standardized solutions are rather generic. Our estimation results confirm these differences. Essential patents introduced to standards set by informal SSOs have a stronger incremental effect on a firm's ROA. This would confirm that informal standards concern a broader field of technology. In comparison, rather specify formal telecommunication standards allow a higher number of patents (reflected by the higher optimal level), while the incremental effect of each patent is lower.

Figure 5-1: Coefficients of M6 multiplied by the normalized number of formal and informal declarations



5.4.3 Robustness Checks

We perform additional robustness checks to test if our results remain robust over different model specifications. All of the robustness checks are performed on the basis of the final model specification (M6), not including the lagged specifications of the explanatory variables.

Our first concern regarding our model is that the dependent variable ROA does not hold the normality assumption. To stabilize the variance of our dependent variable we perform a z-standardization, a log-transformation as well as a Cox-transformation of the ROA variable and re-ran our model with each of the transformed variables. All three models with standardized dependent variables show similar effects of the explanatory variables. Coefficients for formal and informal declarations and the squared terms show slightly smaller values when the Cox-standardized ROA was used. Yet, the coefficients did not change signs and remain significant at the 5% level in the case of formal declarations. The number of consortia declarations, however, is only significant at the 10% level and the squared number of consortia declarations loses significance. In the case of the z-standardized ROA variable, the strength of the effects even increases and all coefficients show the same significance levels as in the original specification. For the log-transformed ROA, the coefficients become a little stronger, but slightly less significant than in the original model. However, the coefficients remain significant at the 5% level. Turning the argument the other way around, we also z-standardized and log-transformed the declaration variables and used them as explanatory variables in our models. As for the z-standardized explanatory variables, the values of the coefficients for formal and informal declarations become smaller but remain significant. As for the log-transformed explanatory variables, we find increasing values of the coefficients for each of the variables and also a slight decrease in significance. Yet, all variables remain significant at least at the 10% level.

Table 5-6: Coefficients of the explanatory variables for the modified models

	# patent declarations	# patent declarations sq[1]	# consortia declarations	# consortia declarations sq
dV: ROA (Original Model (M6))	0.023***	-0.002***	2.663**	-0.052***
dV: Cox-transformed ROA[2]	0.012**	-0.001**	3.392*	-0.076
dV: z-standardized ROA	0.259***	-0.022***	29.924**	-0.586***
dV: Log-transformed ROA	0.026**	-0.002**	2.495**	-0.044**
dV: ROA, z-standardized declaration variables	0.004***	-0.049***	0.004**	-0.0001***
dV: ROA, Log-transformed declaration variables	0.070**	-24.153*	2.746**	-53.662***
dV: ROA, EBITDA instead of EBIT used for ROA calculation	0.017**	-0.001*	1.665	-0.04**
dV: ROIC	0.036**	-0.003**	3.928**	-0.072**
dV: EBIT as a share of sales[2]	0.072***	-0.006***	5.542**	-0.09*
dV: ROA, Lagged control variables[2]	0.022***	-0.002**	2.721**	-0.054***
dV: ROA, Declarations as shares on all patent applications	0.006**	-0.173**	0.106	-0.05

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*
Note: *[1] Coefficient multiplied by 1,000 to make effects visible. [2] These measures could only be calculated with a reduced number of cases due to the construction of the dependent variable or the lagged specifications. Only the coefficients for the relevant explanatory variables are shown. The full results of the models can be consulted in the appendix.*

A second approach to testing the robustness of our results is to replace our explained variable ROA by different, yet similar, dependent variables that account for a firm's financial performance. In a first step, we replaced the earnings before interest and tax in the ROA calculation by earnings before interest, taxes, depreciation and amortization (EBITDA). With the help of this specification, we are able to test if potential effects of amortization or depreciation, which are implicitly represented in our original ROA specification, are responsible for the effects we find for formal and informal patent declarations. Second, we built a variable for the return on invested capital (ROIC), which is calculated as the share of earnings before interest and tax divided by the invested capital of a company in a given year, and used this as a dependent variable in our model. Third, we calculated earnings before interest and tax divided by sales, which is closely related to the net margin of a firm per year. As we can see in Table 5-6, the signs of the coefficients do not change in all of the three models and the values of the coefficients are higher than in the original model. Yet, the significance level drops slightly, but not below the 10% level. An exception is the ROA specification with EBITDA, where the values of the coefficients are slightly smaller than in the original model and the consortia declarations variable loses significance (p=0.117).

In a third approach, we specify the patent related control variables in the model – namely the number of patent applications, the average number of forward citations and the average family size – with a one year lag to account for a possible timely delayed effect on ROA, which might mitigate the results found for our main explanatory variables. However, this is not the case. The coefficients remain robust and significant at least at the 5% level.

Finally, in order to balance our declaration variables to the size of the patent portfolio of a company, we calculate the share of formal as well as informal patent declarations to all patent applications of a company (as well as squared effects) and replace them with our original explanatory variables. As to the results in table 5-6, the coefficients still have the same signs, but informal declarations do no longer show a significant effect. However, one has to keep in mind that the specification of this share is rather vague, since the timing of patenting and declaring a patent to SSOs might strongly differ.

All in all, we conclude that our model seems to deliver robust results over several different specifications, ranging from the standardization and transformation of the dependent and independent variables to changes in the dependent variable as well as changes in the timing of the control variables.

5.5 Discussion of the Results

Our results provide evidence that the financial performance of companies active in technology markets is not only connected to their innovative capabilities and resources, but further depends on the strategic management of their patent portfolio. Most companies own big patent portfolios to protect their innovations and to block competitors. We show that firms should strategically position their patent portfolios on standard platforms as well as on complementary applications in order to generate optimal financial returns.

This article assesses firms' patent portfolios on count and value measures and tests the effect of a patent declaration to a standard on a company's ROA. Our first hypothesis (H1) suggests a curvilinear relationship between the declaration of essential patents and firm performance. Indeed, empirical tests show that the declaration of patents has a positive influence on a firm's performance up to an optimal level and then decreases. From a manager's perspective it is important to influence technological development in SSOs and to control standardized platform with patented components. However, in standard setting firms have to cooperate with competitors (Leiponen, 2008) and share their innovative knowledge with rival market participants. A firm's individual knowledge may thus become collective knowledge and firms risk losing their differentiation advances (Aggarval et al., 2011). Our findings of a curvilinear relationship of patent declarations and financial returns support this argument and suggest that companies should diversify their patent portfolios. On the one hand, firms need to declare a share of patents to SSOs to freely operate and control standardized technology platforms. On the other hand, firms also have to maintain competitive advantage by patenting their platform constructive innovations outside standard setting. The curvilinear relationship of essential patent declarations illustrates this balancing of a firm's patent portfolio, which only has a positive influence on firm performance up to an optimal level and then decreases.

The results of our estimations also provide evidence to confirm our second hypothesis (H2) suggesting the positive incremental effect of a patent declaration to be stronger for informal SSOs compared to formal SSOs. Standard setting allows firms to freely choose their preferred forum for standardization. Firms would thus always select SSOs where technology contributions generate the highest returns (Lerner and Tirole, 2006). Formal SSOs cap royalties of essential patents by demanding F/RAND commitments of participating firms. We predict that patent declarations to informal SSOs might thus generate higher royalties. Furthermore, formal SSOs are open to all stakeholders and seek consensus decisions when selecting technology proposals. Firms may find it less risky to share their valuable contributions in a more exclusive, informal forum. Our estimations confirm a stronger incremental effect of patent declarations to informal SSOs; however, a more precise analysis indicates a higher optimal level of patent declarations for formal SSOs. We argue that this is due to the differing specialization in technology between formal and informal SSOs. Our results suggest that firms carefully choose which SSOs to join, depending on their individual portfolio of technologies. Even though declaring a patent to informal SSOs generates more returns, our results show that patent declaration will decrease a firm's performance at a lower level. Additionally, we only find a possible negative effect of too many patent declarations when declared to informal SSOs. This is different for formal SSOs where the positive incremental effect is weaker, but the optimal level of declaration is higher. Companies with a small but very valuable patent portfolio might thus prefer informal SSOs, while companies with a large portfolio but rather incremental patents would prefer formal SSOs. These results suggest that a firm's patenting decision in the context of standardization should also consider choosing the appropriate standard forum in order to generate higher financial returns.

In our last hypothesis (H3) we predicted that patent declarations also have a lasting effect on a firm's financial performance. Our estimations provide evidence that a company's current and also near future financial performance is connected to patent declarations up to a time lag of one year. We further predicted a decreasing effect, which can only be empirically confirmed in the case of formal SSOs. The effect of patent declarations to informal SSOs even increases in a lag of one year. Again, this suggests that firms with valuable patents may find it more beneficial to declare their patents to informal SSOs. However, the lagged negative effect of over-declaration is also stronger for informal SSOs.

Although prior research has provided evidence for the effects firms' patent portfolios on performance measures as well as effects of firms joining standard setting or contributing to standard setting, this study is the first to acknowledge the case of patents in standardization. We illustrate optimal levels of patent declaration and further show that these levels change among standard settings SSOs. In particular we aggregate SSOs to formal and informal fora and identify different effects for patents. Depending on a firm's patent portfolio in terms of quality and quantity, we are able to indicating which share of patents is financially beneficial to be introduced to which SSOs. Furthermore, we are able to predict future benefits from declaring essential patents.

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Appendix – Robustness Checks

Table A1: Coefficients of the explanatory variables for the modified models (part 1)

	dV: ROA (Original Model (M6))			*dV: Cox-transformed ROA*[2]			dV: z-standardized ROA			dV: Log-transformed ROA			*dV: ROA*, z-standardized declaration variables			*dV: ROA*, Log-transformed declaration variables		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
L1.dependent variable	0.216	***	0.071	0.199	***	0.056	0.216	***	0.071	0.127		0.082	0.216	***	0.071	0.215	***	0.071
# patent declarations	0.023	***	0.008	0.012	**	0.005	0.259	***	0.090	0.026	**	0.010	0.004	***	0.001	0.070	**	0.030
# patent declarations sq[1]	-0.002	***	0.001	-0.001	**	0.000	-0.022	***	0.008	-0.002	**	0.001	-0.049	***	0.019	-24.153	*	13.234
# consortia declarations	2.663	**	1.110	3.392	*	1.870	29.924	**	12.470	2.495	**	1.059	0.004	**	0.002	2.746	**	1.120
# consortia declarations sq	-0.052	***	0.018	-0.076		0.052	-0.586	***	0.206	-0.044	**	0.021	0.000	***	0.000	-53.662	***	20.010
# pool licensor seats	-0.415		1.979	-0.388		1.415	-4.665		22.234	-0.675		2.103	-0.415		1.979	-0.528		1.886
# patent applications[1]	-0.420		13.617	-4.186		11.534	-4.724		153.002	0.256		14.225	-0.420		13.617	-1.679		13.687
R&D/sales	-0.614	***	0.094	-0.370	***	0.081	-6.899	`***	1.059	-0.712	***	0.093	-0.614	***	0.094	-0.615	***	0.095
Sales/employees	0.109		0.072	0.081		0.066	1.226		0.804	0.093		0.075	0.109		0.072	0.112		0.071
# employees[1]	-0.034		0.182	-0.099		0.157	-0.377		2.049	-0.039		0.200	-0.034		0.182	-0.025		0.177
Avg. # FW-Citations	-0.005	**	0.002	0.001		0.003	-0.054	**	0.026	-0.005	*	0.003	-0.005	**	0.002	-0.005	**	0.002
Avg. Family Size	0.002		0.002	0.001		0.002	0.027		0.027	0.003		0.003	0.002		0.002	0.002		0.002
Constant	0.088	***	0.031	-0.299	***	0.036	0.272		0.349	0.101	***	0.035	0.089	***	0.031	0.087	***	0.031
Time Dummies	YES			YES			YES			YES			YES			YES		
Number of companies	134			665			134			134			134			134		
Observations	817			125			817			817			817			817		
R² within	0.363			0.368			0.363			0.311			0.363			0.364		
F	12.135			9.410			12.140			10.850			12.140			12.040		

Table A1 (continued): Coefficients of the explanatory variables for the modified models (part 2)

	***dV: ROA*, EBITDA instead of EBIT used for ROA calculation**		***dV: ROIC***		***dV: EBIT as a share of sales*[2]**		***dV: ROA*, Lagged control variables[2]**		***dV: ROA*, Declarations as shares on all patent applications**	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
L1.dependent variable	0.246 ***	0.064	0.124	0.104	-0.251	0.237	0.225 ***	0.074	0.208 ***	0.073
# patent declarations	0.017 **	0.008	0.036 **	0.016	0.072 ***	0.020	0.022 ***	0.008	0.006 **	0.003
# patent declarations sq[1]	-0.001 *	0.001	-0.003 **	0.002	-0.006 ***	0.002	-0.002 **	0.001	-0.173 **	0.087
# consortia declarations	1.665	1.056	3.928 **	1.833	5.542 **	2.404	2.721 **	1.173	0.106	0.130
# consortia declarations sq	-0.040 **	0.016	-0.072 **	0.036	-0.090 *	0.049	-0.054 ***	0.019	-0.050	0.105
# pool licensor seats	-0.138	2.186	3.144	4.142	-5.126	4.307	-0.463	1.890	0.110	2.026
# patent applications[1]	6.133	13.806	18.067	26.557	40.519 *	24.289	-1.398	17.436	4.445	12.462
R&D/sales	-0.565 ***	0.086	-0.875 ***	0.190	-2.685 ***	0.603	-0.605 ***	0.093	-0.620 ***	0.098
Sales/employees	0.140 **	0.065	0.195	0.135	0.032	0.221	0.095	0.077	0.116 *	0.068
# employees[1]	0.121	0.153	-0.130	0.347	-0.053	0.392	-0.054	0.185	-0.043	0.176
Avg. # FW-Citations	-0.005 **	0.002	-0.008 **	0.004	-0.003	0.004	-0.002	0.002	-0.005 **	0.002
Avg. Family Size	0.002	0.002	0.005	0.004	-0.005	0.004	0.000	0.002	0.003	0.002
Constant	0.098 ***	0.026	0.156 ***	0.056	0.369 ***	0.090	0.104 ***	0.033	0.086 ***	0.030
Time Dummies	YES		YES		YES		YES		YES	
Number of companies	134		134		131		131		134	
Observations	817		817		782		796		817	
R^2 within	0.361		0.250		0.438		0.364		0.365	
F	9.940		11.220		6.090		13.190		46.890	

Significance Level: ***p<0.01, **p<0.05, *p<0.1

Note: [1] Coefficient multiplied by 1,000 to make effects visible. [2] These measures could only be calculated with a reduced number of cases due to the construction of the dependent variable or the lagged specifications of the explanatory variables. L1.dependent variable means that the respective dependent variable was used as a lagged explanatory variable in the models.