Three Essays on the Economics and Design of Patent Systems

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Ilja Rudyk

Referent:	Prof. Dietmar Harhoff, Ph.D.
Korreferent:	Prof. Tobias Kretschmer, Ph.D.
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Introduction

The foundation for modern patent systems was laid in the *Statute of Monopolies* passed in 1623-24 by the British Parliament, where for the first time it was explicitly stated that a monopoly patent could only be granted to the "first and true inventor". The model was then adopted by British colonies. South Carolina was the first to enact a general patent law in 1691. In the course of the next 200 years patent legislation was adopted in most European countries, the United States of America and Japan. In 1883 the patent system was internationalized through the signing of the Paris Convention for the Protection of Industrial Property and in the course of the years became a standard in all industrialized countries. Presently, the convention has more than 170 contracting member states.

The purpose of a modern patent system is to balance static with dynamic efficiency such as to foster technological innovation, which in turn should drive economic growth and development. According to the traditional view, a patent confers a right to exclude others from making commercial use of an invention for a limited period of time, which allows its proprietor to build up temporary market power and extract rents. This creates static inefficiency. In the long run, however, the benefits to society from the inventions should outweigh the costs of the incentive given to the inventors contributing to dynamic efficiency. Already Adam Smith (1776) noted that monopoly is necessarily hurtful to society, but a temporary monopoly granted to an inventor may be a good way of rewarding his risk and expense.[1] Besides, patents should elicit the disclosure of inventions and serve to disseminate technological information.

However, the nature of inventions, and so the role of patent protection has changed over time. Traditionally, a patent has been assumed to protect one single product, thus creating monopoly power in a single market. Scotchmer (1991) was the first economist to recognize that innovation is often sequential. This means that inventions build on one another. If the first inventor receives strong patent protection, the incentives for follow-on invention may be considerably hampered. A patent system that grants an unconditional exclusion right may prevent future inventions from being developed, thus jeopardizing

[1]See Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), book IV, chapter VII, part III.

possible welfare benefits.

Moreover, there is an increase in patenting activity in complex technologies, such as electronics or semiconductors, where products consist of several different technologies which are protected by even more patents. In such an environment it becomes crucial for firms to acquire and maintain a "critical patent mass" to secure their freedom to operate and to be able to take actions against competitors. This in turn creates a so-called patent thicket, a dense web of overlapping patent rights, and forces companies to file even more patent applications. Hall (2005) reported that the number of US patent applications as well as granted patents has increased substantially after patent protection has been strengthened in the 1980s. The growth in patent filings was mostly concentrated in complex technologies and significantly outpaced the growth in R&D expenditures in these industries. Harhoff (2004) reported the same development in the European patent system. Excessive patenting out of defensive and strategic reasons incurs additional costs not only for patent holders, but also for the patent system itself. The flood of patent applications has put a strain on the patent offices, undermining their ability to secure the quality of patents. Patents of low quality, i.e., of uncertain validity and uncertain breadth, may not only cause patent owners and potential competitors to underinvest in the technology, but may also necessitate wasteful litigation. Companies have to spend resources to invalidate patents which should have never been granted. These distortionary effects have certainly a negative impact on welfare.

Economists have long ago started to recognize that the design of the patent system crucially determines the balance between static and dynamic efficiency. The classic economic literature, starting with articles by Nordhaus (1969, 1972), has focused on the optimal patent length, the optimal patent breadth or strength, and their interplay. The still ongoing discussion has produced a voluminous theoretical literature with often ambiguous results.[2] Only during the last decade, researchers increasingly began to realize that other patent design aspects, which have largely been perceived as secondary in the past, can have first-order effects on innovation incentives and welfare.[3] For example, the fees charged by the patent offices can be an important policy tool. In most patent systems patent owners have to pay renewal fees to maintain patent protection. Scotchmer (1999) and Cornelli and Schankerman (1999) were the first to show that such a renewal system is equivalent to a direct revelation mechanism and can provide optimal incentives under certain conditions. If post-grant renewal fees are increasing with patent age, higher value inventions–or high R&D-productivity firms–will receive long-lived patents. In contrast, low-value inventions–or low R&D-productivity firms–will receive short-lived patents and the exclusion right will be removed early. Empirical studies have confirmed that the post-

[2]See Rocket (2010) for an overview.
[3]See Hall and Harhoff (2012) for a recent survey on this topic.

grant renewal fees have an impact on the maintenance rates and have shown that other fees charged by the patent offices, e.g., application fees, examination fees, validation fees, etc., significantly determine patent applicants' behavior.[4] Harhoff and Graham (2010) analyzed the role of an administrative post-grant patent review in ensuring the quality of patents. A post-grant review provides third parties with the opportunity to challenge the patent office's granting decision before the patent issues. This allows for a cost effective dispute resolution alternative to patent litigation. Other studies have identified the government structure in patent offices as an important patent system design parameter. Whether a patent office is self-funding or relies on subsidies from the government (Gans et al. 2004) is just as important as the incentive structure of patent examiners. Whether the compensation scheme favors patent grants or grant refusals, can have important implications for the grant rate (Friebel et al. 2006), and thus welfare. Nevertheless, many institutional aspects of patent systems have not received much attention so far. This thesis is aimed to fill this gap. In particular, we analyze two institutional choices which are offered by many patent offices: the license of right and the deferred patent examination.

Canada, in 1903, followed by the British legislator, in 1919, was the first to provide a patent proprietor with the possibility to offer any third party the opportunity to have a license under the patent, on reasonable terms. In return, the annuity fees required to maintain patent protection were reduced considerably. This system was called "License of Right" (LOR). Germany introduced the license of right in 1936. The purpose of the provision, on the one hand, was to provide the "indigent inventor" with the opportunity to keep patent protection long enough to be able to commercialize it. On the other hand, it should serve the general public, since it grants access to the invention still protected by a patent.

In Chapter 1 we use microdata on patent applications with effect in Germany going back to 1983 to provide, to our knowledge for the first time, evidence on the use of the license of right. In the year 2008 license of right has been declared for more than 4,500 German patent applications, or stated in a different way, almost 6% of all German patents are endorsed LOR at expiration. On average, LOR is declared 8.5 years after the application date for patents granted by the German patent office (DPMA) and 10.5 years after the application date for patents granted by the European patent office (EPO). Usually, patents with LOR are kept for additional 6 years outliving patents without LOR by 2.5 years (if granted by the DPMA), respectively 4.5 years (if granted by the EPO). The usage rates vary considerably across different technology areas as well as applicant types. Besides, the provision is frequently used by large corporations, mostly in complex technology areas like electrical and mechanical engineering.

[4] See de Rassenfosse and van Pottelsberghe (2010) for a review of the literature.

In order to understand the dynamics underlying the declaration decision we construct a dynamic stochastic discrete choice model of patent renewal and LOR declaration. The traditional patent renewal models developed by Pakes and Schankerman (1984) and Pakes (1986) were motivated by two simple observations. First, to keep the patent in force a patentee must pay, usually annually, renewal fees to keep his patent in force. Second, only a fraction of granted patents are renewed for the full patent term. Assuming profit maximizing behavior a patentee will only maintain patent protection if the returns in the current period together with the option value of maintaining patent protection in the future exceed the renewal fees. We incorporate a third decision into this setting, the possibility to declare LOR. A declaration has an impact on the future renewal fees–they are reduced by half–and on the returns from patent protection, since the patentee loses the right to exclude others.

The main result we obtain from the model is that there are two types of declarations, those that are primarily made out of the cost-saving motive, and those that are made out of the commitment motive. The first type describes declarations which were made as an alternative to letting the patent expire. Without the LOR option the patent would have lapsed, but because of the cost advantage the patentee maintains patent protection within the LOR regime. Such declarations clearly have an unambiguously negative impact on welfare. The probability to observe a declaration out of the cost-saving motive is higher if the returns from patent protection are not too low and, given equal returns from patent protection, decreasing with patent age. The latter commitment motive describes declarations made for patents which would have been renewed even without the LOR option. In this case the patentee commits to making licenses available to any third party instead of keeping the invention exclusive. This is likely to improve welfare. We show that the probability of observing a declaration made out of the commitment motive decreases with the returns from patent protection and, given equal returns from patent protection, is more likely for older patents.

Subsequently, we combine our data with a number of patent-based indicators. We use parametric analysis, in particular logistic regression, to analyze what determines the probability to observe a LOR declaration for a patent. We find empirical support for the predictions implied by the theoretical model how the patent's age and the returns it generates determine the probability of observing a LOR declaration. Furthermore, the estimation results indicate that the likelihood of observing a declaration is increasing with the size of the proprietor's patent portfolio, especially if the technology the patent protects is rather peripheral to its business. Once we control for the importance of the technological market, the data indicate that the level of competition has a significantly negative effect on the willingness to license non-exclusively. Interestingly, individual inventors and large corporations are equally likely to declare LOR if we control for their patent portfolio sizes.

In the second chapter we further explore the license of right system. By declaring the willingness to make licenses available to anyone the patentee abandons the right to exclude others. We use the theoretical considerations developed in Chapter 1 to shed light on the value of exclusivity and estimate its distribution. We adjust the theoretical model of renewal and declaration to make it suitable for estimation. We then assign an explicit stochastic specification to the model and apply a simulated generalized method of moments (GMM) estimator. In particular, we fit the predicted proportions of patents which declare LOR in Germany and the proportions of patents lapsing in a given year, both conditional on having been active and not endorsed LOR in the previous period, to the sample hazard proportions. The proportion of patents lapsing conditional on having been active and endorsed LOR in the previous period forms the third type of the fitted hazard proportions. Variation in the data over time as well as across cohorts together with the fee structure at the German patent office allows us to identify the structural parameters of the model. The estimated parameters, in turn, characterize the distributions of the private value of patents as well as the distribution of the value of exclusivity.

Our estimates show that being able to exclude others is very important for most patentees. The distribution of the value of exclusivity for German patents is very skewed and its relative importance even increases with patent age. Nevertheless, for a certain fraction of patents the proprietors are able to maintain a major part of or even increase the returns from patent protection if they commit to license their invention non-exclusively.

Additionally, we perform counterfactual experiments to examine the welfare implications of the license of right system in Germany. How valuable is the option to declare LOR? Is it associated with costs for the patent office? How large is the fraction of unambiguously welfare decreasing declarations?

The welfare implications are twofold. LOR increases the private value of patent rights but lowers the patent office's revenues. However, the patent office's losses due to the LOR system, which we have calculated for the 1983 cohort of patents were only a fraction of the private value it had created. Furthermore, the fraction of unambiguously welfare decreasing declarations was relatively low though increasing with patent age. This means that the majority of declarations, i.e., those declared out of the commitment motive, are likely to have benefited welfare.

Since compulsory licensing is a much-debated topic we also simulate its potential impact on the German patent system. Effectively, compulsory licensing corresponds to requiring all patentees to declare LOR already at the filing date. Simulations show that a very substantial part of the incentives currently provided by the patent system would be lost if we made the LOR declaration compulsory for all patents.

The second institution analyzed in the thesis is the deferment of examination. Most patent systems allow applicants to defer patent examination by some time. Deferred patent examination was first introduced in the 1960s at the Dutch patent office and subsequently in many other countries as a response to mounting backlogs of unexamined patent applications. Since applicants are given time to learn about the value of their invention, some let the examination option lapse and never request examination. Examination loads are reduced substantially in these systems, albeit at the cost of having a large number of pending patent applications.

Economic models of patent renewal have largely ignored this important feature. In Chapter 3 we extend the traditional patent renewal model to incorporate the applicants' decision whether and when to request patent examination, as well as the examination stage itself. From the application filing date on the applicant has three choices. Each year he must decide whether to request examination and incur the necessary expenses, to withdraw his application, or to defer the decision for one more year. Deferment involves costs and is only possible for a limited number of years. We show that the applicant will only request examination if his potential per period returns from patent protection exceed a certain threshold value. In case the invention turns up to be less valuable commercially, he will abandon the application. He will defer the decision if the potential per period returns from patent protection lie in the intermediate range. The threshold values will depend on the age of the application as well as on the expectation on how the returns will evolve in the future. We propose two approaches how the examination procedure can be modeled. One possibility is to assume that examination is an exogenous process and the patent will be granted with a certain probability. The applicant will only abandon the application during an ongoing examination process if the invention becomes completely worthless. The alternative approach is to model the patent grant as an endogenous decision where the applicant, after receiving signals from the examiner, decides himself in each period whether he wants to continue examination or abandon the application. For both approaches we assume that the expectations on how future returns from patent protection will evolve over time may change during examination. During the examination process the patent examiner often objects to some or all claims so that the application will have to be amended or abandoned. Once the patent has been granted the patentee decides in each year whether he wants to keep his patent alive and pay the renewal fees or to let it lapse.

Similar to Chapter 2, the parameter values of the model are estimated structurally using a simulated GMM estimator. In particular, we fit three types of hazard proportions using data from the Canadian patent office with a maximum deferment period of seven years: the proportion of patent applications requesting examination and the proportion of applications withdrawn, both conditional on having been alive and pending in the previous year, and the proportion of patents that are allowed to expire conditional on having been granted and alive in the previous period.

We calculate the private value distributions, confirm that it is very skewed for patents, and show that the same applies to applications. According to our estimates the owner of a pending application can already realize a large part of the returns he would generate if the patent had already been granted. Consequently, a considerable part of the overall value from patent protection–discounted returns from all renewal periods from the filing date until the patent expires–accrues before a patent is even granted. Furthermore, previous patent renewal studies indicated that learning opportunities for granted patents are lost quickly (e.g., Pakes 1986; Lanjouw 1998). This does not seem to be the case for pending patent applications where learning opportunities are relatively high and deteriorate only slowly over time.

In addition, we simulate the impact of changes in the deferment period on the patent office's workload as well as on the patent value distributions. Simulation results show that an additional year of deferment can significantly reduce the number of examination requests and increase the aggregate value of all patent applications. Applicants are given additional time to assess the marketability of their inventions. Applications which turn out to be worthless in the future will be duly withdrawn avoiding a costly examination. Owners of initially less valuable inventions do not abandon applications which will be capable of generating high returns in the future. Both correction mechanisms increase the average value of issued patents as well as applications which do never get granted.

The following two chapters investigate the license of right system with focus on Germany. Nevertheless, both papers are self-contained with an own introduction, conclusion, and appendix. Thus, they can be read independently. The paper on deferred patent examination is presented in Chapter 3. The last chapter shortly summarizes the major results and provides directions for future research. At the end of the dissertation a joint bibliography is provided.

Chapter 1

The License of Right in the German Patent System

1.1 Introduction

Historically, the patent system has been designed for a pioneer inventor to help him or her dominate the initial years of an industry through one or more patents (Wegner and Maebius 2002). The patent or patents would grant the inventor a legal monopoly of limited duration, which would ensure a flow of returns as a reward for his or her invention. This might still be true for technology areas such as pharmaceuticals. However, in modern complex technological areas such as semiconductors, where products consist of a large number of interoperable individual components, collaboration has taken the central stage in the innovation process. A patent system that grants exclusivity on each part has often taken the role of a major impediment to innovation in such areas. Single products or processes are often protected by numerous patents whose ownership is usually fragmented. Additionally, the claims of different patents may be overlapping, fueling uncertainty as to whether the patents of a rival are infringed in the innovation process. If patent rights are fragmented and overlapping, knowledge may be underused and the diffusion of innovation will be considerably hampered. Coordination problems between different right holders and abuses of hold-up situations, all based on the exclusivity right provided by patents, are known and reported phenomena. Hence we may argue that a uniform patent system might not be appropriate for promoting innovation in different industry sectors.

Apart from private coordination mechanisms like patent pooling and cross-licensing agreements, some–mostly legal–scholars have also examined potential solutions within the patent system to alleviate these problems. They propose to restrict the exclusion right conferred by patents in complex technologies and they have recommended the application of liability rules in this area. According to the proposed liability rules, patentees will only have the right to reasonable remuneration and they will not be entitled to get injunctions for preventing the use of such technologies. Such a system can be implemented in two ways. It can either be made compulsory for all patents, as suggested by Geiger and Hilty (2005) for the software sector, or it can be in the form of an optional alternative to the existing patent system. The latter, also called "Soft Intellectual Property", was mentioned in the EPO Scenarios for the Future[5] and was supported by IBM. They suggested to implement a co-existing "Soft IP" system to allow applicants to choose between the costly traditional patent protection and a subsidized "soft" patent.

The mechanism by which an owner of a patent voluntarily decides to permit general access to the patented invention in return for reasonable remuneration, i.e., licensing fees, is not new. In some countries this approach is already institutionalized in their domestic patent legislation as the "License of Right" (LOR) or "Willingness to License" provision.[6] Germany was one of the first countries to implement the license of right system (Sec. 23 German Patent Act (GPA)). Since 1936, the German patent law provides that "[t]he applicant for a patent or the person recorded as patentee in the Register [may] declare to the Patent Office (...) that he is prepared to allow anyone to use the invention in return for reasonable compensation", and "[t]he annual fees falling due after the receipt of the declaration shall be reduced to one half".

Studies like the Gowers Review of Intellectual Property (Gowers 2006) and the Scientific and Technological Options Assessment Report of the European Parliament (STOA 2008) have tried to analyze LOR as a means to increase access to patented inventions. According to the STOA report, "[s]uch an option would be attractive for many applicants. One particular group is independent inventors who have no clear picture of which use their inventions might have and therefore cannot easily promote their inventions. A second group consists of small and medium enterprises which do not have the financial stamina to defend their rights. Another group might be universities of which many already rely on non-exclusive licensing." But as Shovsbo (2009) notes, LOR may also be used strategically to maintain dubious patents. He argues that the reduction in maintenance fees might increase the patentee's incentives "[t]o apply for and maintain the protection for patents of little value". All previous studies suffer from a lack of empirical evidence on the use of the system and more importantly a lack of information as to what actually determines the decision of the patentees to declare LOR.

[5]http://www.epo.org/news-issues/issues/scenarios.html, last accessed in December 2012.

[6]We will use "License of Right " (LOR) and "Willingness to License" interchangeably.

The aim of this paper is threefold. First, we present a comprehensive data set on patent applications in Germany dating back to 1983 and provide evidence of LOR practice. Second, we develop a theoretical model which is an extension of the traditional patent renewal models first developed in Pakes and Schankerman (1984), Schankerman and Pakes (1986) and Pakes (1986). We explicitly introduce the option to declare LOR as an alternative to normal patent protection with the right to exclude others. Our third contribution is a multivariate analysis wherein we test the predictions of the theoretical model and explore possible determinants of the decision to declare willingness to license as well as the decision to let the patent expire.

Using information on legal events published by the German Patent and Trademark Office (DPMA) we analyze all patent applications for which the willingness to license could possibly have been declared in Germany. Against the prevailing view, our data show that the declaration of the willingness to license has frequently been used in Germany. In 2008, for example, the overall number of declarations exceeded 4500. Overall, LOR is declared for almost 6% of all granted patent applications from one cohort during their lifetime. The provision is frequently used by large firms, particularly for patents in electrical and mechanical engineering, but rarely for pharmaceutical and biotechnology patents. Typically, a patent owner declares the willingness to license 8.5 years after the application date for patents which are granted by the German Patents and Trademark Office (DPMA) and 10.5 years for patents which are granted by the European Patent Office (EPO). Once LOR is declared, the patent is maintained for additional 6 years. Compared to other patents, patents with a declaration are maintained 2.5 years longer if they has been granted by the DPMA and 4.5 years if they has been granted by the EPO.

In the theoretical part of this paper, we model the decision-making process of a patent owner. In every year of patent protection the patentee can either let the patent expire, renew it with full patent protection, i.e., with the right to exclude others, or, as a third option, declare a license of right and renew patent protection. The latter two options are not free of charge, but entail yearly fees. Given the patentee's knowledge about the current returns from patent protection with and without the right to exclude others and expectations about how these returns will evolve over time, he will choose the profit maximizing alternative every year. According to our findings using this framework, given the structure of the LOR system in Germany, declarations can arise as a result of two motives . First, if the returns from the full patent protection in a given period are relatively low, patentees may choose to declare LOR and profit from the associated reduction in maintenance fees. This would also cost-effectively prevent the expiration of the patent. We call this the cost-saving motive. However, if the returns from full patent protection in a given period are relatively high, the patentee will declare LOR, as long as his returns without the right to exclude others will not be much smaller. We call this the commitment motive since the patentee commits himself to non-exclusive licensing instead of renewing with full patent protection. We show that the probability that a patentee will declare LOR as well as the probability that he will let his patent expire in a given year highly depends on the age of the patent and the revenues expected from full patent protection.

Using parametric regression analysis we confirm that if the cost-saving motive is the relevant motive for declaration, the patent owner will be more likely to declare LOR when the returns from full patent protection are higher and the patent is young. If, on the other hand, the commitment motive is more pertinent, the probability that he declares LOR will decrease with the revenues from patent protection, but will increase with the patent's maturity. We also confirm the intuitive result that older patents as well as patents with lower returns are less likely to be renewed. Patents in the LOR regime have a higher likelihood to expire.

Since the decision to declare willingness to license and the intention to license non-exclusively are obviously intertwined, this study is also related to the literature on non-exclusive licensing. For instance, Gallini (1984), Shepard (1987), Farrell and Gallini (1988) and Arora and Fosfuri (2003) have developed theoretical models wherein they show that market structures can exist where commitment to non-exclusive licensing, and thus competition, can dominate alternative strategies. After analyzing licensing agreements during the period 1990-1993 in three manufacturing sectors, Anand and Khanna (2000) report that non-exclusive licensing contracts were much more likely to be observed in computers and electronics and were much less used in chemicals and pharmaceuticals. Kim and Vonortas (2006), covering a wider spectrum of industries, find that non-exclusive licensing is most likely in infrastructural technologies such as information and communication technologies (ICTs), biotechnology and advanced materials. The size of a firm's patent stock was also found to be an important determinant of the propensity to license out technology non-exclusively. The patenting intensity in the respective industry–they use it as a proxy for the strength of IP protection–is also found to have a strong positive effect. Interestingly, the level of industry concentration–their measure for competition–and whether a firm was active in a complex product industry were found to be insignificant for the probability of non-exclusive licensing.

In contrast to previous studies, our unit of observation is a single patent and not the company. We confirm the positive effect of a patentee's patent portfolio and find that the type of technology significantly determines the probability of observing a declaration of the willingness to grant licenses non-exclusively. Contrary to Kim and Vonortas (2006), once we control for the importance of the technological market for the patentee, we find that the higher the level of competition, the smaller the declaration probability will be. Furthermore, a LOR declaration is less likely for patents in technologies which are peripheral to a firm's business. Interestingly, once we control for the size of a patentee's patent portfolio, the declaration probability for patents owned by individual inventors is not significantly different from the declaration probability for patents owned by large corporations.

The remainder of the paper is organized as follows. Section 2 offers information on the historical and institutional background of the license of right. In Section 3 we present statistical evidence using data on German patent applications. In Section 4, we show the theoretical model of the decision to declare the license of right and the decision to let the patent expire. Additionally, we discuss how patentees can profit from a LOR declaration. The multivariate analysis of the determinants of the decision to declare LOR and also the decision to let the patent expire is presented in Section 5. The last section summarizes our results and concludes the paper.

1.2 Institutional Background[7]

The origin of the idea to commit oneself to grant licenses to third parties for one's patented invention lies in the Patent Act of Canada from 1903, when Canada still was an English colony. The idea was further developed by the British legislator and introduced as the "Licenses of Right" provision in 1919. In Germany, Sec. 23 GPA (German Patent Act)[8], the so-called "Lizenzbereitschaft", was introduced on October 01, 1936 by decision of the German *Reichsregierung*.[9]

According to Sec. 23 GPA the patent applicant can declare to the German Patent and Trademark Office (DPMA)[10] that he is prepared to allow anyone to use the invention in return for reasonable remuneration. As a consequence, the future annual patent fees are reduced to the half and any person willing to pay a reasonable remuneration is allowed to use the invention. The patent owner loses, in principle, his right to exclude others from using his invention and to grant exclusive licenses. The declaration is published in the Patent Register and the Patent Gazette. If the patent owner and the user of the invention do not agree upon the amount of the remuneration, each party is allowed to request the Patent Division of the DPMA to assess it.

The main purpose of the act, as stated in its explanatory memorandum, was to exert the

[7]Written in cooperation with Daniel Krauspenhaar.

[8]Formerly Sec. 14 GPA.

[9]See Piehler (1938).

[10]From the day of the application for German patent applications (Sec. 23 Par. 1 Cl. 1 GPA), from the day Germany is a designated state for PCT (Patent Cooperation Treaty) applications, or from the day of the publication of the mention of the grant for EPO (European Patent Office) patent applications (Art. 2 Par. 2, 97 Par. 3 of the European Patent Convention (EPC)).

ideas of National Socialism in the field of patent and utility model law. On the one hand, the creative personality should have been promoted and protected against exploitation by facilitating the access to patent protection for inventors who were short of funds. On the other hand, the inventor should make his invention available to the public because he owed his achievements to society.[11]

In more recent times the purposes and aims of Sec. 23 have changed. According to Rogge and Grabinski (2006), giving third parties the possibility to easily take up the patented invention for which willingness to license has been declared should promote the transfer of technology and allow it to be exploited commercially. The publication in the Patent Register and the Patent Gazette should facilitate this process. This must be in the interest of the general public, since the invention can then be used by third parties before the patent expires, but also in the interest of the patent owners, since they will be remunerated. This mechanism should provide stronger incentives to innovate. Individual inventors lacking the assets for commercialization will be able to keep their patent right for a longer period and receive remuneration in case the invention is useful. Furthermore, the option for the remuneration to be assessed by the DPMA should reduce the transfer costs of licensing. It prevents the patent owner from demanding too high compensation and safeguards the patent owner's returns in case the user refuses to pay the appropriate compensation.[12]

Until now there has been one important amendment of Sec. 23 GPA. The provision was often criticized by patent applicants for being too restrictive. Once willingness to license had been declared, it was irrevocable. On June 01, 1992 the possibility to withdraw the willingness to license as long as no one indicated his intention to use the patented invention

[11] See BPMZ (1936).

[12] Sec. 23 GPA does not contain, however, any information what the term "reasonable compensation" means. Indications can be found in the literature and–more important for the practice–in published administrative and court decisions. After the (re)foundation of the DPMA in 1949, the patent office decided only three times about a reasonable amount of remuneration; in every of these cases an appeal was filed to the BPatG (Federal Patent Court) and in one case a further appeal to the BGH (Federal Court of Justice). According to the decisions and the literature the amount of the remuneration should depend on the circumstances of every single case. The aim should be to find a balance between the interest of the patent owner and the users, i.e., the patent owner should be compensated for having made and disclosed the invention; but the users should not be burdened unreasonably. This would be the case if the amount of the compensation caused the (potential) users not to use the invention. The principles of how a reasonable compensation is determined, which were developed for compulsory licensing provisions, the principles of contractual licenses and those for the calculation of damages according to the license analogy should also be applicable. So far, the courts have made - often as a first step - comparisons with license agreements which were concluded before the willingness to license was declared. Additionally, they have considered as relevant the importance of the invention for the user and the value derived from the current state of the art, doubts regarding the validity of the patent, the volume of sales of the user and what is reasonably agreed under comparable conditions. However, the declaration of the willingness to license itself should have, in principle, no relevance for the amount of the remuneration, especially if there is already a significant number of licensees and if non-exclusive licensing contracts were used as an indication before.

was added. The legislator considered the interests of the patent owner preceding those of the society in this case. The option to restore the right to grant an exclusive license should improve the incentives of applicants to declare the willingness to license.

The license of right has been criticized by the industry for not being suitable to achieve the aims of the legislator. One important point of criticism was that the cost savings were only marginal and that the remuneration for a patent endorsed LOR was significantly lower than for a patent with full protection. The patent owner loses his right to grant exclusive licenses, although not always irrevocably since the amendment in 1992, which is regarded as highly valuable by potential licensees (Eggert 1972). The fact that the patent owner is no longer allowed to limit the use of his invention is perceived as an impairment to his bargaining position. Additionally, the system of Sec. 23 GPA might not lead to more licensing activity since the visibility of the declaration - the declaration has to be published in the Patent Register or Patent Gazette - is insufficient.[13] Another complaint made by practitioners was that the declaration of the willingness to license may benefit willful infringers. These are firms which start using a patented technology albeit knowing about its legal protection and without notifying the patent owner. Usually they risk a claim for damages and what might be even more harmful, an injunction. But this risk might not even exist if the patent owner declared the willingness to license. In this case the infringer could continue to use the patented invention after getting caught by formally indicating the use according to Sec. 23 GPA and he might not even have to fear criminal sanctions according to Sec. 142 GPA ("Penal Provisions").[14]

Interestingly, this provision has never existed in Japan and the United States. Conversely, a willingness to license of right is rather widespread in European countries such as Bulgaria (Sec. 30 Bulgarian Patent Act), Italy (Sec. 50 Italian Patent Act), France (ex-Sec. L613-10 Code de la Propriété Intellectuelle), Luxemburg (Sec. 56 Luxembourgian Patent Act 1992/1998), Slovakia (Sec. 25 et seq. Slovakian Patent Act), Spain (Sec. 81 et seq. Spanish Patent Act) and United Kingdom (Sec. 46 et seq. UK Patents Act 1977). Besides, it was included in all proposals for a unified patent system in Europe (Sec. 11 European Patent with Unitary Effects (EPUE)).

Although all license of right provisions share the main characteristics there is no perfect

[13] A survey by the Ifo Institute for Economic Research in 1974 which investigated the effects of the patent system on innovation processes, concluded that the declaration of the willingness to license has no relevance for the conclusion of licensing agreements.

[14] Willfulness may be difficult to prove because of the mass of existing patents. Mes (2005) concludes from the wording of Sec. 23 GPA that only the user who made the indication before the first use is allowed to use the invention; otherwise the patent owner may successfully apply for an injunction. However, the LG Düsseldorf did not agree with this argument. In a decision in 2001 the court denied an injunction after the infringer indicated the use to the patent owner. It is, however, important to note that the defendant claimed not having infringed the patent what was not challenged by the claimant. Therefore, the decision could have been different, if the infringer would have acted willfully.

harmonization. The major difference between the German and the British provision is that the British patent office does not only decide on the amount of the remuneration if one party appeals, but also on many other licensing terms. Therefore, the right to use the patented invention can also be limited to some sort of use only. Furthermore, contrary to Germany, where a license is considered to take effect when the third party's notice reaches the patentee, in Great Britain, prior to exploitation both parties have to agree on the conditions of licensing. In Bulgaria withdrawing the willingness to license is still allowed even after a third party has indicated the use of the patented invention. In Italy and France, it is the ordinary court and not the patent office, which decides on reasonable remuneration.

Regarding the formalities of the declaration in the proposal for the European patent there are no important differences to Sec. 23 GPA; Sec. 11 EPUE does not contain the possibility to withdraw the declaration. With respect to the effects of the declaration one can conclude that Sec. 11 EPUE is almost identical to Sec. 23 GPA. However, the percentage of reduction of the annual fees is not determined yet: Sec. 14 EPUE specifies solely that the renewal fees for the patent which are due after receipt of the statement shall be reduced. Regarding the legal situation between the patent owner and the user, one can conclude that Art. 11 EPUE is less concrete than Sec. 23 GPA. The European provision does not contain any information about the notification process. Additionally, there are no conditions specified under which the patentee may still be allowed to apply for an injunction. Regarding the determination of the amount of remuneration, Sec. 11 EPUE contains the term appropriate compensation. Therefore, the German and the European provision are in this respect identical and the same factors could be relevant for the determination of the compensation. However, at the moment it is unclear if the EPO, a court or another body will be the first instance to determine the amount of compensation.

1.3 Empirical Evidence

1.3.1 Overall Trends

We employ data on legal events for German patent applications provided by the German Patent and Trademark Office (DPMA) updated as of December 24, 2008.[15] We were able

[15]Due to legal provisions, the DPMA has to announce the publication of certain legal documents and events, e.g., publication of the patent application, patent grant, translation of European and PCT patent claims, as well as their changes. The announcement itself is made by a notice that appears in the weekly published Patent Gazette. All information used for the publication in the Patent Gazette is stored in the PU-Band, tagged with the date the particular event was announced in the Patent Gazette (on average 3

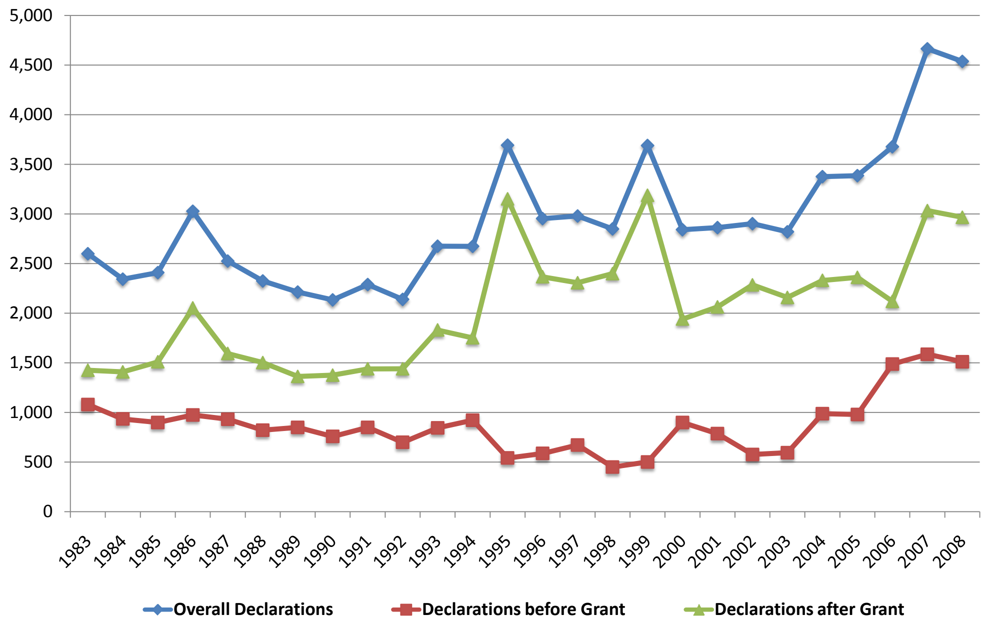

Figure 1.1: Declarations of the Willingness to License in Germany between 1983 and 2008

to identify 76,094 declarations of the willingness to license in Germany made between 1983 and 2008. Of these, 22,722 were made prior to and 53,372 after the first publication of the patent grant.[16] We merged the full data set with additional information from the PATSTAT database provided by the EPO ("EPO Worldwide Patent Statistical Database").[17]

As shown in Figure 1.1, the number of declarations amounted to around 2,500 in the years up to 1992. Almost two thirds were made for already granted patents and about one third for still pending applications. In the following years the provision was used even more often. This can partially be attributed to the increased number of patent applications in the system, but probably also to the statutory change in 1992, which allowed to withdraw the declaration. Indeed, the increase is fully attributed to an increase in post-grant declarations. The number of declarations for pending applications has declined in the period 1983 to 1999. Pre-grant declarations accounted to only 13.8% of all declarations in 1999. Beginning with 2004, the number of declarations started to rise very sharply to more than 4,500 declarations in 2007 and 2008. This time mainly driven by an increase

months after the event has actually occurred). The first entry in the data set we use dates back to March 31, 1981.

[16]The number of declarations in 2008 is not complete due to truncation. The legal events from the last months were most likely published in 2009.

[17]We were using the PATSTAT version of October 2009.

in pre-grant declarations, restoring the share to almost one third. Since for European patent applications which are transferred to Germany it is only possible to declare license of right after the notification of the grant, the additional declarations in this period must have occurred for German patent applications only.

Next, we group the patent applications into cohorts according to their application year.[18] Overall, 1,845,343 patent applications filed between 1983 and 2006 had the possibility to declare the willingness to license in Germany, consisting of 845,724 European patent applications and 999,619 patent applications filed with the German patent office.[19] For 57,045 of them the willingness to license has been declared. Overall, 1,074,627 patent applications have already been granted before December 24, 2008, 342,585 by the DPMA and 732,042 by the EPO. Exactly 42,943 of them have ever been endorsed LOR.

Figure 1.2 shows the share of all patents with LOR in each cohort. For patent cohorts 1983 to 1988, for which we can observe the full patent term, willingness to license has been declared for around 5.7% of all granted patent applications. If we only consider patents granted by the DPMA the share is 9%. For patents granted by the EPO the share is 3.2% for the 1983 cohort and rises to 4.4% for the 1990 cohort. However, the trend for EPO granted patents is positive. The difference in the usage rates between European and nationally granted patent applications can have various explanations. Patents granted by the EPO may be more valuable on average since the European route is usually associated with higher application costs. Furthermore, declaring LOR is not possible for European patent applications until the right has been transferred to Germany. In addition applicants who filed with the DPMA might have had better knowledge of the LOR provision in Germany. The usage rates decrease beginning with cohort 1991. Since patent protection can be maintained for up to 20 years, many patents from these cohorts were in force on December 24, 2008. Most of them still had the possibility to declare the willingness to license causing a truncation bias.

[18] We excluded all applications for utility patents, all patent applications without a publication number from the DPMA, all withdrawn PCT (Patent Convention Treaty) applications and all applications submitted before 1983 and after 2006 from the data. We did not consider applications from 2007 and 2008 as most of them were still pending. Applications prior to 1983 were also dropped as there was a change in the use of legal event codes for German patent applications at the DPMA. In order to reduce the number of sources of errors we therefore decided to limit our analysis to patent applications from the application years 1983-2006.

[19] Starting with the year 1983 the overall number of applications per cohort has increased constantly and reached its peak in 2000 with 102,671 patent applications with effect in Germany. It decreases for subsequent cohorts down to 55,231 applications in 2006. EPO patent applications only enter our data set once they are declared as granted and are transferred to Germany.

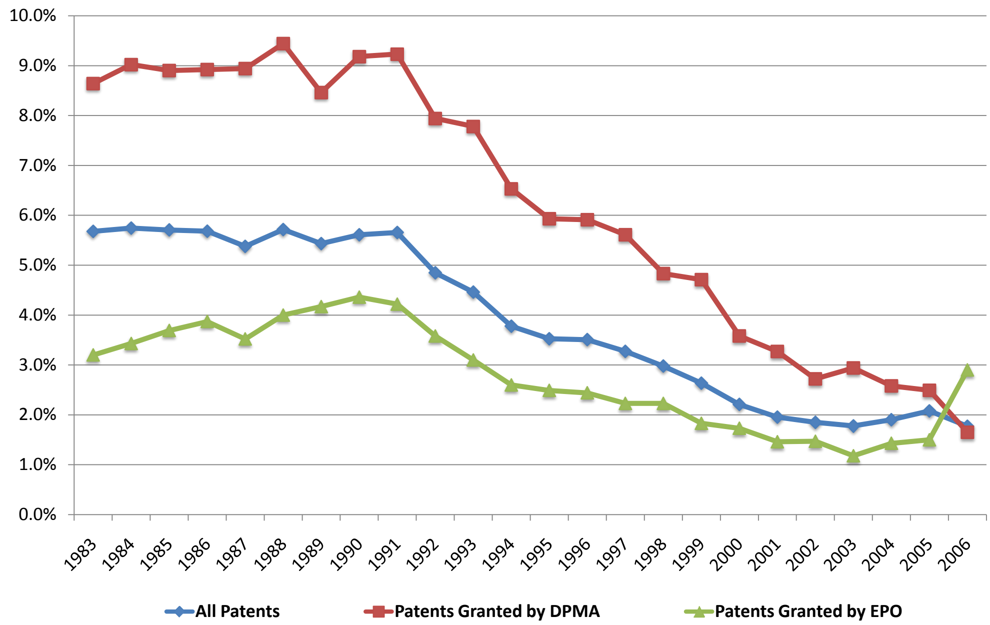

Figure 1.2: LOR Usage Rates by Application Year (Cohorts 1983-2006)

1.3.2 Who Are the Users of the License of Right Provision?

Technology Areas

Patents in different technology areas usually serve different purposes. We divided all patents in six higher-level technology areas:[20] electrical engineering, instruments, process engineering, chemistry and pharmaceuticals, mechanical engineering and consumer goods and construction. One can see in Figure 1.3 that for cohorts 1983 to 1991 in the areas of electrical and mechanical engineering declarations occurred for more than 11%, respectively 8% of all granted patent applications with effect in Germany. Both technology areas are recognized by the literature as being complex.[21] For patents in discrete technology areas LOR has rarely been used. In the areas of chemistry, pharmaceuticals and process engineering the willingness to license has been declared for less than 2%, respectively 3% of all patents. This is not surprising, since these are the industries in which the rights provided by patents are considered particularly important to protect innova-

[20]We used the ISI-OST-INPI patent classification updated as of February 2005. It is based on the codes of the International Patent Classification (IPC) and distinguishes between 30 different fields of technology and six higher-level technology areas (see Schmoch, 2008). The classification system was jointly elaborated by the Fraunhofer Institute of Systems and Innovation Research (ISI) and the Observatoire des Sciences et des Technologies (OST), in cooperation with the French Patent Office (INPI).

[21]See for example Cohen et al. (2000) or von Graevenitz et al. (2012).

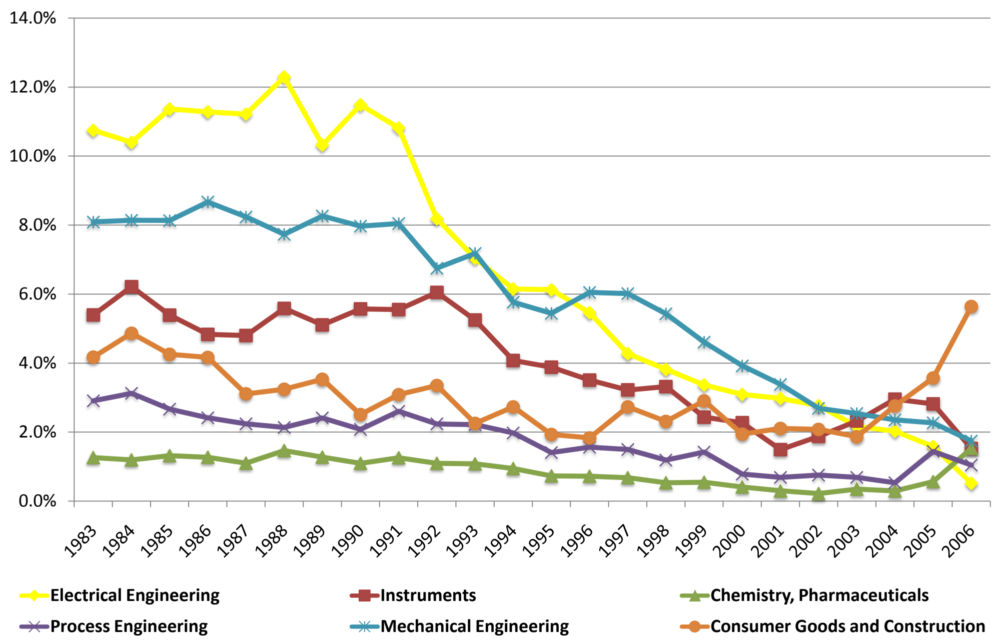

Figure 1.3: LOR Usage Rates by Technology Area and Application Year (Cohorts 1983-2006)

tions (see Gambardella et al. 2008). Additionally, Kim and Vonortas (2006) report that chemical companies register by far the highest share of exclusive licenses. With almost 6%, respectively 4%, the usage rates for patents in the area of instruments and the area of consumer goods and construction lie between the two extremes. Again, it is difficult to make a statement for younger cohorts due to truncation.

There is also considerable variation within individual technology areas as one can see in Figure 1.4.[22] For example in the area of electrical engineering, for 14.4%, respectively 13%, of all patents in audiovisual and semiconductor technologies LOR has been declared, whereas the usage rate for IT was considerably lower with only 6.8%. Significant differences between lower-level technological classes were also present in mechanical engineering. Usage rates for patents in motors and transportation were high with 12.3%, respectively 11.3%, whereas only 3.7% of patents in machine tools were ever endorsed LOR.

[22]Here, we have limited our analysis to patents from cohorts 1983 to 1988 as these cohorts can be observed over the full patent term.

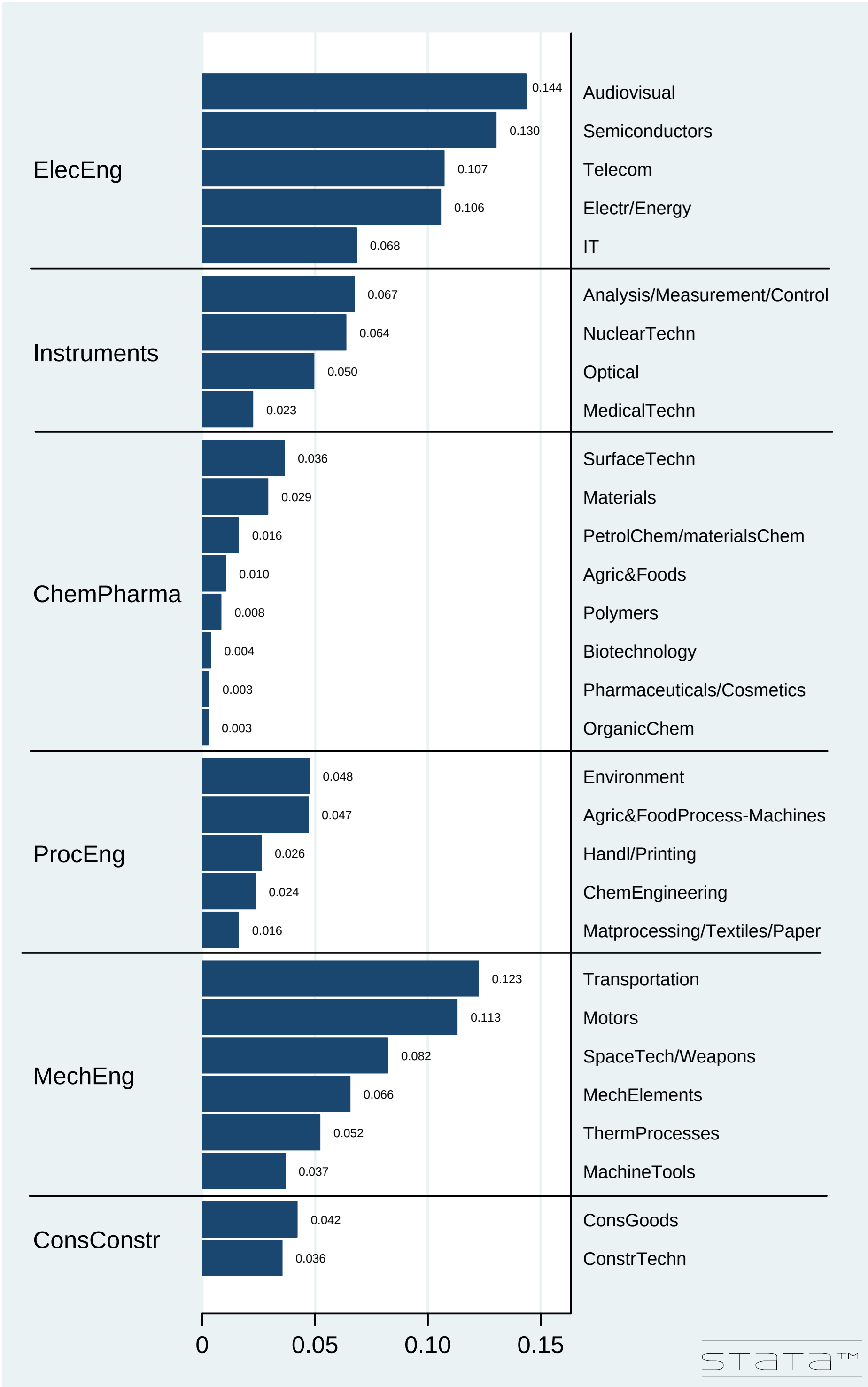

Figure 1.4: LOR Usage Rates by Lower Technology Area (Cohorts 1983-1988)

Applicant Types

The differences in the usage rates of LOR declarations according to applicants' nationality are presented in Figure 1.5.[23] As several applicants may be assigned to a single patent, we are only using the country of the first applicant.[24] The between-cohort variation is high for all nationalities. Overall, German (DE) applicants have declared LOR for 5.7% of all granted patent applications in cohorts 1983 to 2006. Applicants from the Netherlands (NL), with 6.8% and Japan (JP), with 5.8%, were also frequent users. Interestingly, these are countries without a license of right provision in their patent systems. Starting with cohort 1988 the usage rates for patents owned by Japanese and German applicants are almost equal and decreasing for younger cohorts due to truncation. The curve of usage rates for patents owned by Dutch applicants has a bell-shape with a peak for the 1995 cohort at almost 14%. Another particularity is that more than 95% of patents owned by Dutch applicants and for which LOR has been declared belong to only one firm, PHILIPS ELECTRONICS. Applicants from France (2%), Great Britain (0.5%) and Italy (0.1%), countries where a similar provision existed, rarely declared LOR. French applicants seem to have discovered this option in the German patent system more recently as indicated by the increase in the usage rate for younger cohorts. However, these declarations were made by only two firms, PEUGEOT CITROEN and THOMSON LICENSING.[25] Applicants from the United States have declared LOR for only 1.5% of their patents.

As already explained above, one of the main intentions of the lawmaker and the justification for the subsidy the patent owner receives upon LOR declaration, is to support small and individual inventors. We use the EEE-PPAT[26] data to divide the patents into five groups according to the type of the first applicant. The first category, non-profit organizations and universities, comprises patents that belonged to universities, hospitals and other private and non-private non-profit organizations. The second category includes those patents that belonged to individual inventors. Patents that were owned by private companies are further divided according to the company's size, proxied by the number of granted patent applications filed by the same firm in one year: small corporation, medium corporation and large corporation. About 3% of the patents were filed by non-profit organizations and universities, 10% by individual inventors, 30% by small, 29% by medium

[23]We present countries with at least 30,000 patents in the time period under consideration.

[24]In our data for 39,287 patents, most of them with application years 1983-1992, no country code was assigned, of which for 2,386 the willingness to license has been declared.

[25]THOMSON LICENSING S.A. (France) is a wholly-owned subsidiary of THOMSON and houses its IP and licensing activities. Thomson has acquired former German companies like TELEFUNKEN, NORDMENDE or SABA in the past.

[26]The ECOOM-EUROSTAT–EPO PATSTAT Person Augmented Table (EEE-PPAT) contains a sector code for applicant names, as described in Du Plessis et al. (2009) and two levels of harmonized names for applicants, as described in Magerman (2009) and Peeters (2009).

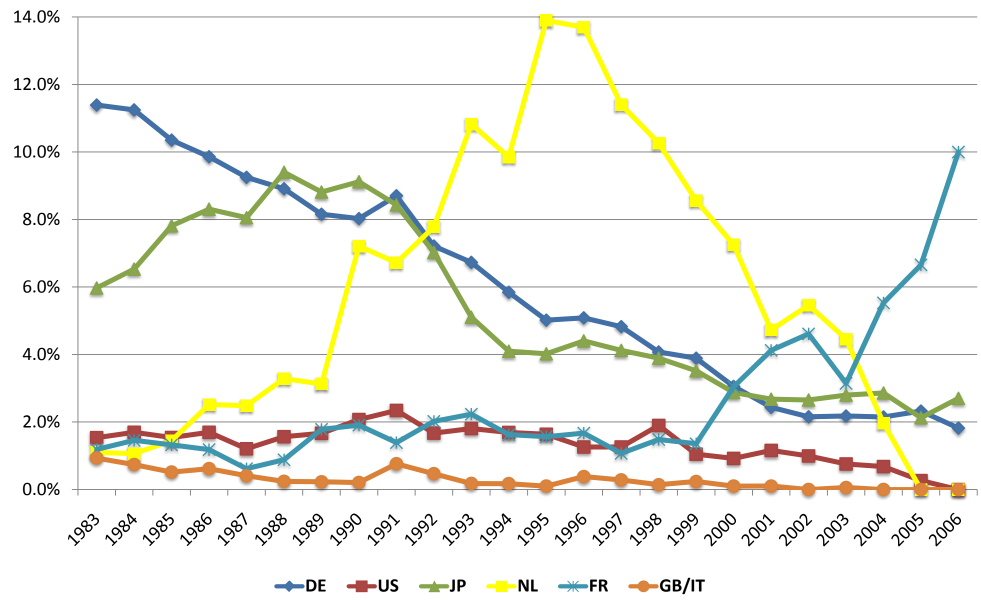

Figure 1.5: LOR Usage Rates by Nationality of First Applicant and Application Year (Cohorts 1983-2006)

and 28% by large corporations.[27]

The usage rates are very heterogeneous across different applicant types (see Figure 1.6). Large corporations have declared LOR most frequently. For 9.4% of patents in cohort 1983 owned by large corporations LOR has been declared. For the younger cohorts 1984 to 1988, for which we can observe the full patent term, the number has even increased to 13.2%. For patents owned by medium corporations we see the opposite trend. For patents applied for in 1983 the rate was 7.3% and almost as high as for large corporations but has declined to less than 5% for patents in cohort 1987. Contrary to the intention of the lawmaker, small corporations and individual inventors have not declared willingness to license very often. For patents in cohort 1983 the usage rate was about 2.25% for both groups. In the subsequent cohorts the usage rate for patents owned by small firms has decreased slightly. However, for patents owned by individual inventors it has constantly increased up to 3% for cohort 1988 and even up to 3.5% for cohort 1997. This might indicate that the importance of the declaration of the willingness to license has increased over time for individual inventors.[28]

[27]We categorize companies with less than 5 granted patent applications filed in a given year as small and companies with more than 50 as large.

[28]This conclusion is not possible for cohorts before 1998. As explained above, European and German patent applications which were still under examination in December 2008 did not enter the data set.

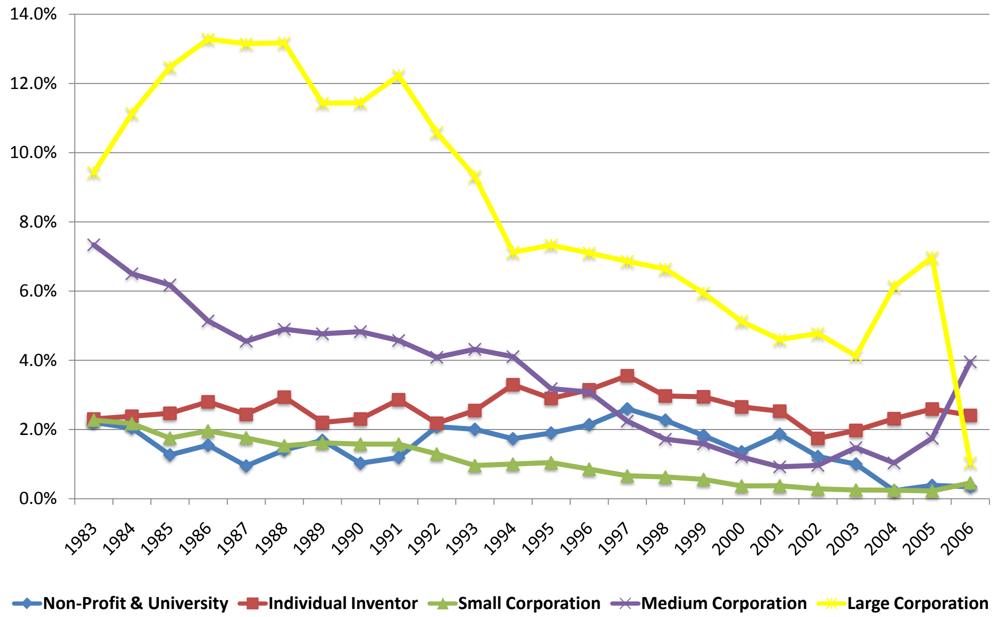

Figure 1.6: LOR Usage Rates by Applicant Type and Application Year for All Patents (Cohorts 1983-2006)

We have seen above that there is a difference between the usage rates of patents granted by the EPO and those granted by the DPMA.[29] This finding is also confirmed by the data shown in Figures 1.7 and 1.8. For patents granted by the EPO, less than 1% have ever been endorsed LOR if they were filed by universities and non-profit organizations or by individual inventors. For patents granted by the DPMA, however, their usage rates were significantly higher and increasing, except for the youngest cohorts. Again, this indicates that the importance of the LOR system might have increased for these applicant types. For small, medium and large corporations we see a similar picture in both patent groups except that the usage rates are more than twice as high for national patent applications. For cohorts 1987 and 1988 large corporations have declared LOR for more than a quarter of patents granted by the DPMA but for less than 10% of patents granted by the EPO.

Now, we focus on the patterns of LOR declaration across applicant types within individual technology areas. We concentrate on cohorts 1983 to 1988. Tables 1.1-1.3 show that there are interesting differences. For example, we have seen that, in the aggregate, non-profit organizations and universities rarely declare LOR. This is true for all technology areas

[29]For patents granted by the EPO the willingness to license can only be declared once the patent takes effect in Germany. Furthermore, European patent applications might be of higher value to their owners implying a different value distribution, and thus different renewal and declaration decisions.

All	**Non-Profit&Univ**	**IndivInventor**	**SmallCorp**	**MediumCorp**	**LargeCorp**	$\sum$
ElecEng	7.06% (62)†	4.64% (100)	4.62% (392)	15.23% (1,640)	16.60% (3,116)	11.41% (5,310)
Instruments	1.20% (23)	2.09% (83)	1.98% (199)	5.59% (503)	13.02% (1,116)	5.41% (1,924)
ChemPharma	0.23% (6)	1.25% (27)	0.60% (74)	1.08% (196)	2.48% (303)	1.26% (606)
ProcEng	0.86% (7)	2.30% (118)	1.59% (250)	3.00% (318)	6.10% (275)	2.56% (968)
MechEng	1.38% (12)	2.93% (162)	2.06% (307)	7.75% (1,016)	32.11% (2,096)	8.02% (3,593)
ConsConstr	2.23% (5)	2.79% (140)	1.49% (126)	7.82% (269)	30.65% (202)	4.00% (742)
$\sum$	1.56% (115)	2.56% (630)	1.89% (1,348)	5.71% (3,942)	12.18% (7,108)	5.68% (13,143)

† Absolute number of declarations in parentheses.

Table 1.1: LOR Usage Rates by Technology Area and Applicant Type for All Patents (Cohorts 1983-1988)

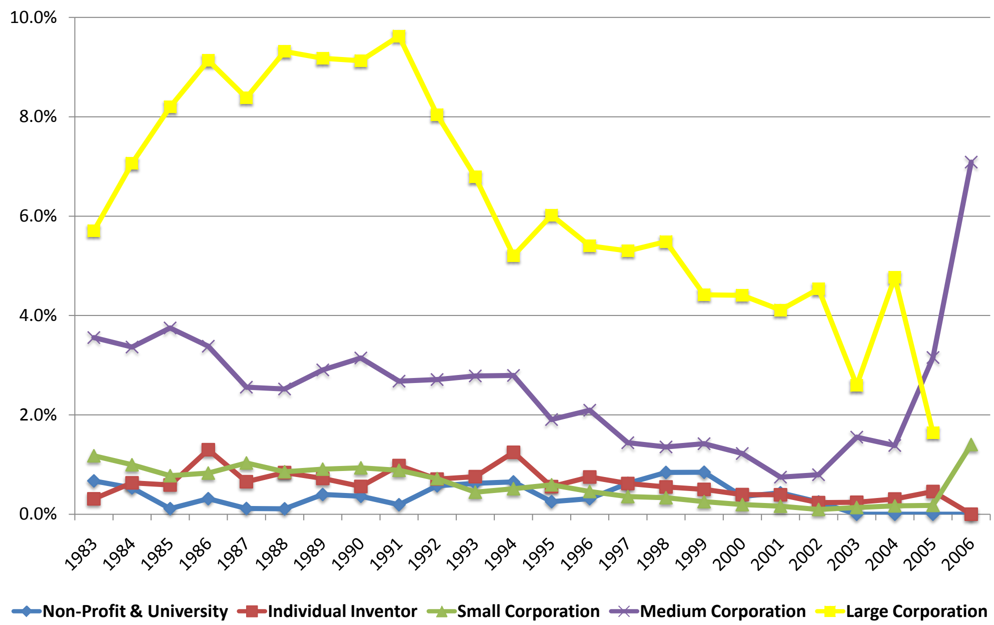

Figure 1.7: LOR Usage Rates by Applicant Type and Application Year for Patents Granted by the EPO (Cohorts 1983-2006)

except electrical engineering. For patents granted by the DPMA willingness to license has been declared for 62 patents (27.80%). Although, aggregated over all applicant types, the willingness to license has mostly been declared for patents in electrical engineering, we see now that the usage rates of large corporations were highest in mechanical engineering (32.11%) and consumer and construction goods (30.65%). For patents granted by the DPMA the usage rates even reached 44.78%, respectively 57.56% (see Table 1.3). Although medium sized corporations have also actively declared willingness to license in these areas, with 7.75% and 7.82% (see Table 1.1), their usage rates were highest for patents in electrical engineering with 16.23%, especially for those granted by the DPMA (27.83%). For small corporations and individual inventors we see the following patterns. If they declared willingness to license, then mostly for patents granted by the DPMA and predominantly in complex technology areas like electrical and mechanical engineering.

1.3.3 Timing and Duration

On average, LOR has been declared 9.0 to 9.5 years after the application for patents in cohorts 1983 to 1988 for which we observe the full patent term. The distribution is rather symmetrical. The cohort means almost equal the median values and are slightly

EU	Non-Profit&Univ	IndivInventor	SmallCorp	MediumCorp	LargeCorp	$\sum$
ElecEng	0.00% (0)†	2.61% (27)	2.10% (106)	8.54% (600)	12.40% (1,752)	8.15% (2,485)
Instruments	0.31% (4)	0.70% (14)	1.07% (67)	3.19% (186)	10.14% (603)	3.91% (874)
ChemPharma	0.05% (1)	0.25% (3)	0.31% (28)	0.61% (90)	1.92% (212)	0.87% (334)
ProcEng	0.66% (3)	0.44% (10)	0.61% (54)	1.47% (87)	3.98% (125)	1.32% (279)
MechEng	1.03% (5)	0.60% (14)	1.36% (107)	5.18% (322)	18.08% (560)	4.76% (1,008)
ConsConstr	1.74% (2)	0.63% (14)	0.51% (22)	2.81% (45)	11.86% (46)	1.46% (129)
$\sum$	0.29% (15)	0.73% (82)	0.92% (384)	3.11% (1,330)	8.04% (3,298)	3.58% (5,109)

† Absolute number of declarations in parentheses.

Table 1.2: LOR Usage Rates by Technology Area and Applicant Type for Patents Granted by the EPO (Cohorts 1983-1988)

DPMA	Non-Profit&Univ	IndivInventor	SmallCorp	MediumCorp	LargeCorp	$\sum$
ElecEng	27.80% (62)†	6.50% (73)	8.32% (286)	27.83% (1,040)	29.41% (1,364)	17.60% (2,825)
Instruments	3.05% (19)	3.53% (69)	3.52% (132)	9.99% (317)	19.55% (513)	7.91% (1,050)
ChemPharma	1.04% (5)	2.49% (24)	1.42% (46)	3.21% (106)	7.82% (91)	2.85% (272)
ProcEng	1.12% (4)	3.82% (108)	2.88% (196)	4.94% (231)	11.00% (150)	4.11% (689)
MechEng	1.84% (7)	4.64% (148)	2.85% (200)	10.09% (694)	44.78% (1,536)	10.95% (2,585)
ConsConstr	2.75% (3)	4.51% (126)	2.53% (104)	12.19% (224)	57.56% (156)	6.30% (613)
$\sum$	4.40% (100)	4.09% (548)	3.29% (964)	9.96% (2,612)	22.02% (3,810)	9.02% (8,034)

† Absolute number of declarations in parentheses.

Table 1.3: LOR Usage Rates by Technology Area and Applicant Type for Patents Granted by the DPMA (Cohorts 1983-1988)

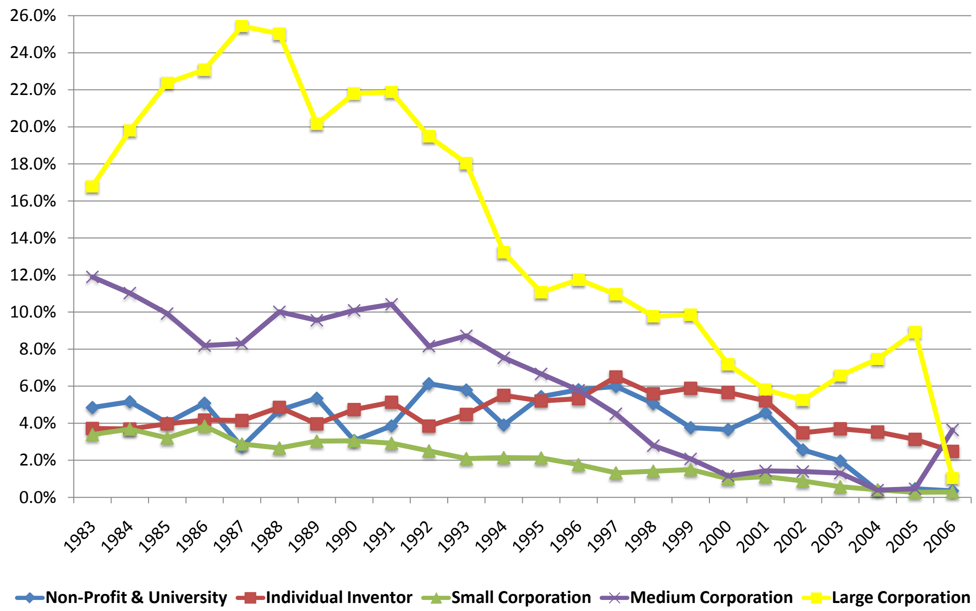

Figure 1.8: LOR Usage Rates by Applicant Type and Application Year for Patents Granted by the DPMA (Cohorts 1983-2006)

decreasing for younger cohorts, indicating a tendency to declare earlier. Due to truncation, for cohorts 1989-2006 the distributions of the time between application and declaration get more and more left-skewed and the average values, as well as median values, smaller. Since applicants of patents granted by the EPO are not able to declare the willingness to license until they have been granted, there is a difference of up to 2.5 years between the cohort averages of patents granted by the EPO and DPMA (see Figure 1.9).[30]

In Figures 1.10 and 1.11 we look at potential differences across technology areas and applicant types for patents in cohorts 1983 to 1988. On average, non-profit organizations and universities tend to declare LOR later, independent of the granting authority. Large corporations together with individual inventors declare earliest, especially for DPMA granted patents. For patents in electrical engineering and consumer goods and construction declarations occur earlier than in other technological areas if the patent has been granted by the DPMA, but later if it has been granted by the EPO.

Once LOR had been declared, on average, a patent continued to exist for additional 5.7 years for applications filed in 1983. The time period in which patents have been endorsed LOR has increased for subsequent application years. Patents in cohort 1988, the youngest

[30]Interestingly, this is less than the average time the EPO needs to get a patent granted (about 4.8 years on average).

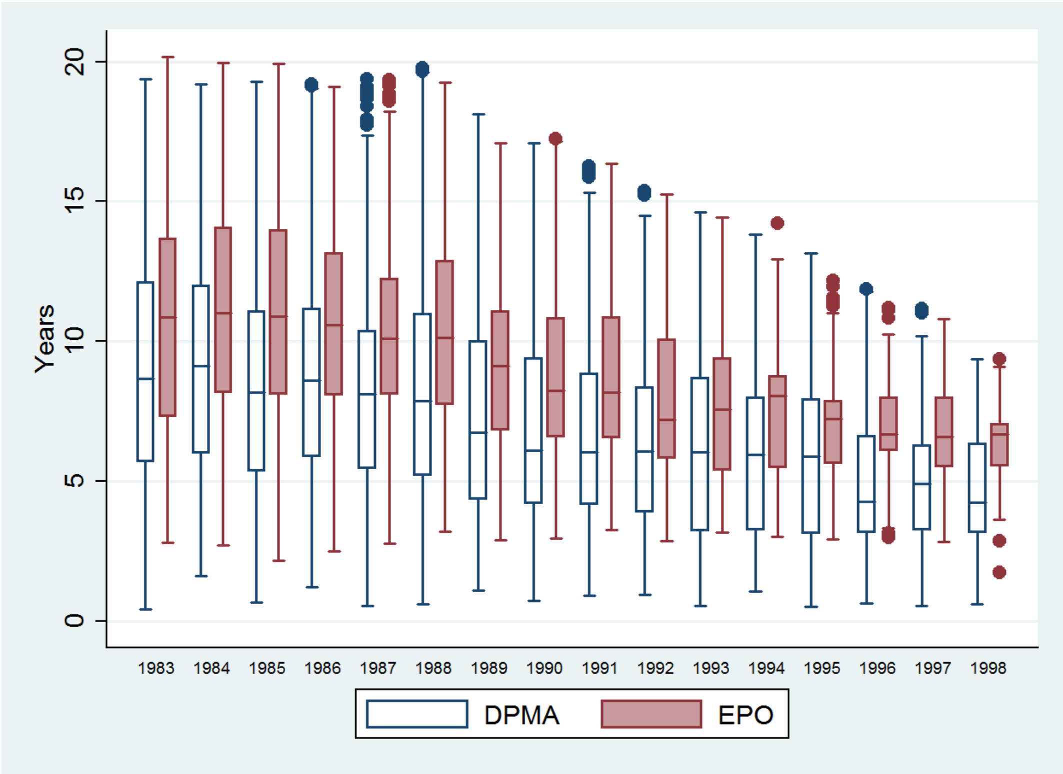

Figure 1.9: Time between Application and Declaration by Application Year (Cohorts 1983-1998)

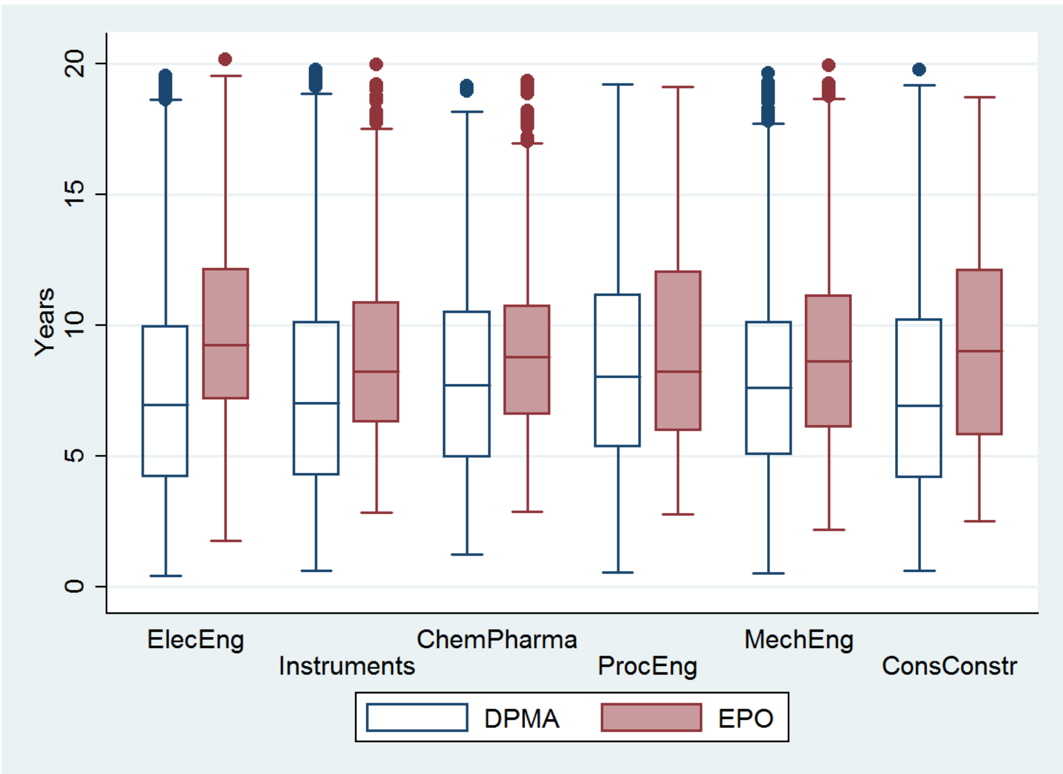

Figure 1.10: Time between Application and Declaration by Technology Area (Cohorts 1983-1988)

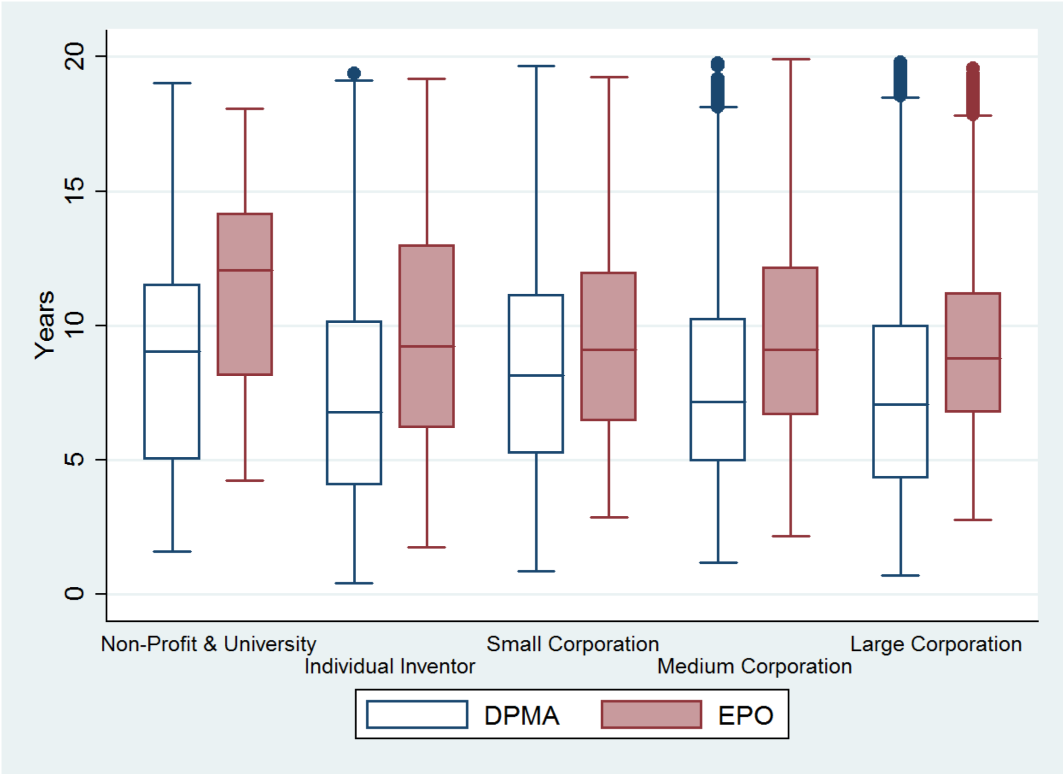

Figure 1.11: Time between Application and Declaration by Applicant Type (Cohorts 1983-1988)

one for which we observe the full patent term, have been renewed for almost 6.5 additional years. Again, we see a decline for patents filed after 1988 (see Figure 1.12). There is almost no difference between EPO and DPMA granted patents except for the youngest cohorts.

According to Figure 1.14, medium and large corporations have tended to hold their patents for a longer period compared to small corporations and individual inventors once LOR had been declared. Since these applicants are the ones who hold the biggest share of patents in electrical engineering, the average time period in this technology area is somewhat higher compared to other technology areas (see Figure 1.13). It is lowest for patents in process engineering

We now turn to the question whether patents endorsed license of right have been maintained longer compared to other patents. One of the justifications of the lawmaker for the subsidy awarded by the provision was to promote innovation by giving small inventors a chance to keep their patent rights for a longer period, until they have found a way to exploit their invention commercially. As shown in Figure 1.15, the provision seems indeed to be effective in extending patent protection.

Patents for which LOR has never been declared have been maintained for 13 years on average, independent of the granting authority. For patents endorsed LOR, however,

Figure 1.12: Time between Declaration and Expiration by Application Year (Cohorts 1983-1998)

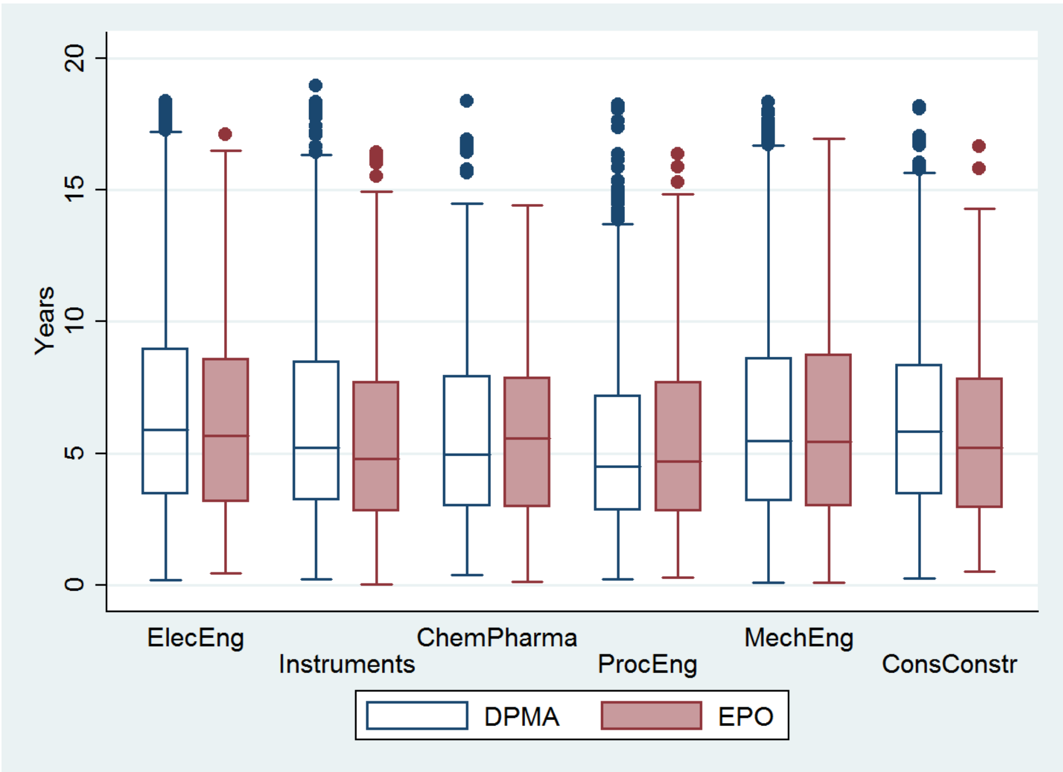

Figure 1.13: Time between Declaration and Expiration by Technology Area (Cohorts 1983-1988)

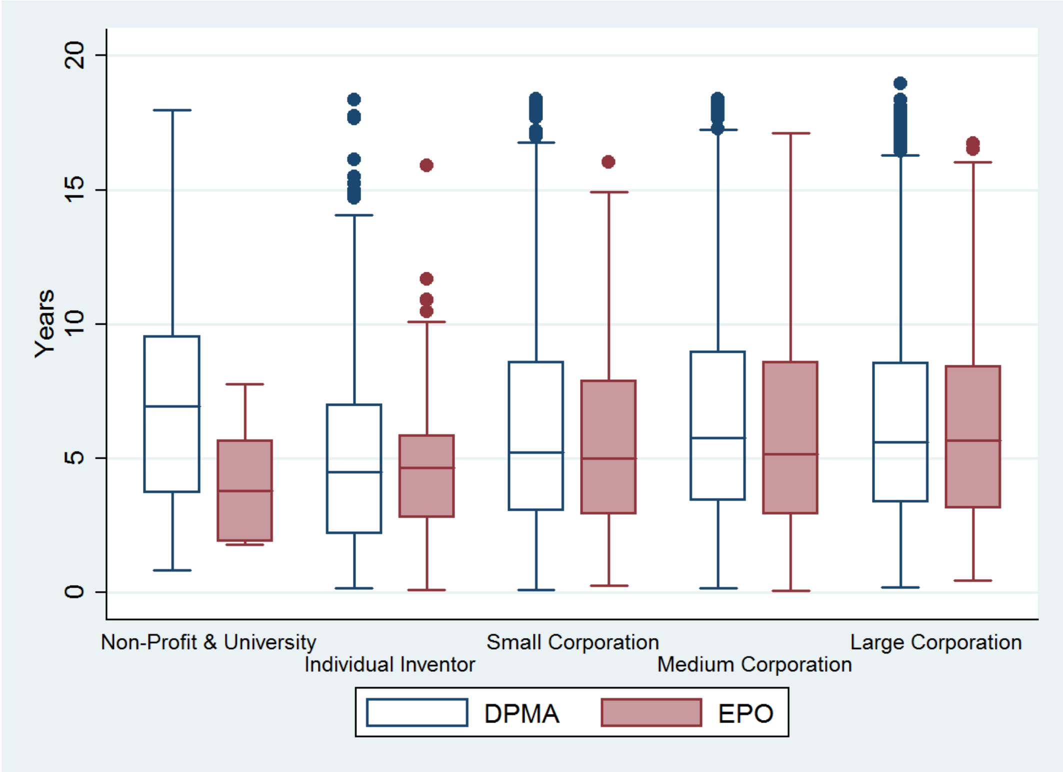

Figure 1.14: Time between Declaration and Expiration by Applicant Type (Cohorts 1983-1988)

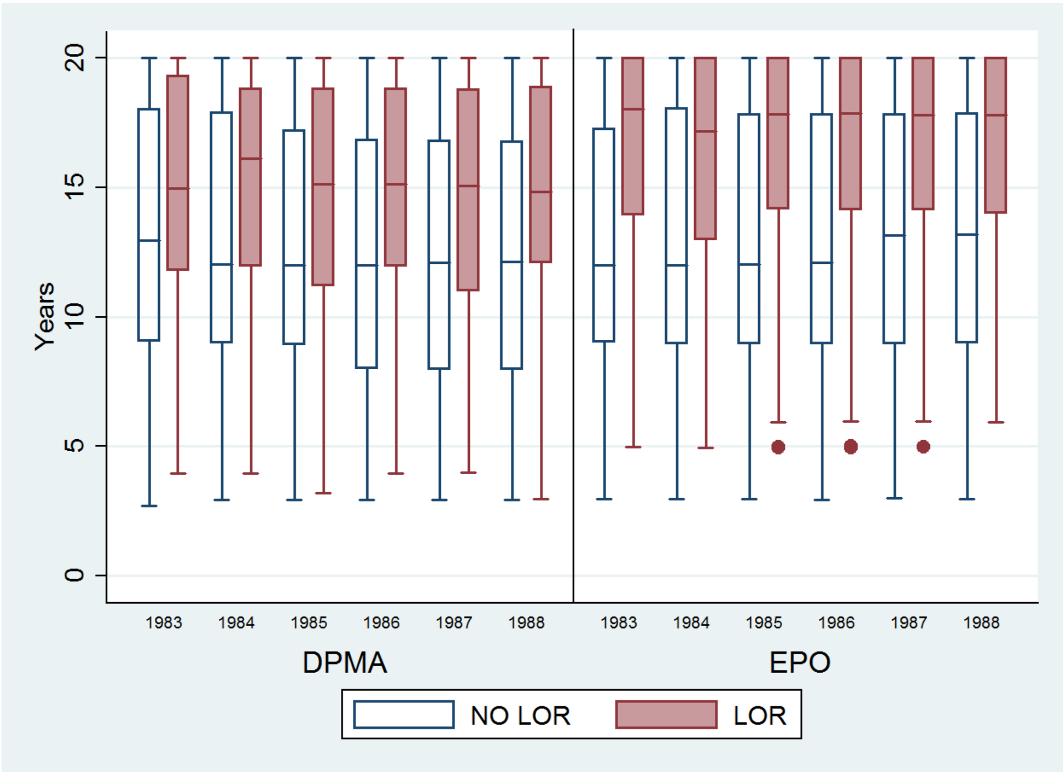

Figure 1.15: Patent Lifetime (Cohorts 1983-1988)

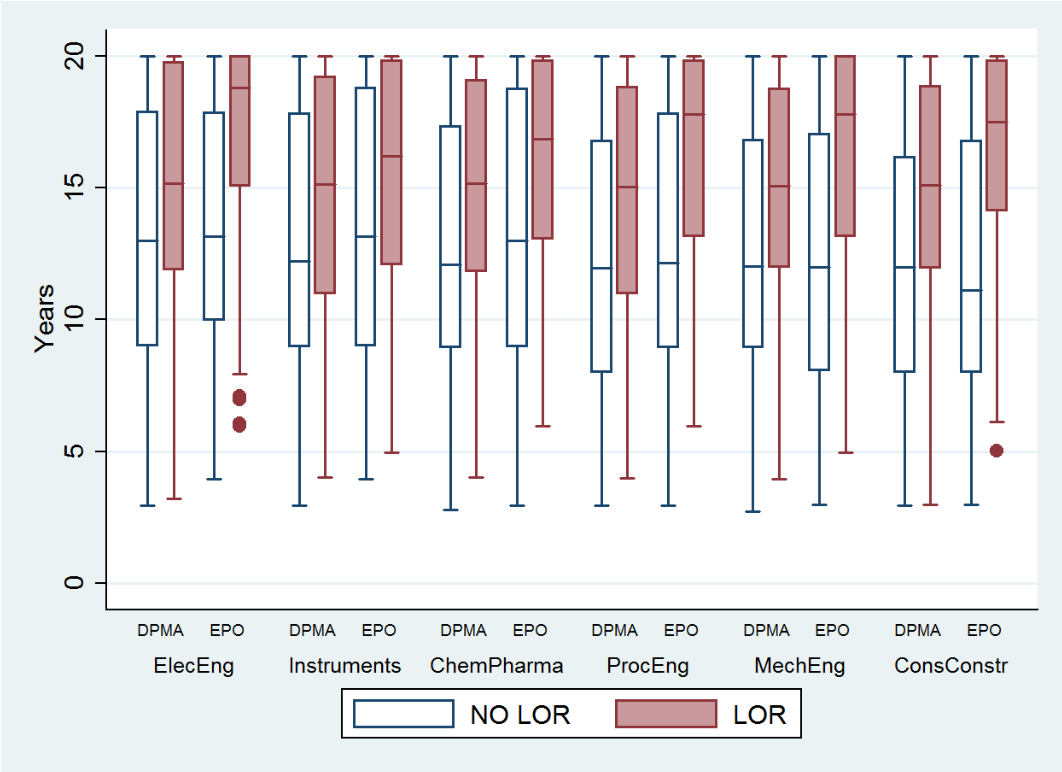

Figure 1.16: Patent Lifetime by Technology Area (Cohorts 1983-1988)

protection has been extended up to 15.5 years for patents granted by the DPMA, and up to 17.5 years for patents granted by the EPO. The difference remained constant over the cohorts considered here. Interestingly, we see the same pattern across different technology areas and applicant types (see Figures 1.16 and 1.17).

1.3.4 Licensing Evidence

To our knowledge, the German patent office has assessed the reasonable compensation in connection with Sec. 23 GPA in at least three cases. Thus, evidence that licensing agreements have indeed been concluded exists. Additionally, several interviews with managers responsible for the IP strategy in large German companies in the areas of electrical and mechanical engineering have been conducted. In their opinion, however, revenue licensing only occurs in very rare cases for patents endorsed LOR and which are owned by large companies. Their explanation was that licensing in Germany, at least in the areas of electrical and mechanical engineering, usually occurs within cross-licensing agreements, or if somebody, be it willfully or innocently, infringes a patent. In general, firms do not look for already patented technologies but try to develop them by themselves. The fact that especially in the high-technology areas licensing requires a lot of additional support–besides of what is written on a patent document–to implement the new technology is a

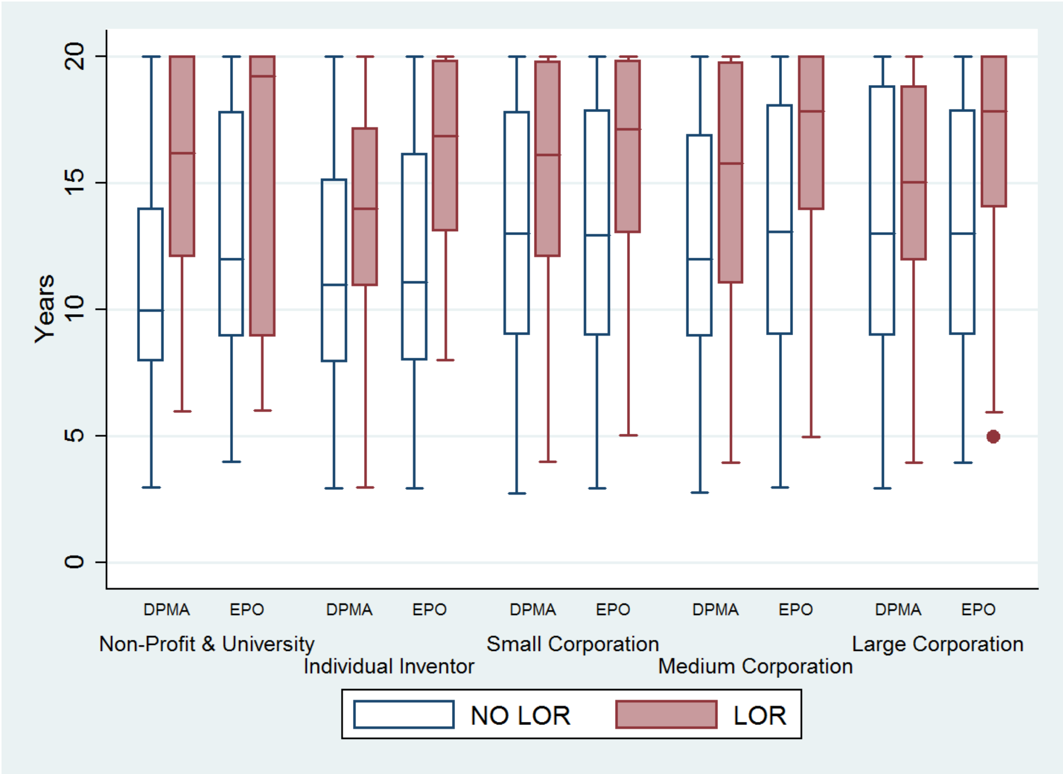

Figure 1.17: Patent Lifetime by Applicant Type (Cohorts 1983-1988)

major reason.

Although information about licensing agreements is usually confidential in Germany, we were able to use data collected within the first PatVal-EU project.[31] The PatVal-EU data set was constructed by collecting information from the inventors of European patents. The objective of the PatVal-EU survey was to collect information on the economic value of European patents, and on other aspects of the innovation process and its output that is not available from other sources. Given the design of the survey it was possible to assign the use to each patent:

1. *Licensing*: The patent is not used internally by the applicant, but it is licensed out to another party;
2. *Internal*: The patent is exploited internally for commercial or industrial purposes. It can be used in a production process or it can be incorporated in a product;

[31]The full scale PatVal-EU survey was conducted from May 2003 to January 2004, and it was directed to the inventors of 27,531 EPO patents with priority date in 1993-1998 located in France, Germany, Italy, the Netherlands, Spain and the United Kingdom. The survey deliberately oversampled patents which were considered to be important (patents with at least one forward citation and that were opposed) in order to increase the sample of valuable patents. In the end, the European inventors responded to 9,624 questionnaires covering 9,017 patents. A detailed description of the research design and of descriptive statistics is presented in Giuri et al. (2007).

	LOR (N=200)	NO LOR (N=5,989)	Difference (t-stat)†
1. Licensing	3.50%	5.86%	-2.36%* (-1.41)
2. Internal	46.50%	51.06%	-4.56% (-1.27)
3. Licensing & Internal	2.50%	3.84%	-1.34% (-0.98)
1. + 2. + 3.	52.5%	60.76%	-8.26%*** (-2.35)
4. Cross-Licensing	7.50%	2.92%	4.58%*** (3.70)
5. Blocking	19.00%	19.24%	-0.24% (-0.08)
6. Sleeping	21.00%	17.08%	3.92%* (1.44)
Total	100%	100%	

†Mean comparison t-test on equality of means $H_0 : diff = 0$. Significance level: 0.05***; 0.1**; 0.2*

Table 1.4: LOR and Patent Use

3. *Licensing & Internal*: The patent is both licensed to another party and used internally by the applicant organization;

4. *Cross-Licensing*: The patent is licensed to another party in exchange for another patented innovation;

5. *Blocking*: The patent is not used (neither internally, nor for licensing). It is held unused in order to block competitors;

6. *Sleeping*: The patent is "sleeping" in the sense that it is not employed in any of the uses described above.

After merging our data set with the PatVal-EU survey data we were left with 6,189 granted patent applications with effect in Germany and information on its use. For 200 (3.23%) patents LOR was declared before December 24, 2008.[32] We conducted a *t-test* for the differences of means between the group of patents with and without a declaration across different uses.

The results in Table 1.4 indicate that patents with LOR have been used significantly more often for cross-licensing than patents without LOR declaration. Only 2.92% of all patents without a declaration were part of a cross-licensing agreement compared to 7.5% of patents endorsed LOR. Cross-licensing is reported to be common in electric engineering (see Hall and Ziedonis 2001). Indeed, almost 50% of all patents for which LOR has been declared are in electrical engineering. Furthermore, patents endorsed LOR were reported to be used significantly less often internally or for revenue licensing. As expected, the willingness to license has often been declared for sleeping patents. Interestingly, there is almost no difference for patents which were used for blocking purposes although blocking,

[32]For 165 patents the willingness to license had been declared before the survey started on May 2003. This justifies the use of the information obtained by the survey.

by definition, relies on the ability to exclude others. A possible explanation for this can be that the intended use of patents can change over time. Patents meant for blocking purposes might turn into sleeping ones.

1.3.5 Withdrawal of the Declaration

In 1992 the lawmaker tried to react to the concerns expressed by the industry that an exclusive license is often regarded as more valuable by potential licensees than a non-exclusive one. A declaration of the willingness to license early in a patent's life could have hindered the optimal exploitation of the innovation in the future. This fear of being locked in, which was perceived as a devaluation of the patent right once the declaration had taken effect, might have caused many patentees not to declare LOR. Thus, the German Patent Act was amended and the option was added to withdraw the declaration as long as no intention of using the invention had been notified. The first potential licensee is now still able to ask for an exclusive license despite an existing LOR declaration. From the static point of view, however, once the invention exists the possibility to withdraw the declaration has only welfare decreasing effects. First, it undermines the commitment effect of the LOR system. Second, it allows the patent owner to leave the LOR regime and retain the right to exclude. He can retrieve the means to grant an injunction given that no prior notification of use has been made.

Surprisingly, the first declaration was not withdrawn until the year 2000, almost 8 years after the amendment had come into force. Since then LOR has been withdrawn for only 386 patent applications (99 European and 287 German patent applications) in all technology areas and by all types of applicants. In a few cases the willingness to license was even repeatedly declared and withdrawn. In 116 cases the withdrawal had occurred even before the patent was finally granted.

In Table 1.5 we relate the number of withdrawals to all declarations made after 1993.[33] LOR declarations have most frequently been withdrawn in discrete technology areas like process engineering, chemistry and pharmaceuticals, and especially consumer goods and construction. In these areas a single patent often covers all of what is needed for one product. This means that commercialization of the protected invention is alleviated since it does not hinge on complementary rights as in complex technology areas. Declarations have been withdrawn by all types of applicants but most frequently by individual inventors (38% of all withdrawals) followed by large corporations (26.5% of all withdrawals). Table 1.5 shows that individual inventors were as well by far the most frequent users of

[33]The earliest declaration of the willingness to license, which was subsequently withdrawn, was made in 1993.

All	Non-Profit&Univ.	IndivInventor	SmallCorp	MediumCorp	LargeCorp	$\sum$
ElecEng	2.83% (3)†	4.90% (15)	2.05% (19)	0.79% (29)	0.59% (54)	0.86% (121)
Instruments	1.80% (3)	6.38% (22)	3.16% (13)	0.89% (10)	0.34% (14)	1.02% (62)
ChemPharma	0.00% (0)	7.75% (11)	1.83% (3)	1.06% (4)	0.59% (5)	1.44% (23)
ProcEng	0.00% (0)	8.35% (33)	1.82% (9)	1.32% (8)	0.18% (2)	1.97% (52)
MechEng	2.78% (3)	4.44% (29)	1.76% (12)	0.50% (13)	0.33% (24)	0.72% (81)
ConsConstr	0.00% (0)	6.88% (34)	2.24% (7)	0.00% (0)	0.43% (2)	2.17% (43)
$\sum$	1.75% (9)	6.17% (144)	2.11% (63)	0.71% (64)	0.44% (101)	1.01% (381)

† Absolute number of withdrawals in parentheses.

Table 1.5: Withdrawals by Technology Area and Applicant Type as a Fraction of all Declarations Made between 1993 and 2008

the possibility of withdrawing the declaration in relative terms. They are followed by small corporations and non-profit organizations and universities. Interestingly, large corporations come last. It is very likely that LOR is withdrawn when the patent owner finds a way how to exploit the invention himself or intends to license it exclusively. Therefore the provision might in fact have helped small and individual inventors to commercialize their inventions as intended by the legislator.

An interesting question pertains to the time it took to withdraw the LOR declaration after it had been declared. In the areas of process engineering, mechanical engineering and consumer goods and construction the majority has been withdrawn within the first year after the declaration (see Figure 1.18). In these three areas almost 55% of all patent applications belonged to individual inventors who withdrew very soon after the declaration. Corporations, the medium sized ones in particular, tended to wait longer in case they withdrew. Only in the area of instruments the majority of withdrawals occurred more than 2.5 years after the declaration.

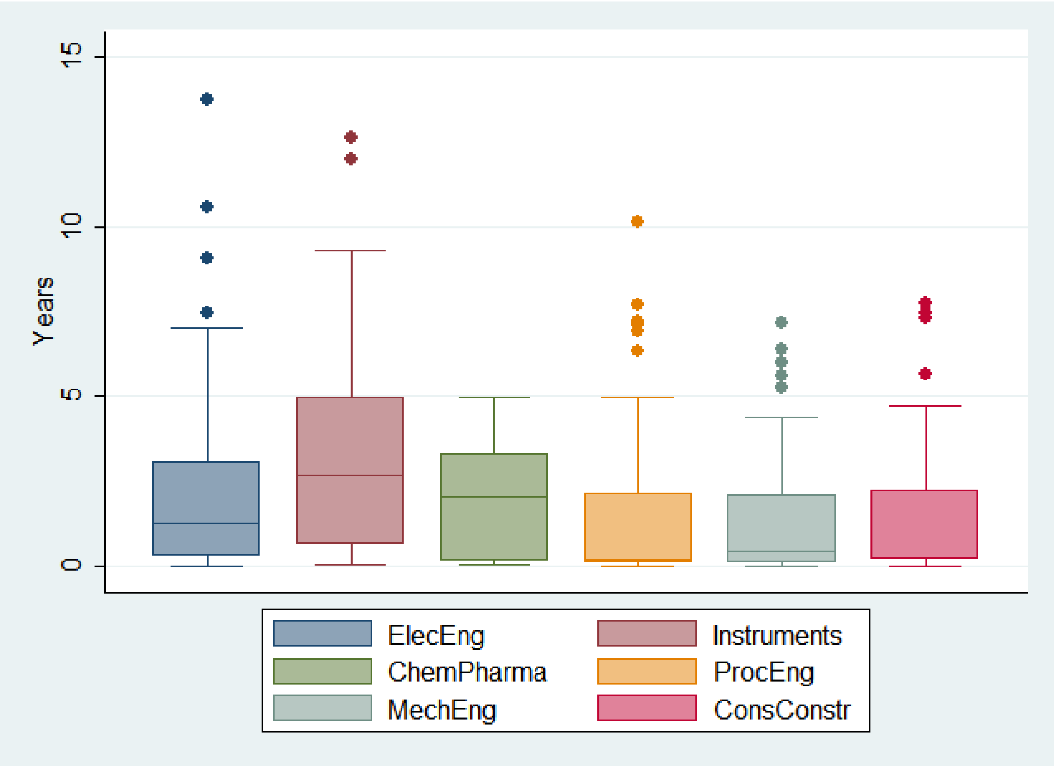

Figure 1.18: Time between Declaration and Withdrawal by Technology Area (Cohorts 1983-1988)

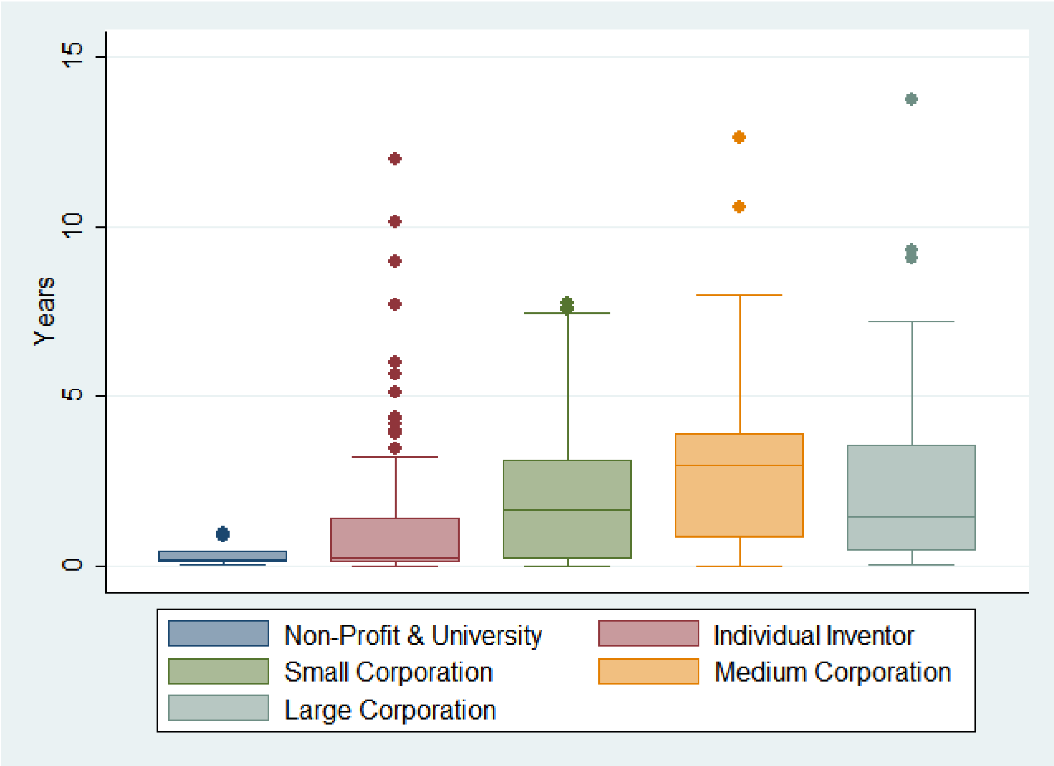

Figure 1.19: Time between Declaration and Withdrawal by Applicant Type (Cohorts 1983-1988)

1.4 Theoretical Foundations

1.4.1 Theoretical Model of the Declaration of the License of Right and Patent Renewal

In this section we develop a model that incorporates both, the decision of an agent to renew a patent and the decision to declare the willingness to license. It builds on previous work done by Pakes (1986) and Lanjouw (1998), who were the first to build a dynamic stochastic model of the patent renewal decision.[34]

General Set-up

The patent system In our model an agent can acquire a patent with full protection, which allows him to exclude others from the patented invention. Preserving protection is not free of charge, so he must pay renewal fees $c_t = f_t$ at the beginning of every period $t \in 1, ..., T$. Let $T < \infty$ be the maximum number of years a patent can be renewed.

[34] Serrano (2011) has also used a patent renewal model and incorporated a third decision, namely the decision to transfer the patent in his paper.

We assume that the fees are rising with the patent's maturity as it is common for most patent systems. Furthermore, if the agent refuses to pay the fees, the patent expires irrevocably. Additionally, we introduce a second type of protection, the license of right (LOR). Contrary to the full protection regime it is not allowed to exclude others any more, but the right for reasonable remuneration through licensing still exists. Since LOR might be seen as inferior to full protection, the patent owner has to pay only half of the usual renewal fees $c_t = \frac{1}{2} f_t$ for all future periods. Once LOR is chosen the patentee cannot return to full protection anymore.

The agents We assume that every patent belongs to exactly one profit maximizing agent and generates a per period return z_t.[35] He can choose between up to three different strategies in the beginning of every period. Dependent on his previous choices he can either keep full protection (K) and pay f_t, declare LOR (L) and pay $\frac{1}{2} f_t$, or let the patent expire (X) and avoid any payments.

Evolution of returns The type of protection determines the returns z_t of an agent in every period. We assume that the yearly returns in case of full patent protection, $z_t = r_t$, differ from returns from a patent endorsed LOR, $z_t = y_t$, and are 0 if the patent expires, $z_t = 0$. The exact per period returns are assumed to be known to the agent only at the beginning of each period.

We allow the returns to evolve in the following way over time:[36]

- In the beginning an initial return is assigned to each patent, r_1, which is drawn i.i.d. from a continuous distribution F_{IR} on a positive domain.
- If full protection is kept (K), the returns in the next period will be multiplied by a yearly growth rate g_t^k, $t \in 2, ..., T$. This means that the yearly returns in the second period will be $r_2 = g_2^k r_1$ and $r_t = g_t^k r_{t-1}$ in the following ones. In each year t the growth rates $g_t^k \in \left[0, B^K\right]$ are drawn from a distribution with the cumulative density function $F_{g^k}(u^k \mid t) = Pr\left[g^k \leq u^k | t\right]$. Furthermore, we assume that the probability to draw a high growth rate and increase the yearly returns from patent protection decreases with a patent's maturity in the sense of first-order stochastic dominance $(F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1))$.[37] Agents are assumed to know the true probability distributions $F_{g^k}(u^k \mid t)$, $t \in 2, ..., T$ already in the first year.

[35] Alternatively, one could assume that all patents are independent of each other.

[36] The following stochastic specification fulfills the Markov property. This means that the returns in the future periods will be independent of past periods' returns.

[37] Usually, the application and usage of an invention is determined early in a patent's life. The probability to discover new uses in later periods should accordingly be lower.

- During the LOR regime (L) the returns differ by a multiplicative factor from the ones in the K-regime, $y_t = g_t^l r_t$, $t \in 1, ..., T$. The LOR factor represents the part of returns from full patent protection that can be realized by the patentee if he gives up his right to exclude others. In each period the values $g_t^l \in \left[0, B^L\right]$ are drawn anew from a distribution with the cumulative density function $F_{g^l}(u^l) = Pr\left[g^l \leq u^l\right]$. The probability distribution $F_{g^l}(u^l)$ is assumed to be known to all agents.

Maximization problem In the beginning of each period the agent chooses the strategy with the highest expected value. Unlike in deterministic models, where the value functions consist only of returns in the current period, here, the option value of future periods also has to be taken into account. Assume the patentee has kept full patent protection in all previous years $1, ..., t-1$. If the agent decides to keep full patent protection (K) in year t, his value function $\widetilde{V}^K(t, r_t)$ will consist of the current returns r_t, less the renewal fees f_t, plus the value of having the option to choose the optimal strategy in the next period. This option value will be determined by r_t and is defined as the discounted expected value of the optimal strategy in year $t+1$, $\widetilde{V_K}(t+1, r_{t+1}, y_{t+1})$.[38] With β representing the discount factor between the periods it follows:

$$\widetilde{V}^K(t, r_t) = r_t - f_t + \beta E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] \tag{1.1}$$

$$\text{with } E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] = \int \int \widetilde{V_K}(t+1, u^k r_t, u^l u^k r_t) dF_{g^k}(u^k \mid t) dF_{g^l}(u^l)$$

Similarly, if he decides to choose strategy (L) instead, the yearly returns will be multiplied by the the factor g_t^l in each period, $y_t = g_t^l r_t$, and the renewal fees reduced by one half. Since strategy (K) will not be possible once LOR has been declared, the option value is now defined as the discounted expected value of the optimal strategy in year $t+1$, $\widetilde{V_L}(t+1, y_{t+1})$.[39] The expected value of choosing strategy (L) can now be written as

$$\widetilde{V}^L(t, r_t, y_t) = y_t - \frac{1}{2} f_t + \beta E\left[\widetilde{V_L}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] \tag{1.2}$$

$$\text{with } E\left[\widetilde{V_L}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] = \int \int \widetilde{V_L}(t+1, u^k r_t, u^l u^k r_t) dF_{g^k}(u^k \mid t) dF_{g^l}(u^l)$$

[38] Subscript K means that strategy (K) was chosen in all previous periods.
[39] Subscript L means that strategy (L) was chosen in one of the previous periods.

However, if he decides to let the patent expire he will lose all possible returns from patent protection, but also the obligation to pay renewal fees:

$$\widetilde{V}^X(t) = 0 \tag{1.3}$$

Now, we can define $\widetilde{V_K}(t, r_t, y_t)$, the value function of the optimal strategy in period t, if the patent has been renewed with full patent protection throughout the periods $1, ..., t-1$,

$$\widetilde{V_K}(t, r_t, y_t) = max\left\{\widetilde{V}^K(t, r_t), \widetilde{V}^L(t, r_t, y_t), \widetilde{V}^X(t)\right\}$$

and $\widetilde{V_L}(t+1, r_{t+1}, y_{t+1})$, the value function of the optimal strategy in period t, if the strategy (L) was chosen in one of the previous periods,

$$\widetilde{V_L}(t, r_t, y_t) = max\left\{\widetilde{V}^L(t, r_t, y_t), \widetilde{V}^X(t)\right\}$$

Since the maximum number of years a patent can exist is finite, there is no option value in the last period, such that $\beta E\left[\widetilde{V_i}(T+1, r_{T+1}, y_{T+1}) \mid r_T\right] = 0$ for $i \in \{K, L\}$.

Some properties of the value functions are provided in the following lemma.

Lemma 1.1. *The value functions* $\widetilde{V}^K(t, r)$ *and* $\widetilde{V}^L(t, r, y)$*, with* $t = 1, ..., T$*, are*

(i) increasing and (ii) continuous in the current returns r *and* y*,*

(iii) and weakly decreasing in t*.*

Proof. See Appendix 1.7.1. ■

The agent's decision in year t whether to keep the patent with full protection (K), to declare LOR (L), or to let it expire (X) will be fully determined by the per period returns r_t and the non-exclusivity factor g_t^l. The optimal strategy will depend on whether r_t and g_t^l (and thus y_t) will exceed the following threshold values, or not.

Definition 1.1.

$\{\hat{r}_t\}_{t=1}^{T}$: *patent returns that make the agent indifferent between choosing strategy (K) and choosing strategy (X). It depends on the age of the patent* t *and is defined as the solution to* $\widetilde{V}^K(t, r_t) = \widetilde{V}^X(t) = 0$.

$\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^{T}$: *LOR factor that makes the agent indifferent between declaring LOR (L) and keeping full patent protection (K). It depends on the age of the patent* t *and the level of per period returns* r_t*. It is defined as the solution to* $\widetilde{V}^K(t, r_t) = \widetilde{V}^L(t, r_t, y_t) = \widetilde{V}^L(t, r_t, g_t^l r_t)$.

$\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^{T}$: *LOR factor that makes the agent indifferent between declaring LOR (L) and letting the patent expire (X). It depends on the age of the patent* t *and the level of per period returns* r_t*. It is defined as the solution to* $\widetilde{V}^L(t, r_t, g_t^l r_t) = \widetilde{V}^X(t) = 0$.

Lemma 1.1 guarantees that these cut-off values exist and are unique.[40] They are functions in the (r_t, g_t^l)-space and divide it in three, respectively two, decision regions (see Figures 1.20 and 1.21).

Consider a patent that has been renewed with full protection up to period t. The patentee has three options. He can renew the patent with full protection (K), declare LOR (L), or let it expire (X). Letting the patent expire will be the optimal strategy if and only if the per period returns and the LOR factor are too low, $r_t < \hat{r}_t$ and $g_t^l < \hat{g}_t^{l-}(r_t)$. In this case, renewal in whatever regime would not justify the statutory renewal fees. This corresponds to the region in the lower left part of Figure 1.20. If in turn the current per period returns are high enough, such that renewal is optimal in any case, $r_t \geq \hat{r}_t$, the agent will renew the patent with full protection (K), as long as the LOR factor is not too high, $g_t^l < \hat{g}_t^{l+}(r_t)$. These patents are located in the lower right part of the figure. The last strategy to consider is LOR. A declaration of the willingness to license can become optimal out of two motives, the cost-saving and the commitment motive. The cost-saving motive will be relevant if the per period returns are too low to maintain full patent protection, $r_t < \hat{r}_t$, while the LOR factor is still large enough, $g_t^l \geq \hat{g}_t^{l-}(r_t)$. In this case, as long as exclusivity is not too valuable, the reduction in renewal fees can induce the agent to declare LOR and renew the patent. The commitment motive will be relevant if the per period returns are such that the patent will be renewed in any case, $r_t \geq \hat{r}_t$, but the commitment to abandon exclusivity is of similar value as the right to exclude others, $g_t^l \geq \hat{g}_t^{l+}(r_t)$.

Consider now a patent that has been renewed up to period t and for which LOR has been declared in one of the previous periods. In this case the patentee has only two options. He can either renew the patent with LOR (L) for the next period or let it expire (X). Given

[40] Since the value functions are weakly increasing and continuous in y_t, they must also be weakly increasing in g_t^l for a given r_t.

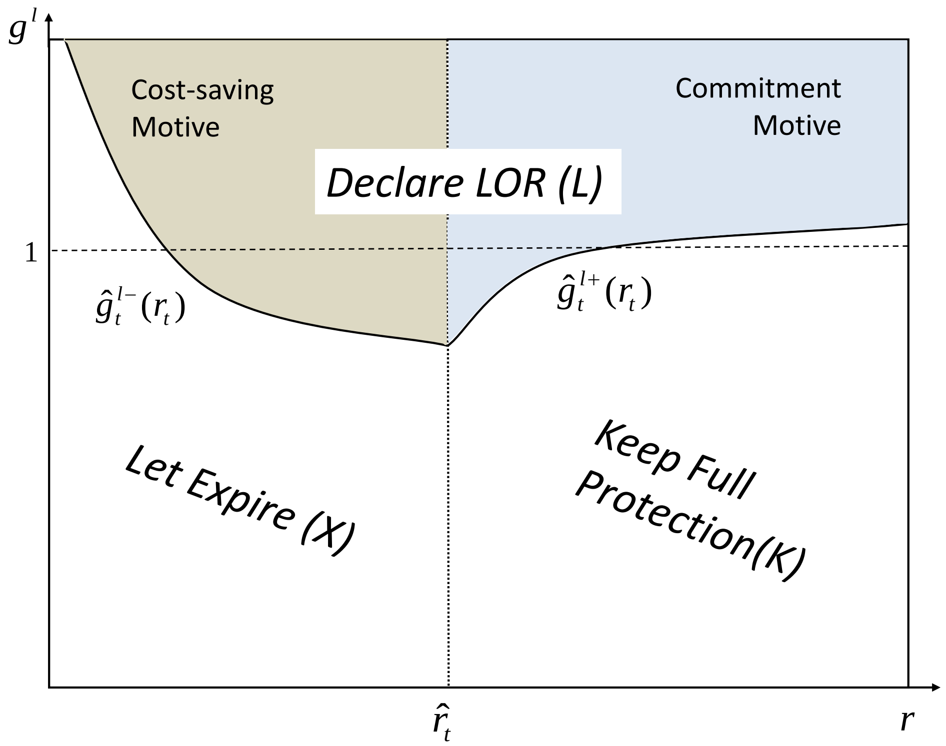

Figure 1.20: Strategy Space of a Patent with Full Protection

the current period's returns from full patent protection r_t, renewal will only be optimal if $g_t^l \geq \hat{g}_t^{l-}(r_t)$. These are all (r_t, g_t^l) combinations that lie above the $\hat{g}_t^{l-}(r_t)$-curve in Figure 1.21. All patents that lie below this function will not be renewed, since the revenues will be too low to justify even the reduced renewal fees.

Corollary 1.1. *The probability of expiration in a given year is higher for patents endorsed LOR compared to patents with full patent protection.*

Proof. See Appendix 1.7.1. ■

The intuition for the corollary is the following. As long as LOR has not been declared, the patentee can still choose among all three options. Thus, he will only let his patent expire if the expected returns in case of full protection as well as LOR are too low, i.e., $g_t^l < \hat{g}_t^{l-}(r_t)$ and $r_t < \hat{r}_t$. In turn, if LOR has already been declared in the past he will let his patent expire even if full protection was profitable, since $g_t^l \geq \hat{g}_t^{l-}(r_t)$ is the only condition relevant for renewal.

1.4.2 Comparative Statics

In this section we analyze how the returns from patent protection (selection effect) and the age of a patent (horizon effect) determine the agent's strategy choices.

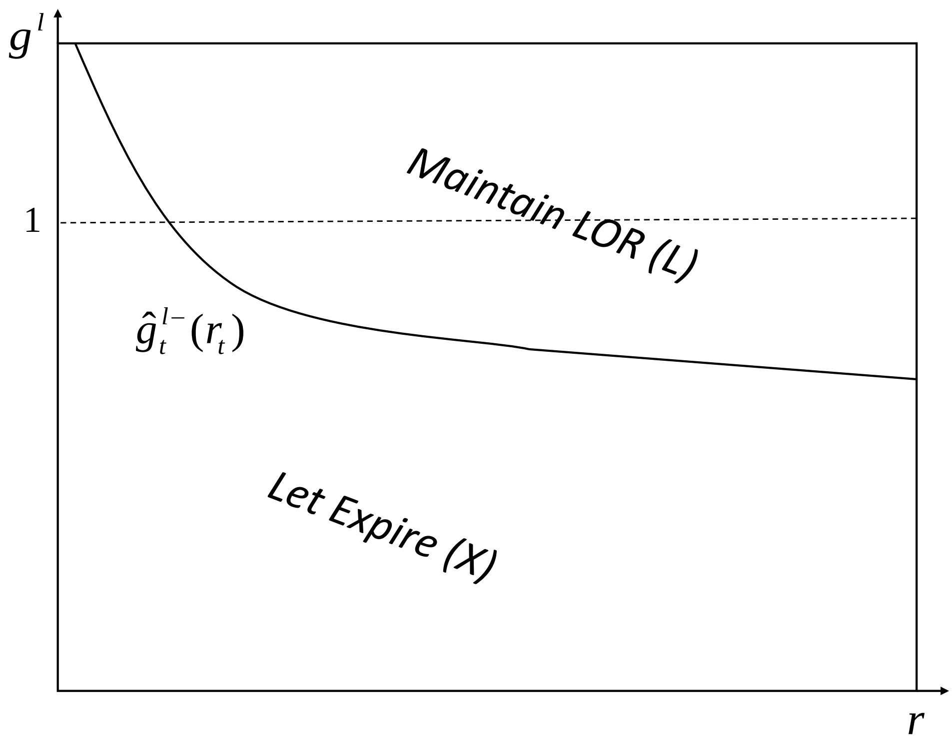

Figure 1.21: Strategy Space of a Patent Endorsed LOR

Selection effect

The selection effect tells us how the probability of observing a LOR declaration or an expiration decision for a patent changes with the per period returns r_t.

Proposition 1.1. *If the difference between the option values of strategies (K) and (L),* $E\left[\widetilde{V_K}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right]$*, is not concave in* r_t*, then*

(i) $\hat{g}_t^{l-}(r_t)$ *will be weakly decreasing in* r_t *and*

(ii) $\hat{g}_t^{l+}(r_t)$ *will be weakly increasing in* r_t*.*

Proof. See Appendix 1.7.1. ■

Again, assume that an agent has renewed his patent up to period t. There are two cases to be considered. If the patentee has already declared LOR in one of the previous periods he has to decide whether to keep this patent right (L) or to let it expire (X). He will only renew if this period's returns from patent protection $y_t = g_t^l r_t$ and the option value $\beta E\left[\widetilde{V_L}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right]$ are high enough to cover the renewal fees $\frac{f_t}{2}$. We know from Lemma 1.1 that the option value is non-decreasing in r_t. Thus, the higher r_t, the lower can be the LOR factor g_t^l for the agent to still renew the patent. This is why the function $\hat{g}_t^{l-}(r_t)$ in Figure 1.21 is decreasing. If we define the probability for a patent endorsed

LOR to expire in year t as $Pr(g_t^l < \hat{g}_t^{l-}(r_t))$, then this probability must also be decreasing in r_t.

Consider now the case that the patent has been renewed with full protection in all previous periods. If the returns from full patent protection are low, $r_t < \hat{r}_t$, i.e., the patent is of low value, he will decide not to keep full patent protection and the choice will be between (L) and (X). This is equivalent to the first case and the cut-off value function $\hat{g}_t^{l-}(r_t)$ will be decreasing in r_t in the respective region (Figure 1.20). If, however, the returns from full patent protection are high enough, $r_t \geq \hat{r}_t$, the agent will choose between (K) and (L). Assume that the difference in the option values in case of full patent protection and LOR is not concave in r_t.[41] Now, the higher the per period returns r_t, the less important will be the reduction in renewal fees relative to the reduction in expected future returns due to the loss of exclusivity. Therefore, for valuable patents a high LOR factor g_t^l is needed for the patentee to choose LOR in this period. This is represented by an increasing function $\hat{g}_t^{l+}(r_t)$ in Figure 1.20. To sum up, if the current returns from full patent protection are low, then the probability of observing a declaration in period t, defined as $Pr(g_t^l \geq \hat{g}_t^{l-}(r_t) \mid r_t < \hat{r}_t)$ will be increasing in r_t. However, if the patent is of relatively high value, the probability of observing a declaration, $Pr(g_t^l \geq \hat{g}_t^{l+}(r_t) \mid r_t < \hat{r}_t)$ will be increasing in r_t.

Horizon effect

In our model, by assumption, not only the renewal fees but also the probability distribution of the growth rates vary with t. Consequently, the patent age should have an impact on both the decision to declare LOR and the decision to let the patent expire. This is reflected in the following two propositions.

Proposition 1.2. *The cut-off value $\hat{r}_t$ is non-decreasing in t.*

Proof. See Appendix 1.7.1. ■

The threshold value $\hat{r}_t$ is only relevant for patents that kept full protection in all previous periods. It divides these patents in two categories. The ones that would certainly have been dropped (if $r_t < \hat{r}_t$) and the ones that would certainly have been renewed with full protection ($r_t \geq \hat{r}_t$), if the LOR system had not existed. Given that the renewal fees

[41] Simulations with different distribution functions (f.e. exponential, uniform, Rayleigh) have shown that it is sufficient to assume that $E(g^l) < 1$ and that the density function $F'_{g^l}(u^l)$ is decreasing fast enough for higher values of g^l. The reduction in maintenance fees in each year is fixed and independent of r_t, whereas the "expected loss" in returns from the declaration, $[1 - E(g^l)]r_t$, increases with r_t. These assumptions are justified since we would observe far more declarations in the data if $E(g^l) \geq 1$ was the case and $F_{g^l}(u^l)$ was increasing for higher values.

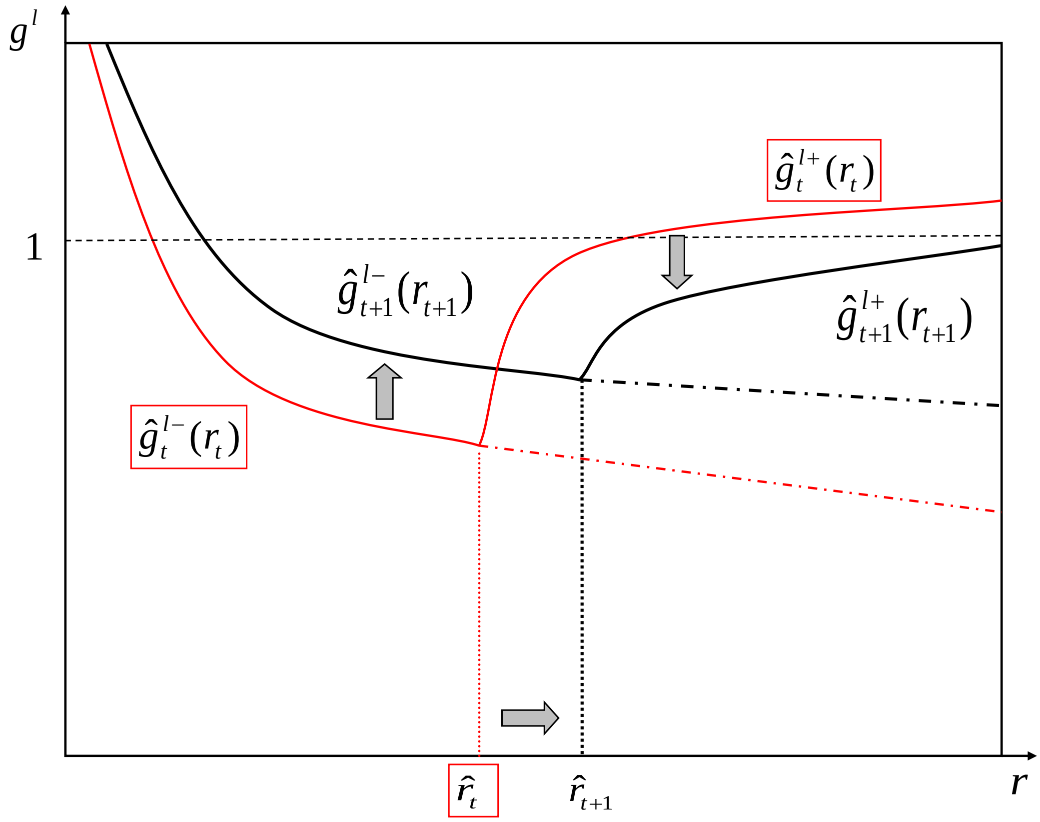

Figure 1.22: Selection and Horizon Effect

are increasing and the option value is decreasing with t, the per period returns r_t needed to belong to the second category will increase with the maturity of the patent. This is represented by the shift of $\hat{r}_t$ to the right for the older period in Figure 1.22.

Proposition 1.3. *Given per period returns from full patent protection r*

(i) $\hat{g}_t^{l-}(r)$ is non-decreasing in t and

(ii) $\hat{g}_t^{l+}(r)$ is non-increasing in t.

Proof. See Appendix 1.7.1. ■

Consider patents that generate equal per period returns from full patent protection r, but at different ages. If a patent is already endorsed LOR, the factor g_t^l will determine whether the patent owner renews the patent (L) or let it expire (X). Compared to later periods, in earlier periods not only are the renewal fees lower, but the option values are higher, too. The minimum factor needed for the patentee to renew the patent in a given period, $\hat{g}_t^{l-}(r)$, must not exceed the ones of the subsequent period, $\hat{g}_{t+1}^{l-}(r)$. This shifts the threshold value function $\hat{g}^{l-}(r)$ upwards for older patents (see Figure 1.22). The implication is that if you compare two patents of different age, both with equal per period returns r and both endorsed LOR, the older one will have the same or higher probability to expire: $Pr(g_t^l < \hat{g}_t^{l-}(r)) \leq Pr(g_{t+1}^l < \hat{g}_{t+1}^{l-}(r))$.

For patents which have kept the right to exclude others, the patent's maturity influences not only the probability of expiration but also the probability of declaration. The probability of expiration in year t for a patent with full protection is defined as $Pr(g_t^l < \hat{g}_t^{l-}(r) \wedge r < \hat{r}_t)$. We know from Proposition 1.2 and Proposition 1.3 that $\hat{r}_t$ and $\hat{g}_t^{l-}$ are increasing with a patent's age t, thus unambiguously increasing the probability of expiration.

The effect on the probability of declaration is less clear. From above we know that there are two types of patents for which LOR will be declared.

The first group consists of patents for which the per period returns are too low for the agents to keep full protection, $r_t < \hat{r}_t$. However, if the LOR factor g_t^l and the reduction in maintenance fees are high enough, they will choose to declare LOR instead. On the one hand, according to Proposition 1.2, the probability for a patent to fall into this category, $Pr(r < \hat{r}_t)$ rises with a patent's maturity, since $\hat{r}_t$ is increasing with age t. On the other hand, for older patents, a higher LOR factor will be necessary for the LOR regime to be profitable ($\hat{g}_t^{l-}(r)$ is non-decreasing in t), making a declaration for this type of patents less likely to occur. $Pr((g_t^l \geq \hat{g}_t^{l-}(r)|r < \hat{r}_t))$ will decrease with t.

The second group consists of patents with per period returns high enough for renewal with full protection, $r \geq \hat{r}_t$, but for which declaring LOR is even more profitable. In this case, maturity reduces the probability to fall into this category (again, $\hat{r}_t$ is increasing with t), $Pr(r \geq \hat{r}_t)$. At the same time, a lower LOR factor is needed for a patent owner to be willing to declare LOR regime ($\hat{g}_t^{l+}(r)$ is non-increasing in t), which increases the probability of this type of declaration, $Pr((g_t^l \geq \hat{g}_t^{l+}(r)|r \geq \hat{r}_t))$. The reason is that the losses in option value the patentee will suffer if he chooses strategy (L) instead of strategy (K), will decrease with every period as the patent approaches year T.[42] Furthermore, the absolute reduction in maintenance fees soars, since the renewal fees are increasing in t.

Overall, the effect of patent age on the probability of observing a LOR declaration $Pr((g_t^l \geq \hat{g}_t^{l-}(r) \wedge r < \hat{r}_t)) + Pr((g_t^l \geq \hat{g}_t^{l+}(r) \wedge r \geq \hat{r}_t))$ is ambiguous.

[42] The losses in option value arise because once LOR (L) has been declared it is not possible to choose strategy (K) anymore, but it is always possible to switch from full patent protection (K) to (L).

1.4.3 How to Profit from the Declaration of the Willingness to License

In the model presented above we have explicitly assumed that patent owners are able to generate returns from patent protection if they declare LOR. We have stated that the LOR growth rate g^l represents the fraction of returns from full patent protection that can be realized when the patentee forgoes the exclusion right and has only a right to reasonable remuneration. In our model g^l is even allowed to exceed 1. In this section we will discuss how patentees can profit from a LOR declaration and when it can be superior to a renewal with full patent protection.

Complementary assets theory As Teece (1986) already noticed, "the successful commercialization of an innovation requires that the know-how in question be utilized in conjunction with other capabilities or assets. Services such as marketing, competitive manufacturing and after-sales support are almost always needed. These services are often obtained from complementary assets". According to his classification there are three types of complementary assets depending on the relationship between the asset and the innovation. Teece calls innovations with bilateral dependence co-specialized, with unilateral dependence, specialized and assets which do not need to be tailored to the innovation, generic. If the complementary assets needed are specialized or co-specialized contractual relationships are exposed to hazards. One or both parties will have to commit capital to certain irreversible investments which will be valueless if the relationship between the patent owner and licensee breaks down. This constitutes a classical hold-up situation. Because of this risk a licensee-licensor relationship with many specialized or co-specialized complementary assets involved will tend to be exclusive in order to overcome the problem of possible opportunism from the patent owner. In the case of generic assets, it might be optimal for the inventor who lacks and cannot afford them to license its technology to as many firms as possible. In this case the revenues from patents with and without LOR should be equal. Hence, a declaration of the willingness to license might be a profitable option even at an early stage of a patent's life when the renewal fees are almost negligible. Patent owners who lack complementary assets, most probably individual inventors, should declare the willingness to license more often, especially if the assets are generic.

Licensing as a commitment device The declaration of the willingness to license can also act as a credible commitment to allow competition, as it cannot be withdrawn once the intention of using the invention has been notified. Shepard (1987) shows that if the setup costs required for using a product are high, buyers of a new product may be reluctant to incur these costs if the patent owner may raise the prices ex post. This reduces the demand and also the profits of a monopolist. By declaring the willingness to license, the seller, on the one hand, invites competitors into the market, thus committing to competitive instead of monopoly prices in the future. On the other hand, he can ensure a higher demand and can collect royalties from his competitors. Farrell and Gallini (1988) show that this strategy can be profitable even for negligible royalties as long as the product-specific setup costs incurred by technology users are sufficiently high.

According to Arora and Fosfuri (2003), even if there are no product-specific setup costs, commitment to non-exclusive licensing can be a profitable strategy if there are possible alternatives which compete with the innovator's technology. Since the gains from licensing to other entrants, which do not possess the required technology (revenue effect) might be higher than losses from an increase of competition in the already competitive product market (rent dissipation effect), patent owners might declare willingness to license. The rent dissipation effect is lowest if the firm has a small market share and the competing technological alternatives are highly substitutable. The licensor will internalize fewer losses due to increased competition from licensing. However, if the competition in the market for technology is too strong and the number of potential licensees is bounded, a licensor will have weaker bargaining power vis-à-vis the prospective licensees and the revenue effect might be too small.

Diffusion of innovation Harhoff et al. (2003) argue that a user-innovator can have sufficient incentives to freely reveal his innovation instead of patenting or keeping it secret and profiting from in-house use. By doing this he can increase the diffusion of the innovation relative to what it would be if it were held secret or exclusive. The increased diffusion could have several positive externalities for the agent. Among these are network effects, reputational gains and related innovations induced among and revealed by other user-innovators. Already Shepard (1987) mentions that in industries which undergo substantial modifications and in which complementary devices extending its applications are developed, cooperation on product development can substantially reduce industry R&D costs. By revealing the innovation, the particular development tasks can be undertaken by the most efficient firm, thereby reducing duplicative R&D. Furthermore, the revealed innovation can become an informal standard in the industry, thus preempting the development or adoption of other versions of the innovation. This will give the innovator a comparative advantage if the innovation that is revealed is designed in a way that is especially appropriate to conditions unique to the innovator (Allen 2003). These positive effects should be less important in the case of the declaration of the willingness to license compared to completely free revealing, as the patent owner still maintains the patent right. Nonetheless, as patent owners credibly commit to open the technology, the positive effects can still be significant. For example, in industries in which standards play a crucial role, such as semiconductors or telecommunication, firms may license aggressively because they would like their technology to be widely diffused. Negative effects from free revealing come from the possible loss of competitive advantage to other innovation users, which will be higher the stronger the competition between them is. Contrary to free revealing, in case of having a patent with a declared willingness to license, these negative effects can partially be offset by the income from licensing payments. However, one should also take into account that contrary to free revealing, licensing is in general associated with positive transaction costs, as they are usually complex and hard to monitor. Summing up, if the positive external effects from putting the technology into public domain can possibly offset its losses, willingness to license should be declared.

Patent portfolio strategies Kim and Vonortas (2006) have found that the size of the stock of technical knowledge, especially the current patent stock, is very important for selling technology non-exclusively. They argue that firms with large patent portfolios may have more technologies available than they can exploit internally. In every technological division of larger firms the corresponding patent portfolios are reviewed regularly. Thus, it is necessary to decide each year which patents should be renewed and which not, as the costs of maintaining them are increasing exponentially from year to year. One possible alternative to letting a patent expire can be to declare the willingness to license and save half of the renewal fees, thus committing to be ready to license the technology non-exclusively. Furthermore, firms may be interested in extending the revenue stream from technologies that have passed their prime for internal use but which are still of value to others. Inferior technological substitutes, for example, might still be valuable to low-quality producers.

According to recent literature, large firms are reported to have set up a dense web of patents, so called "patent thickets", in certain fields such as semiconductors (see von Graevenitz et al. 2012). Firms are trying to accumulate large patent portfolios in order to be able to navigate the dense web of property rights. Hence, the technology is often protected by multiple patents, not all being considered "essential". If considered individually, they might not even be valuable to the owner but important if they are part of a portfolio. As costs to maintain a portfolio of patents are increasing with every patent, declaring the willingness to license for patents which are not considered essential but have potential to be valuable seems to be a lucrative strategy. This makes it possible to maintain a strong patent protection/portfolio at lower costs in a technological area where "battles" usually occur for packages of patents and not for a single one.

Cross-licensing Another possibility to save costs, which is closely related to the patent portfolio argument, might be within the scope of cross-licensing. Cross-licensing agreements typically consist of many patents (patent packages) which are exchanged between firms to guarantee the freedom to operate. Interviews have confirmed that in many technological areas where cross-licensing agreements are conducted, the instrument of declaring willingness to license is often used. Following the considerations above, it might be advantageous to declare the willingness to license for patents once a cross-licensing agreement has been set up. Also for patents which were intended to, but did not become part of a cross-licensing agreement, the decision to let a patent expire can be postponed due to lower renewal fees. In the case of an existing cross-licensing agreement, especially if all relevant competitors are involved, declaring the willingness to license can even be a mutually beneficial strategy. Furthermore, the declaration of the willingness to license itself can constitute a type of cross-licensing agreement if all parties can agree on it.

Non-core technologies Many firms own not only patents which are related to the core technologies of its business but also to technologies that might be considered as fringe or peripheral.[43] During an innovation or research process many other valuable applications might develop which cannot be applied or exploited by the firm but still might have some value. As long as this innovation does not create value for competitors, willingness to license can come into consideration. These firms usually do not readily look for potential licensees, so the expected returns from licensing are very uncertain. However, since the patent has a low private value to the firm[44] and the declaration of the willingness to license might even increase the probability to find a licensee, declaring LOR might be beneficial. Especially for firms acting in markets where products and processes are of complex and multi-technological nature, spin-offs that are peripheral to the core technologies might be very likely. Moreover, as firms do not exploit any production and commercialization possibilities, they do not face any competition in their non-core technologies. Thus, they have lower incentives to protect them strategically than in the case of core-technologies.

Patent prosecution and litigation As Lanjouw and Schankerman (2001) have shown, small firms are more likely to be involved in patent litigation than large firms. Large firms have broader patent pools which can be used for cross-licensing, as well as repeated interactions with licensing partners and bigger legal departments. Thus, the question arises whether by declaring the willingness to license a small firm can reduce its risk of being litigated escaping the cost associated with the legal proceeding. If the patentee

[43] Gambardella and Torrisi (1998) and Giuri et al. (2004) show that large firms have a broader technological than product diversification.

[44] This value can only stem from potential licensing revenues.

declares the willingness to license he commits to making licenses available to anybody, thus abandoning the option to hold-up potential plaintiffs. This strategy seems to be even more appealing in the case of relatively broad patents as the risk of being litigated might be increasing with the extent to which a given patent covers the field to which it pertains.[45]

The declaration of the willingness to license can also constitute a possible settlement outcome in patent litigation or opposition proceedings. The declaration could serve as a signal to stop litigating or prosecuting and to credibly start talking about licensing terms. Especially small firms, which usually have a weaker bargaining position vis-à-vis bigger firms, can thereby opt for the patent office to mediate for reasonable licensing terms in case the parties cannot agree on a compensation scheme. For instance, in the considered time span, willingness to license has been declared 708 times during an opposition proceeding (338 of which successfully survived the proceedings and some were still not decided on December 24, 2008) and 19 during an invalidity proceeding.

1.5 Multivariate Analysis

In this section we further elaborate on the predictions developed in the theoretical part using data on 776,519 German patents from cohorts 1983-1998.[46] We first derive the respective hypotheses for both the decision to declare LOR and the decision to let the patent expire. We then describe the dependent variables and test them using parametric models. The discussion of the results of the empirical analysis follows.

1.5.1 Hypotheses

The first hypotheses about the probability of observing a declaration of LOR can be directly derived from the theoretical model of declaration and renewal. Propositions 1.1 and 1.3 tell us that the effects of age and returns from patent protection are different for patents with sufficiently low[47] returns in a given year, so that without the possibility to declare LOR the owner would let the patent expire, and patents with relatively high patent returns, so that the patentee would renew his patent in any case. If the patent is

[45]Only if the potential plaintiff has developed a similar innovation, or has an incentive to use the technology exclusively, the patentee might run the risk of being litigated because of the declaration.

[46]We restrict the sample to patents filed before 1999 for the following reasons. We want to observe at least 10 periods for each cohort. Besides, EPO granted patent applications only take effect in Germany once they are granted. For a relevant share of European patent applications examination can take up to, or even more than 10 years.

[47]Sufficiently low as defined in Definition 1.1.

of sufficiently low value, then according to Proposition 1.1(i) and Proposition 1.3(i), the probability that a patent owner declares LOR should increase with the returns from patent protection in a given year and should decrease with its age. If, however, we look at patents of sufficiently high value, then, according to Proposition 1.1(ii) and Proposition 1.3(ii), the probability of observing a declaration in a given year should decrease with the returns from patent protection but increase with a patent's maturity. On the one hand, if the returns from patent protection are very high, the reduction in maintenance fees becomes marginal compared to possibly forfeited returns due to the loss of exclusivity. On the other hand, the older the patent, the higher will be the reduction in maintenance fees in absolute terms and the lower will be the option value of future returns from exclusivity.

> ***Hypothesis 1*** *Given its age, the probability to observe a declaration of LOR for an active patent*
>
> ***a)*** *increases in its revenues from patent protection for patents with sufficiently low returns,*
>
> ***b)*** *decreases in its revenues from patent protection for patents with sufficiently high returns.*

> ***Hypothesis 2*** *Given its revenues from patent protection, the probability to observe a declaration of LOR for an active patent*
>
> ***a)*** *decreases with patent age for patents with sufficiently low returns,*
>
> ***b)*** *increases with patent age for patents with sufficiently high returns.*

The second set of hypotheses related to the probability of observing a declaration of LOR can be derived from the considerations how a patent owner can realize profits from patent protection without having the possibility to exclude others. The higher the possible returns from the commitment to not exclude others are, respectively the smaller the forfeited returns from the loss of exclusivity, the higher should be the probability to observe a declaration of LOR.

As already explained above, patent owners who lack the complementary assets necessary to commercialize their invention might as well find it profitable to declare the willingness to license to make their patent more visible to potential licensees and to reduce the maintenance costs.

> ***Hypothesis 3*** *Ceteris paribus, a patent owner who lacks complementary assets to commercialize his patented invention is more likely to declare LOR.*

LOR, with its commitment value, can be beneficial where indirect network effects are very important for the commercial success of an invention, so that the diffusion of innovation becomes a crucial factor. Such conditions usually prevail in technologies where products and processes are of complex and multi-technological nature such as electrical and mechanical engineering. A complex technology is defined as a technology in which products depend on the combination of large numbers of complementary patents. Since these are also the same technology areas where cross-licensing is reported to be very common we state our next hypotheses:

> ***Hypothesis 4*** *Ceteris paribus, it is more likely to observe a declaration of LOR for a patent in a complex technology area than for a patent in a discrete technology area.*

The patent portfolio can be another influential factor of the decision to declare LOR. The bigger the portfolio is, the higher are the costs to maintain it and the smaller might be the importance of the value of exclusivity of a single patent. Furthermore, firms owning large portfolios of patents engage more often in cross-licensing.

> ***Hypothesis 5*** *Ceteris paribus, the probability to observe a declaration of LOR for a patent is increasing with its owner's patent portfolio size.*

The importance of the technology area the patent belongs to for its owner has also been identified as a possible driver of the decision to declare LOR. As argued above, the incentive to give up exclusivity for patents in peripheral technologies or markets should be higher.

> ***Hypothesis 6*** *Ceteris paribus, it is less likely to observe a declaration of LOR for a patent that protects a core technology than for a patent that protects a non-core technology of its owner.*

In the theoretical part we have argued that in case of existing set-up costs for the use of the technology, or if the competing technological alternatives are highly substitutable, commitment to competition through commitment to licensing can be a profitable strategy for the patentees. Nevertheless, we think that these market situations are very special and unlikely to prevail in many product markets. On average, firms will be reluctant to give up their right to exclude others if the market is very contested. Especially if there are many players in the market the right to injunctions or to grant exclusive licenses can considerably increase the bargaining position of a firm or constitute a comparative advantage.

Hypothesis 7 *Ceteris paribus, it is less likely to observe a declaration of LOR for a patent if the level of competition in the technology area is high.*

Now, we turn to the probability of observing a patent lapse. According to Proposition 1.1(i), the lower the returns from patent protection in a given year the higher should be the probability that the patent owner will let his patent expire. From Proposition 1.3(i) we know that two patents with the same returns from patent protection but different maturity should have different probabilities of expiration. Since the maintenance fees are non-decreasing in age, it should be more likely for a younger patent to be renewed. Furthermore, from Corollary 1.1 we know that the probability to observe an expiration of a patent of a certain age should be higher for patents endorsed LOR. We summarize these results in the following hypotheses.

Hypothesis 8 *Given its age, the probability of an active patent (endorsed or not endorsed LOR) to be allowed to expire decreases with its revenues from patent protection.*

Hypothesis 9 *Given its revenues from patent protection, the probability of an active patent (endorsed or not endorsed LOR) to be allowed to expire increases with patent age.*

Hypothesis 10 *Active patents of the same age endorsed LOR are more likely to be allowed to expire than patents not endorsed LOR.*

1.5.2 Empirical Strategy and Variables

In order to examine the impact of the different factors on the probability to observe a declaration or the probability that a patent is allowed to expire, we conduct several logistic regressions using robust standard errors.[48] All regressions have a similar structure. The dichotomous dependent variable is either the decision to declare the willingness to license (LOR) or the decision to let the patent expire (EXP) in period $t \in \{3, .., 20\}$.[49]

[48]We have also used other parametric specifications for binary choice models such as probit and complementary log-log. Since the complementary log-log model is asymmetric around 0, assuming a cumulative density function of the extreme value distribution $F(X^{'}\beta) = C(X^{'}\beta) = 1 - exp(-exp(X^{'}\beta))$, its use is recommended by the literature (Kim and Zeng 2001) when the distribution of the dependent variable is skewed, such that there is a high proportion of one outcome. As the declaration of the willingness to license occurs in rare cases, the complementary log-log model may be more appropriate for the data. However, results have not shown any major differences between the logit and the complementary log-log specification. We decided to use the logit specification since it is more often used in the literature.

[49]We decided not to consider the first two years for two reasons. First of all, the maintenance fees are 0 in both periods. Furthermore, applications which had gone through the PCT route only entered the

Dependent variables:

- LOR = dummy variable equal to 1 if the decision to declare willingness to license was taken in year $t \in \{3, .., 20\}$.

- EXP = dummy variable equal to 1 if the decision to let the patent expire was taken in year $t \in \{3, .., 20\}$.

For instance, for a patent for which LOR was declared for year 6 and which was not renewed in period 18 we observe 4 decisions whether or not to declare LOR (years 3 to 6) and 16 decisions whether or not to let the patent expire. The variable LOR will exhibit three times the value 0 and one time the value 1. The variable EXP will exhibit fifteen times the value 0 and one time the value 1. Since applicants who applied for a European patent do not have the possibility to declare the willingness to license until the examination process at the EPO is completed, we excluded observations for EPO patent applications prior to the grant decision for regressions on the decision to declare LOR.

Explanatory variables We construct five variables which were frequently used in the literature to proxy for returns from patent protection:[50] the number of citations the patent application has received, the patent family size, whether the patent was opposed at the EPO or DPMA after the grant decision, the number of inventors and the number of different technology areas in which the patent has been classified.

The number of citations a patent application receives in subsequent patent applications has been found to be strongly associated with the value of patents (Harhoff et al. 2003) as they reveal the existence of downstream research efforts and thus technological importance.

- N_CIT = number of patent citations received up to the decision period.

Each additional application in another country requires additional costs for filing and enforcing the patent. Hence, the number of patents filed with different patent authorities referring to the same invention, must be correlated with the expected value of the patent and should be a better proxy for the monetary value of the patent to their owners. Other things being equal, a patent with greater geographical scope of patent protection reflects a higher market potential of the invention and will theoretically have greater value.

national stage at the DPMA or the EPO 30 months after their priority date which is typically 18 months from the application date.

[50] See OECD Patent Statistics Manual (2009).

- *FAM_SIZE* = number of equivalents defined as patents with the same set of priorities.[51]

Harhoff et al. (2003) find that successful defense against opposition (in the German patent system) is a particularly strong predictor of patent value. As opposing a patent is costly, only patents with some damaging effects on competition are worth opposing. Hence, the fact that a patent is opposed can be interpreted as a signal of monetary value, at least to third parties.[52]

- *OPPOSITION* = dummy variable equal to 1 if the patent has successfully survived an opposition, otherwise equal to 0.

The number of inventors designated in a patent application, may proxy for the cost of the research behind the invention. A bigger research team is usually associated with higher expenses and therefore might be correlated with the technological value of the invention for the applicant.

- *N_INV* = number of inventors designated in the patent application.

The scope of a patent defines the legal dimensions of protection and thereby the extent of market power attributed to the patent. A broader scope refers to a broader area of technology from which others are excluded and provides stronger protection.

- *N_IPC* = number of different technological areas in which the patent has been classified by the examiners.

Since all measures are only weakly correlated with each other (see Appendix 1.7.2), probably because there is much noise in their relationship with the actual economic value of patents and they capture different dimensions of value (see van Zeebroeck 2011), the results will be interpreted with care. The fact that a given patent has been cited by subsequent patent applications suggests that it has been used by patent examiners to limit the scope of protection claimed by a subsequent patentee, to the benefit of society, and thus indicating the social (Trajtenberg 1990), rather than the private value of the patent. The family size, on the other hand, should be more suited to reflect the private value of a patent. However, the decision in how many countries the applicant should apply for

[51] Data set EQUIVALENTS_102009.dta created by Dietmar Harhoff (http://www.en.inno-tec.bwl.uni-muenchen.de/research/proj/patent-cit-project/index.html, retrieved: April 04, 2012).

[52] As already explained above, some declarations were made before or during the opposition proceedings which may indicate an endogeneity problem. Nevertheless, these cases only represent a small fraction of all declarations and the results do not change significantly if we exclude them.

a patent needs to be taken at the initial stage of filing. For some inventions this value may be already known at this stage but for others it is only revealed over time. Besides, not all jurisdictions should be regarded as evenly important, since the market sizes may differ considerably. Although survival of an opposition might be the strongest predictor of patent value, only less than 5.6% of all patents have successfully survived opposition. The number of technical classes in which the patent had been classified by the examiners was not found very informative for the patent value by Harhoff et al. (2002). It should rather be interpreted as a measure of the generality, or breadth of the technology. A holder of a patent, which covers a broad technological space, might be less likely to be present or interested strategically in all the applications protected by the property right. Hence, he will be more inclined to license it or allow it to lapse if the maintenance costs rise.

However, the major disadvantage of all proxies for patent value is that they are rather correlated with the aggregated value from patent protection and to a lesser degree with returns in a given period. Even *N_CIT* is not perfectly able to capture the evolution of returns during a patent's life. Only because a patent was cited in one period doesn't mean that its returns from patent protection were smaller in the previous or will be higher in the subsequent period. This drawback of our measures will hinder us to distinguish between patents with sufficiently low and sufficiently high returns from patent protection in a given period. We will not be able to distinguish whether LOR was declared because it was a better alternative to letting the patent expire (cost-saving motive) or because declaring LOR was a better alternative to renewing with full protection (commitment motive). This means that we will be limited in our ability to test *Hypothesis 1a)* and *1b)*, as well as *Hypothesis 2a)* and *2b),* separately.

The variables *AGE* and *WITH_LOR* directly determine the age of the patent in each decision period and whether it has already been endorsed LOR.

- *AGE* = dummy variables equal to 1 if decision was taken in period t, $t \in \{3, .., 20\}$.
- *WITH_LOR* = dummy variable equal to 1 if willingness to license was declared in one of the previous periods.

Larger firms are integrated, and typically own the complementary assets needed for commercialization of the invention, or they at least have the financial means to acquire them. Smaller firms, individual inventors, non-profit organizations or universities are the ones who more likely lack them, or at least face bigger obstacles to acquire them.

- *APPLCT_TYPE* = dummy variables for five applicant types: non-profit organization and university, individual inventor, small, medium, or large corporation.[53]

Based on the codes of the International Patent Classification (IPC) we subdivide the patents into six higher-level technology classes (see Schmoch, 2008).[54] The literature is quite consent that instruments, electrical and mechanical engineering are complex, whereas chemistry and pharmaceuticals as well as process engineering are discrete technology areas.[55]

- *TECH_AREA* = dummy variables for six higher-level technological areas (electrical engineering, mechanical engineering, instruments, chemistry and pharmaceuticals, process engineering, consumer and construction goods).

We approximate the size of a firm's patent portfolio by taking the number of granted patent applications filed by the patent owner within 3 years around the application date.[56]

- *PORTFOL_SIZE* = number of granted patent applications filed by the applicant within a 3 year time period around the application date.[57]

We use two measures to determine whether the patent belongs to the core of a firm's business. If we regard an IPC 4 patent class as one technological market, then the proportion of patents held by the patent owner in this class should proxy for its market strength and the importance of the firm in the market. To proxy for the importance of the technological market for the firm, i.e., the IPC4 patent class, we take the share of its patent portfolio that belongs to the same patent class. It will be important to control for the size of the patent portfolio since applicants who have filed only a few patent applications will always have a higher share.

- *IPC4_SHARE* = share of granted patent applications in the same IPC 4 class filed by the patent owner in a 3 year time period around the application date.

[53]How the variables were constructed is described in Section 1.3.2.

[54]We are using the ISI-OST-INPI patent classification updated as of February 2005. The classification system was jointly elaborated by the Fraunhofer Institute of Systems and Innovation Research (ISI) and the Observatoire des Sciences et des Technologies (OST), in cooperation with the French Patent Office (INPI).

[55]See Cohen et al. (2000) or von Graevenitz et al. (2012).

[56]We have also constructed dynamic versions of the variables *PORTFOL_SIZE, IPC4_SHARE, IPC4_PORTFOL* and *IPC4_C4*. However, the disadvantage of the dynamic versions was that we were not able to construct them for all years. Beginning with cohort 1999 onwards the number of patents is truncated due to long examination periods. Nevertheless, the dynamic versions of the variables for years prior to 1999 were highly correlated with the respective static variables.

[57]We have also used measures based on a 5 year period. The results did not change significantly but the method implied the cost of losing observations. We have refrained from using only a one year period to capture possible variation in a firm's intertemporal patenting behavior.

- *IPC4_PORTFOL* = share of granted patent applications filed by the patent owner in the same IPC 4 class out of all patent applications filed by him in a 3 year time period around the application date.

To approximate for the level of competition we construct a measure of ownership concentration in a 4-digit IPC patent class proposed by Gambardella et al. (2007). Although it rather measures technological competition, it should be correlated with competition in the product market as well. We use a dummy variable *SMALL_CLASS* to control for very small technological classes.

- *IPC4_C4* = share of granted patent applications filed by the 4 most frequent users in one IPC 4 class in a 3 year time period around the application date.

Control variables Throughout all regressions we use the following control variables:

- *EPO* = dummy variable equal to 1 if the applicant took the EPO route instead of the national DPMA route.
- *APPLCT_CNTRY* = dummy variables for the five major applicant countries (Germany, Japan, USA, France, the Netherlands/Belgium) and one dummy variable if assignment was missing.
- *NOGRANT_YEAR* = dummy variable equal to 1 if the patent was not yet granted in the decision period. This variable should control for the fact that we are only analyzing applications which were actually granted.
- *SMALL_CLASS* = dummy variable equal to 1 if the main IPC 4 class of the patent comprises less than 10 granted patent applications in a 3 year time period around the application date. This variable singles out cases for which concentration measures do not make sense.
- *YEAR* = dummy variables for the years 1985-2008 (*AGE* and *YEAR* together determine the application year of the patent).

1.5.3 Empirical Results

Descriptive Statistics

We present descriptive statistics for patents as the unit of observation as well as a single period of a patent's life. The sample comprises 776,519 patents with effect in Germany from cohorts 1983 to 1998 (see Appendix 1.7.2). Whereas only 35,415 (4.56%) of the granted patent applications were filed in 1983, by 1998 the number almost doubled to 60,188 (7.60%). The empirical analysis is based on 5,424,860 periods in which the decision to declare LOR could have been taken and 7,316,518 periods for the decision to let the patent expire.[58] The difference between the sample sizes accrues from the fact that for the decision to declare LOR we do not consider periods during which an EPO patent application (68.50% of patents in the sample) has not yet been granted and periods in which LOR has already been declared.

Overall, for 4.68% of all patents in the sample LOR has been declared. This corresponds to 0.59% of all relevant periods. For 62.06% of the patents, which corresponds to 5.99% of all relevant periods, the patent owner decided not to renew the patent. On average, 2.25 inventors were designated on the patent application. The average patent was assigned to 4.41 different technology areas with a family size of 6.67 and has been cited by 1.75 subsequent patent applications within the first five years and by 2.43 within the first seven years past application. The most frequently cited patent has received 549 citations during the full patent term. 5.57% of all patents have successfully survived an opposition either at the EPO or at the DPMA. The sample is divided into 6 main technology areas with 21.67% of all patents in electrical engineering, 15.87% in instruments, 19.90% in chemistry and pharmaceuticals, 15.97% in process engineering, 19.09% in mechanical engineering and 7.50% in consumer and construction goods. Furthermore, only 3.15% of all patents were owned by a non-profit organization or university, 9.71% by an individual inventor, 30.23% by a small corporation, 29.06% by a medium corporation and 27.84% by a large corporation. Almost one third of all patents were filed by German applicants. The next largest groups form applicants from the USA and Japan with almost 20% each. 4.15% of granted patent applications were unassigned. Although only 3.10% of all patents were filed by applicants from the Netherlands and Belgium, they account for an over-proportionally high percentage of LOR declarations. The average size of an applicant's patent portfolio was 274 patents with a relatively high standard deviation of 627 patents. The largest portfolio was filed by Siemens in the late 1990s with 5,520 granted patent applications. The average concentration measure *IPC4_C4* in a 4 digit IPC class was 20% with the lowest concentration value of 3%. The average share of patents filed in the same IPC 4 patent class was 2.58% with a standard deviation of 5.09%. The average share of patents in the applicant's patent portfolio that belonged to the same technological market, represented by the same IPC 4 patent class, was 38.12% with a standard deviation of 37.63%.

At the level of one decision period, the correlation coefficients between the value proxies

[58] Due to missing values, we lose 477,197 (8.1%) LOR decision periods and 589,548 (7.5%) periods relevant for the expiration decision.

are relatively low. The highest correlation is between the number of citations *N_CIT* and the family size *FAM_SIZE* with a coefficient of 0.34. The highest correlation coefficient is between *IPC4_C4* and *IPC4_SHARE* at 0.56. The explanation is that if the portion of patents in one IPC 4 class owned by the same applicant is high, then it is likely that he is also one of the 4 most frequent users in this class. As expected, the correlation is negative between *PORTFOL_SIZE* and *IPC4_PORTFOL* and positive between *PORTFOL_SIZE* and *IPC4_SHARE*. This means that compared to applicants with small patent portfolios, applicants with large patent portfolios tend to have more diversified patent portfolios and tend to own a larger share of patents in the respective IPC 4 classes.

Estimation Results

The results of the regressions on the probability to declare the willingness to license (LOR) are presented in Table 1.6 and the results of the regressions on the probability to let the patent expire (EXP) in Table 1.7. The regressions were performed separately for patents granted by the DPMA, patents granted by the EPO and the aggregated data set (ALL). To uncover possible nonlinear relationships for each empirical specification, we additionally estimated a model in which we subdivided the metric variables in several intervals with, if possible, equal number of observations. We then constructed a dummy variable for each interval and used them instead of the metric version in the regressions.[59]

The coefficients of the control variables are consistent with the analysis in Section 1.3.[60] Patents which were granted by the EPO are less likely endorsed the willingness to license and less likely allowed to expire. The size of the effect decreases once we include the proxies for value. Furthermore, patentees were less likely to declare LOR before the patent was granted than after grant. The nationality of the applicant has different effects on both probabilities. EPO patent applications filed by applicants from the Netherlands and Belgium have the highest probability of being endorsed license of right followed by applicants from Germany and Japan. For national patent applications, German applicants are most likely to declare LOR followed by applicants from Japan and USA, and less so applicants from the Netherlands and Belgium as well as from France. With respect to the decision to let the patent expire, independent of the application route, patents owned by applicants from Japan have the lowest probability of expiration, whereas patents owned by

[59]Supplementary regressions are presented in Appendix 1.7.3. We also check the robustness of variables describing applicant and market characteristics. The results remain robust to different numbers of intervals. Here, we only present the specification which we think is most suitable to describe the relationship. If we suspected a quadratic relationship we added a quadratic term to test the hypothesis. Regressions with a quadratic term are presented only if sufficient support has been found.

[60]The estimates with the control variables can be provided on demand.

LOR[a]	OPPOSED	FAM_SIZE TOP10	EPO	DPMA	ALL (a)	ALL (b)
log(N_CIT)			-0.034 (0.011)**	-0.012 (0.011)	-0.031 (0.008)***	set of dummies[b]
log(FAM_SIZE)			-0.521 (0.020)***	-0.381 (0.012)***	-0.406 (0.010)***	set of dummies
OPPOSITION			-0.185 (0.044)***	-0.214 (0.035)***	-0.195 (0.028)***	-0.179 (0.028)***
log(N_INV)			-0.041 (0.014)**	-0.124 (0.015)***	-0.084 (0.010)***	-0.080 (0.010)***
log(N_IPC)			0.026 (0.016)	0.015 (0.015)	0.018 (0.011)	0.023 (0.011)*
AGE						
4	-0.167 (0.190)	0.728 (0.279)**	1.230 (0.720)†	-0.247 (0.043)***	-0.250 (0.042)***	-0.250 (0.042)***
5	0.070 (0.183)	0.956 (0.266)***	1.735 (0.707)*	0.309 (0.039)***	0.260 (0.037)***	0.258 (0.037)***
6	0.288 (0.179)	0.698 (0.276)*	1.915 (0.706)**	0.204 (0.042)***	0.239 (0.037)***	0.236 (0.037)***
7	0.541 (0.177)**	0.959 (0.269)***	2.104 (0.706)**	0.633 (0.040)***	0.573 (0.036)***	0.571 (0.036)***
8	0.642 (0.178)***	1.394 (0.261)***	2.160 (0.706)**	0.572 (0.041)***	0.585 (0.037)***	0.586 (0.037)***
9	0.909 (0.174)***	1.377 (0.263)***	2.195 (0.706)**	0.707 (0.042)***	0.680 (0.037)***	0.683 (0.037)***
10	1.046 (0.173)***	1.448 (0.262)***	2.387 (0.706)***	0.915 (0.042)***	0.889 (0.037)***	0.893 (0.037)***
11	1.341 (0.172)***	1.438 (0.271)***	2.188 (0.706)**	0.981 (0.044)***	0.810 (0.039)***	0.820 (0.039)***
12	1.284 (0.178)***	1.800 (0.266)***	2.255 (0.707)**	1.021 (0.047)***	0.863 (0.040)***	0.877 (0.040)***
13	1.278 (0.183)***	1.847 (0.274)***	2.162 (0.707)**	1.092 (0.051)***	0.845 (0.042)***	0.860 (0.042)***
14	1.154 (0.194)***	1.697 (0.287)***	2.169 (0.707)**	1.030 (0.057)***	0.818 (0.045)***	0.834 (0.045)***
15	1.627 (0.190)***	2.038 (0.279)***	2.321 (0.707)**	1.091 (0.061)***	0.929 (0.046)***	0.948 (0.047)***
16	1.314 (0.209)***	2.027 (0.296)***	2.356 (0.708)***	1.061 (0.069)***	0.937 (0.050)***	0.956 (0.050)***
17	1.704 (0.206)***	2.193 (0.293)***	2.196 (0.709)**	0.929 (0.082)***	0.787 (0.058)***	0.808 (0.058)***
18	1.379 (0.242)***	1.894 (0.324)***	2.152 (0.710)**	0.828 (0.099)***	0.718 (0.067)***	0.740 (0.067)***
19	1.622 (0.251)***	2.229 (0.325)***	2.042 (0.712)**	0.834 (0.113)***	0.652 (0.078)***	0.677 (0.079)***
20	1.786 (0.261)***	1.835 (0.378)***	1.957 (0.717)**	0.907 (0.132)***	0.638 (0.096)***	0.663 (0.096)***
APPLCT_TYPE						
INDIV. INVENTOR	-0.877 (0.235)***	0.239 (0.286)	0.408 (0.147)**	0.484 (0.074)***	0.451 (0.064)***	1.035 (0.074)***
SMALL CORP.	-1.073 (0.217)***	-0.669 (0.269)*	0.294 (0.135)*	-0.284 (0.071)***	-0.165 (0.060)**	0.438 (0.072)***
MEDIUM CORP.	0.015 (0.211)	0.509 (0.258)*	1.218 (0.129)***	0.481 (0.060)***	0.657 (0.053)***	0.661 (0.057)***
LARGE CORP.	0.685 (0.210)***	1.152 (0.258)***	1.858 (0.132)***	1.000 (0.059)***	1.217 (0.054)***	0.963 (0.053)***
TECH_AREA						
INSTRUMENTS	-0.623 (0.079)***	-1.023 (0.112)***	-0.237 (0.023)***	-0.340 (0.025)***	-0.292 (0.017)***	-0.180 (0.018)***
CHEM.&PHARMA.	-1.994 (0.121)***	-2.906 (0.162)***	-1.749 (0.040)***	-1.066 (0.045)***	-1.551 (0.030)***	-1.445 (0.031)***
PROCESS ENG.	-1.289 (0.091)***	-1.393 (0.114)***	-0.997 (0.036)***	-0.843 (0.032)***	-0.915 (0.024)***	-0.793 (0.026)***
MECHANIC. ENG.	-0.512 (0.066)***	-0.575 (0.096)***	0.063 (0.024)**	-0.187 (0.020)***	-0.107 (0.015)***	-0.031 (0.017)†
CONS.&CONSTR.	-0.557 (0.107)***	-1.453 (0.193)***	-0.810 (0.061)***	-0.234 (0.035)***	-0.384 (0.029)***	-0.244 (0.031)***
log(PORTFOL_SIZE)			0.054 (0.011)***	0.061 (0.011)***	0.058 (0.008)***	set of dummies
IPC4_SHARE			-5.394 (0.228)***	-3.955 (0.264)***	-4.679 (0.171)***	set of dummies
IPC4_PORTFOL			-0.454 (0.060)***	-0.863 (0.046)***	-0.707 (0.037)***	set of dummies
IPC4_C4			1.502 (0.077)***	1.181 (0.076)***	1.383 (0.054)***	set of dummies
control variables: *EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS*						
log pseudolikelihood	-9,230.5	-6,426.6	-84,179.9	-88,073.5	-173,348.0	-172,229.3
Pseudo R2	0.115	0.155	0.141	0.092	0.117	0.123
Observations	372,196	656,116	3,378,131	2,046,637	5,424,860	5,424,860

[a] Robust standard errors in parenthesis.

[b] We subdivided the metric variable in several intervals und created a dummy variable for each interval. We have used the set of dummy variables instead of the metric variable for the regression.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Table 1.6: Determinants of the Probability to Observe a Declaration of the Willingness to License

EXP[a]	**EPO**	**DPMA**		**ALL**	
		(a)	**(b)**	**(a)**	**(b)**
log(N_CIT)	-0.274 (0.003)***	-0.202 (0.004)***	-0.202 (0.004)***	-0.254 (0.002)***	set of dummies[b]
log(FAM_SIZE)	-0.222 (0.004)***	0.001 (0.004)	0.001 (0.004)	-0.122 (0.003)***	set of dummies
OPPOSITION	-0.545 (0.011)***	-0.293 (0.011)***	-0.293 (0.011)***	-0.434 (0.008)***	-0.428 (0.008)***
log(N_INV)	-0.043 (0.004)***	-0.053 (0.005)***	-0.053 (0.005)***	-0.048 (0.003)***	-0.043 (0.003)***
log(N_IPC)	0.030 (0.004)***	0.012 (0.005)*	0.013 (0.005)*	0.028 (0.003)***	0.035 (0.003)***
AGE					
4	1.424 (0.158)***	0.365 (0.027)***	0.365 (0.027)***	0.392 (0.026)***	0.384 (0.026)***
5	1.931 (0.157)***	0.786 (0.025)***	0.786 (0.025)***	0.829 (0.024)***	0.816 (0.024)***
6	2.275 (0.157)***	1.251 (0.024)***	1.251 (0.024)***	1.217 (0.023)***	1.200 (0.023)***
7	2.520 (0.157)***	1.464 (0.024)***	1.464 (0.024)***	1.434 (0.023)***	1.416 (0.023)***
8	2.729 (0.157)***	1.499 (0.024)***	1.499 (0.024)***	1.573 (0.023)***	1.555 (0.023)***
9	2.859 (0.157)***	1.538 (0.024)***	1.538 (0.024)***	1.670 (0.023)***	1.653 (0.023)***
10	3.010 (0.157)***	1.558 (0.025)***	1.558 (0.025)***	1.777 (0.023)***	1.761 (0.023)***
11	3.132 (0.157)***	1.637 (0.025)***	1.637 (0.025)***	1.884 (0.023)***	1.867 (0.023)***
12	3.201 (0.157)***	1.682 (0.025)***	1.681 (0.025)***	1.945 (0.023)***	1.929 (0.023)***
13	3.258 (0.157)***	1.694 (0.026)***	1.694 (0.026)***	1.989 (0.023)***	1.972 (0.023)***
14	3.342 (0.157)***	1.779 (0.026)***	1.779 (0.026)***	2.075 (0.024)***	2.057 (0.024)***
15	3.437 (0.157)***	1.844 (0.027)***	1.844 (0.027)***	2.161 (0.024)***	2.144 (0.024)***
16	3.544 (0.157)***	1.905 (0.028)***	1.905 (0.028)***	2.254 (0.024)***	2.238 (0.024)***
17	3.701 (0.157)***	1.972 (0.029)***	1.972 (0.029)***	2.385 (0.025)***	2.369 (0.025)***
18	3.877 (0.157)***	2.167 (0.030)***	2.166 (0.030)***	2.565 (0.025)***	2.551 (0.025)***
19	4.024 (0.157)***	2.326 (0.031)***	2.325 (0.031)***	2.711 (0.026)***	2.697 (0.026)***
20	4.381 (0.158)***	2.689 (0.033)***	2.689 (0.033)***	3.067 (0.026)***	3.053 (0.026)***
WITH_LOR	0.066 (0.012)***	0.069 (0.011)***	0.068 (0.011)***	0.036 (0.008)***	0.032 (0.008)***
APPLCT_TYPE					
INDIV. INVENTOR	0.062 (0.015)***	0.033 (0.020)†	0.033 (0.020)†	0.055 (0.012)***	0.043 (0.012)***
SMALL CORP.	-0.073 (0.013)***	-0.205 (0.018)***	-0.206 (0.018)***	-0.127 (0.010)***	-0.124 (0.011)***
MEDIUM CORP.	-0.048 (0.012)***	-0.167 (0.016)***	-0.169 (0.016)***	-0.105 (0.010)***	-0.100 (0.010)***
LARGE CORP.	0.027 (0.015)†	-0.139 (0.018)***	-0.139 (0.018)***	-0.057 (0.012)***	-0.097 (0.013)***
TECH_AREA					
INSTRUMENTS	-0.008 (0.007)	0.039 (0.010)***	0.043 (0.010)***	0.004 (0.006)	0.011 (0.006)†
CHEM.&PHARMA.	0.142 (0.006)***	0.184 (0.011)***	0.188 (0.011)***	0.135 (0.006)***	0.177 (0.006)***
PROCESS ENG.	0.090 (0.007)***	0.194 (0.010)***	0.201 (0.010)***	0.121 (0.006)***	0.158 (0.006)***
MECHANIC. ENG.	0.030 (0.007)***	0.081 (0.009)***	0.083 (0.009)***	0.044 (0.005)***	0.059 (0.006)***
CONS.&CONSTR.	0.127 (0.010)***	0.100 (0.011)***	0.104 (0.011)***	0.095 (0.007)***	0.126 (0.008)***
log(PORTFOL_SIZE)	-0.025 (0.003)***	-0.020 (0.004)***	-0.020 (0.004)***	-0.018 (0.002)***	set of dummies
IPC4_SHARE	-0.545 (0.056)***	-0.009 (0.084)	0.029 (0.086)	-0.405 (0.047)***	set of dummies
IPC4_PORTFOL	-0.100 (0.010)***	-0.094 (0.013)***	-0.095 (0.013)***	-0.093 (0.008)***	set of dummies
IPC4_C4	0.073 (0.020)***	0.023 (0.029)	0.197 (0.078)*	0.077 (0.017)***	set of dummies
IPC4_C4_sq			-0.334 (0.139)*		
control variables: ***EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS***					
log pseudolikelihood	-945,350.3	-488,468.4	-488,465.5	-1,438,580.74	-1,436,712.2
Pseudo R2	0.141	0.114	0.114	0.133	0.134
Observations	5,186,822	2,128,796	2,128,796	7,316,518	7,316,518

[a] Robust standard errors in parenthesis.

[b] We subdivided the metric variable in several intervals und created a dummy variable for each interval. We have used the set of dummy variables instead of the metric variable for the regression.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Table 1.7: Determinants of the Probability to Observe a Decision to Let the Patent Expire

applicants from the Netherlands and Belgium the highest. For German patent applicants it is more likely to let patents expire that were granted by the DPMA than those that were granted by the EPO.

Now we turn to the interpretation of the results in the light of the hypotheses. We recall that our measures of patent value are limited in proxying for the returns from patent protection in a given period. This applies especially to periods in which the returns are sufficiently low, so that according to the theoretical model the applicant would not renew the patent with full protection. By definition this is the case in at most one period for each patent. In all other periods the returns must be sufficiently high. According to the descriptive statistics the returns must have been sufficiently low in less than 8.3% of all decision periods relevant for the declaration of LOR[61] and sufficiently high in more than 91.7% of all decision periods. However, except for *N_CIT*, the value of our proxies for returns from patent protection is the same in all periods for the same patent. This means that our variables are capable of capturing the effect of higher returns from patent protection on the probability to observe a declaration described in *Hypothesis 1b).* However, the size of the real effect is likely underestimated. Throughout all regressions the probability to observe a declaration is decreasing in our correlates for the overall patent value: the size of the patent family, the number of inventors and if the patent has successfully survived an opposition. This is in line with *Hypothesis 1b).* The coefficient of *log(N_IPC)* is positive and insignificant, but becomes negative and highly significant once we exclude other value correlates. The probability is also decreasing with the number of citations received, but the effect is relatively small and for DPMA granted patents becomes even insignificant. The reason is that *N_CIT* is a dynamic measure and more capable of capturing a change in the returns from patent protection between periods.[62] Since *N_CIT* should be better able to distinguish between periods with sufficiently low and sufficiently high returns from patent protection, the smaller effect on the probability of observing LOR is in line with *Hypothesis 1a).* According to *Hypothesis 1a)* the probability should increase with higher returns from patent protection for periods with sufficiently low revenues, counteracting the effect for periods with sufficiently high revenues (*Hypothesis 1b)*).

In order to test *Hypothesis 2a)* and *Hypothesis 2b)* we again need to control for the returns from patent protection in the given period. Since we are not able to do that, the

[61]These are all decision periods in which the applicant had the possibility to declare LOR and in fact declared LOR (32,041) and decision periods in which the patent has been allowed to lapse (419,429). According to the theoretical model sufficiently low returns from patent protection in one period are defined as those returns which are low enough so that the patentee will either let his patent expire or declare LOR, but never renew with full patent protection.

[62]We have also used the number of patent citations received in the first 7 years after application as an alternative static version and the negative effect on the probability of observing a declaration was considerably higher.

variable *AGE* combines both countervailing effects on the probability to observe a LOR declaration. Overall, the age has an inverted U-shaped relationship with the probability of observing a declaration. First it increases until age 10, respectively 11, remains rather constant for the following years and decreases for older patents. This is perfectly consistent with our theoretical model. For younger ages the share of patents with sufficiently low returns is negligible, so that the positive effect of age on *LOR* should dominate (*Hypothesis 2b)*). When patents mature, the share of patents with sufficiently low returns starts to increase, which is confirmed by the increasing proportion of patents that expire, and so does the negative effect of age on the probability (*Hypothesis 2a)*). For very high ages the latter begins to dominate. To confirm the result we ran the regressions on two sub-samples. One with patents which have successfully survived opposition and one with patents which belong to the top 10th percentile according to the size of the patent family. Both sub-samples should have a high share of observations with sufficiently high returns for all ages, such that the effect described in *Hypothesis 2b)* should prevail. And indeed, the probability increases in a patent's maturity throughout almost all ages.

In the descriptive statistics we observed that contrary to *Hypothesis 3* the LOR option is mostly used by medium and large corporations and less so by applicants who are assumed to be lacking complementary assets. However, once we control for the portfolio size of the applicant there is no significant difference in the effect on the probability to observe a declaration of LOR between individual inventors and large corporations.[63] Patents owned by small and medium sized corporations have a significantly lower probability of being endorsed LOR, followed by patents filed by non-profit organizations and universities. Furthermore, owners of patents in the area of electrical and mechanical engineering, which are clearly complex technologies, are most likely to declare LOR. Owners of patents in discrete technological areas like chemistry & pharmaceuticals and process engineering are the least likely. This confirms *Hypothesis 4.*

As expected, the size of the applicant's portfolio positively influences the decision to declare LOR (*Hypothesis 5*). Although the probability is not monotonically increasing in the number of granted patent applications, the probability is significantly higher for patents owned by applicants with a medium-sized patent portfolio compared to patents owned by applicants with small patent portfolios, and even higher for patents with large patent portfolios.

Being part of a patent owner's core technology has a negative effect on the probability

[63] The difference between individual and large corporations becomes insignificant once we subdivide *PORTFOL_SIZE* in several intervals und create a dummy variable for each interval. If we use *log(PORTFOL_SIZE)* instead, there is no convergence in probabilities. We believe that the dummy variables approach is better able to capture possible nonlinearities in the effect of *PORTFOL_SIZE*. Therefore, it should be more suitable to control for the size of the patent portfolio.

to observe a LOR declaration (*Hypothesis 6*). If the presence of the patent owner in the IPC 4 class is high the patent has a significantly lower probability of being endorsed LOR in a given period. The probability is highest for very low values of *IPC4_SHARE*. The probability of observing a declaration is also significantly higher if the technology represents a large part of the applicant's patent portfolio. Interestingly, the effect of the importance of the technology within the firm's patent portfolio is smaller for European patent applications than for patents granted by the DPMA. One possible explanation may be the fact that the share of patents filed by German applicants within the national patent applications is above 60%, whereas the share for European patent applications filed by German applicants is only 20%. Contrary to German patent applicants, for non-German applicants the German market does not have to be a core market. Hence, *IPC4_PORTFOL* may misrepresent the importance of the technology for these firms.

In *Hypothesis 7* we stated that patent owners will be less likely to declare LOR for patents in technological areas where competition is high. This is confirmed by the data. Once we control for the importance of the technological market for the patentee (*IPC4_PORTFOL* and *IPC4_SHARE*) the effect becomes even stronger (see Appendix 1.7.3). If the share of granted patent applications filed by the 4 most frequent users in one IPC 4 class (*IPC4_C4*) is below 15%, the probability of observing a declaration for a patent in a given period is considerably reduced compared to patents in technological classes with a value above 15%.

The regressions on the probability to observe an expiration are presented in Table 1.7. According to *Hypotheses 8-10* the probability should decrease with returns from patent protection, increase with the patent's age and be higher for patents endorsed LOR. Independent of the application route and throughout all regressions the probability is indeed increasing with each additional renewal year. Furthermore, patents for which LOR has been declared in one of the previous periods are more likely not to be renewed. The picture seems to be less clear in terms of the effect of the returns from patent protection in a given period. The probability is increasing with the number of different IPC classes if we include other value correlates as well. However, if we regress *EXP* on *log(N_IPC)* as the unique proxy for patent value, the coefficient turns negative. The coefficient of *log(FAM_SIZE)* is negative and significant for patents granted by the EPO. However, the coefficient is positive, though insignificant, for patents granted by the DPMA. The explanation might again be the fact that the size of the patent family is determined in the beginning of a patent's life and does not take the evolution of returns, especially not the speed of the depreciation of returns into account. Nevertheless, if the patent belongs to the top 10th percentile according to the size of the patent family, independent of the granting authority, the expiration probability is significantly reduced (see Appendix 1.7.3). In contrast, the number of citations received up to a certain period is a dynamic measure and should rather be able to capture the change in returns between periods. The probability of observing a decision to let the patent expire is monotonically decreasing with each additional citation which is in accordance with *Hypothesis 8*. Furthermore, the probability is clearly lower for patents which have successfully survived opposition and increasing with the number of inventors.

Corporations, especially small ones, are less likely to let their patents expire compared to non-profit organizations and universities as well as individual inventors. The latter often lack the means to appropriate value from the patented inventions. Small corporations usually rely more heavily on the ability to protect their business interests through patents compared to large corporations. Patents in discrete technologies are also less likely to lapse compared to patents in complex technologies. Furthermore, applicants with larger patent portfolios seem to be less willing to let their patents expire. The effect remains if we control for patent value and increases if we additionally control for market characteristics (see Appendix 1.7.3). This can be ascribed to the effect that the private value of a patent within a patent portfolio is often higher than its stand alone value. Expiration is also less likely if the patent protects a core technology. The importance of the technology within the applicant's patent portfolio has a significant negative effect on the probability to let the patent expire prematurely. *IPC4_SHARE* has a negative and significant effect for European patent applications but not for patents granted by the DPMA. Technological competition significantly reduces the probability to observe an expiration decision once we control for the technology's importance to its owner.

1.6 Conclusion

In this paper, our theoretical and econometric analysis of a newly created data set has allowed us to assemble important facts regarding the "Willingness to License", as the "License of Right" (LOR) is called in Germany. To the best of our knowledge this is the first study of this kind. The previous lack of interest can partially be explained by the fact that LOR is neither part of the U.S. nor the Japanese patent system, the two largest patent systems worldwide. However, "License of Right" is an inherent part of the forthcoming European Patent with Unitary Effect[64] that is supposed to be the prevailing patent system in the European Union and should–contrary to the current patent system in the European Patent Organization–not only deal with grant but also cover post grant issues. This will automatically introduce the "License of Right" system in 38 member

[64]European Commission, Proposal for a Regulation of the European Parliament and of the Council Implementing Enhanced Cooperation in the Area of the Creation of Unitary Patent Protection: 2011/0093 (COD) (Brussels 2011). http://ec.europa.eu/internal_market/indprop/docs/patent/com2011-215-final_en.pdf, last accessed December, 2012.

states of the European Patent Organization.

Using data on German patents we show that for almost 6% of all patents willingness to license is declared. For patents granted by the German Patent and Trademark Office (DPMA) the number goes up to even more than 11%. The decision to declare LOR is significantly affected not only by the characteristics of the patent but also by the characteristics of its owner and the technological area it belongs to. The likelihood to observe a declaration is considerably larger in complex technical areas such as electrical and mechanical engineering compared to discrete ones. Moreover, patents which are owned by large corporations are more likely to be endorsed LOR. They can use the provision to reduce the costs of their patent portfolios or to supplement cross-licensing agreements. Once we control for the patent portfolio size, patents owned by individual inventors become equally likely to be endorsed LOR. Somewhat surprisingly, for patents filed by non-profit organizations and universities the probability is significantly reduced. Moreover, it is less likely to observe a declaration if the patent belongs to the applicant's core technology or if the level of competition in the market is high.

Within our theoretical framework we show that the effects of returns from patent protection and the age of the patent on the probability to declare the willingness to license heavily depend on the motive for the declaration. If pure cost-saving considerations are relevant, the probability increases with the returns from patent protection and decreases with a patent's maturity. If licensing (commitment) considerations prevail, the effects are completely reversed. However, we are not able to determine empirically what motive is the relevant one in each period of a patent's life. Using static measures for correlates of patent value, like the number of received patent citations within a given period, the patent family size and survival of an opposition procedure, we show that patents of presumably higher total value have a lower probability to be endorsed LOR. However, if we use a dynamic measure for the returns from patent protection, which should be better capable of capturing changes in returns from patent protection, the effect on probability vanishes. For younger patents the probability is increasing with a patent's age and decreasing for older ones. However, for presumably very valuable patents, for which the (licensing) commitment motive should prevail in all periods, the probability is almost monotonically increasing in a patent's age.

Although the willingness to license is declared for a significant number of patents in Germany, we lack evidence on whether the inventions are indeed taken up and exploited by third parties. Data on licensing agreements is rarely available. Nevertheless, the prevalent opinion by practitioners and also researchers is that the market for technology licensing is underdeveloped (see Gambardella et al. 2007). This might be due to a lack of awareness but also due to the nature of the German technology market. According to the practitioners we have interviewed, firms usually do not actively search for existing technology but try to develop the technology themselves. As a consequence of this, licensing agreements are often only the outcome of litigation settlements. Thus, as already proposed by Schovsbo (2009) and Gowers (2006), in order to promote licensing of patents endorsed LOR it is important to create a desirable environment and provide support for active use of the system. A first step would be to increase the visibility of the patents endorsed LOR by creating an innovation pool, which would enable third parties to easily identify what patents relevant to their area of R&D are available for licensing. Here, Singapore is a leading example. The Singapore government has established a special web base for all patents endorsed license of right which anyone can easily access. A second step would be to introduce a model license agreement provided by the patent office to further reduce the transaction costs involved in the conclusion of licensing contracts.

The German patent system incentivizes applicants to declare the willingness to license and open up their inventions by reducing their maintenance fees for patents. Shovsbo (2009) argues that this mechanism may entail substantial social costs. Patentees may use the reduction in maintenance fees to apply for patents of little value or "artificially" extend patent protection. The first objection is easily invalidated since in almost all patent systems the maintenance fees, especially in the first 5 years, are marginal compared to the costs that have to be involved to get a patent granted. The possible reduction in maintenance fees should not play a major role for the decision to apply for a patent and request a costly examination. The second argument, however, may be important for the general welfare assessment of the LOR system. From the theoretical model we were able to determine two motives for the declaration, the cost-saving and the commitment motive. The first one is unambiguously welfare decreasing, since without the LOR option the patentee would have let his patent lapse. The commitment motive, however, can be welfare increasing, since the patentee voluntarily eliminates exclusivity from an otherwise valuable patent. Hence, the welfare assessment will heavily depend on the ratio of the two motives. Unfortunately, we do not have a reliable measure for the returns from patent protection in a given period, which would allow us to categorize the declarations. However, the problem can potentially be solved using structural estimation techniques by using the theoretical model developed in this paper and applying a simulated GMM estimator. A comparison of simulation results of one patent system with and one without the LOR option should then allow for explicit welfare statements.

1.7 Appendix

1.7.1 Proofs

List of Variables

- f_t = renewal fees in period t , $t \in 1, ..., T$
- r_1 = initial return
- $g_t^k \in \left[0, B^K\right]$= growth rate of returns from full protection (K) in year t
- $F_{g^k}(u^k \mid t)$ = c.d.f. of g_t^k in year t, $f_t(u^k)$ is the corresponding p.d.f.
- $r_t = g_t^k r_{t-1}$ returns in year t from full patent protection (K)
- $g_t^l \in \left[0, B^l\right]$ = LOR factor in year t
- $y_t = g_t^l g_t^k r_{t-1}$ = returns in year t if LOR declared (L)
- $F_{g^l}(u^l)$ = c.d.f. of g_t^l , $f(u^l)$ is the corresponding p.d.f.
- $\widetilde{V}^K(t, r_t)$ = value function in period t if strategy (K) chosen
- $\widetilde{V}^L(t, r_t, y_t)$ = value function in period t if strategy (L) chosen
- $\widetilde{V}^X(t) = 0$ if the patent expires
- $\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) = max\left\{\widetilde{V}^K(t+1, r_{t+1}), \widetilde{V}^L(t+1, r_{t+1}, y_{t+1}), \widetilde{V}^X(t+1)\right\}$ = value function of the optimal strategy in year $t+1$ if strategy (K) chosen in year t
- $\widetilde{V_L}(t+1, r_{t+1}, y_{t+1}) = max\left\{\widetilde{V}^L(t+1, r_{t+1}, y_{t+1}), \widetilde{V}^X(t+1)\right\}$ = value function of the optimal strategy in year $t+1$ if strategy (L) chosen in year t
- $\{\hat{r}_t\}_{t=1}^T$: patent returns that make the agent indifferent between (K) and (X). It is the solution to $\widetilde{V}^K(t, r_t) = \widetilde{V}^X(t) = 0$
- $\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^T$: growth rates that make the agent indifferent between declaring LOR (L) and keeping full patent protection (K). It depends on the level of per period returns r_t and is defined as the solution to $\widetilde{V}^K(t, r_t) = \widetilde{V}^L(t, r_t, g_t^l r_t)$
- $\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^T$: growth rates that make the agent indifferent between declaring LOR (L) and letting a patent expire (X). It depends on the level of per period returns r_t and is defined as the solution to $\widetilde{V}^L(t, r_t, g_t^l r_t) = \widetilde{V}^X(t) = 0$

Proof of Lemma 1.1

Proof. It suffices to show the properties for $\widetilde{V}^L(t, r_t, y_t)$ and $\widetilde{V}^K(t, r_t)$. Proofs are done by induction.

(i)

Consider the last period $t = T$:

$\widetilde{V}^K(T, r_T) = r_T - f_T$ and $\widetilde{V}^L(T, r_T, y_T) = y_T - \frac{f_T}{2} = g_T^l r_T - \frac{f_T}{2}$ are clearly increasing in r_T and y_T.

Remember, $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l)$ are independent of returns and is defined as $y_t = g_t^l r_t = g_t^l g_t^k r_{t-1}$.

It is trivial to show that $\widetilde{V}^L(t, r_t, y_t)$ is increasing in y_t.

Now, assume that for $r < r'$,

$$\widetilde{V}^L(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r) < \widetilde{V}^L(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r') \ .$$

Then, $\widetilde{V_L}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r) \leq \widetilde{V_L}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')$.

Thus, $E\left[\widetilde{V_L}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] \leq E\left[\widetilde{V_L}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')\right]$.

Then,

$$\widetilde{V}^L(t, r, g_t^l r) = -\tfrac{f_t}{2} + g_t^l r + \beta E\left[\widetilde{V_L}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] <$$
$$< -\tfrac{f_t}{2} + g_t^l r' + \beta E\left[\widetilde{V_L}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')\right] = \widetilde{V}^L(t, r', g_t^l r').$$

Further assume that for $r < r'$,

$\widetilde{V}^K(t+1, g_{t+1}^k r) < \widetilde{V}^K(t+1, g_{t+1}^k r')$.

We know that $\widetilde{V}^L(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r) < \widetilde{V}^L(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')$,

and thus, $\widetilde{V_K}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r) \leq \widetilde{V_K}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')$.

In this case,

$E\left[\widetilde{V_K}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] \leq E\left[\widetilde{V_K}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')\right]$.

Then,

$$\widetilde{V}^K(t, r) = -f_t + r + \beta E\left[\widetilde{V_K}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] <$$
$$< -f_t + r' + \beta E\left[\widetilde{V_K}(t+1, g_{t+1}^k r', g_{t+1}^l g_{t+1}^k r')\right] = \widetilde{V}^K(t, r').$$

(ii)

$\widetilde{V}^L(T, r_T, y_T)$ and $\widetilde{V}^K(T, r_T)$ are clearly continuous in y_T and r_T.

Since $E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right]$ and $E\left[\widetilde{V_L}(t+1, r_{t+1}, y_{t+1} \mid r_t)\right]$ are independent of y_t, $\widetilde{V_K}(t, r_t, y_t)$ and $\widetilde{V_L}(t, r_t, y_t)$ are clearly continuous in y_t for any $t < T$.

To prove continuity in r_t, assume that $\widetilde{V_K}(t, r_t, y_t)$ and $\widetilde{V_L}(t, r_t, y_t)$ are continuous in r_t for an arbitrary t.

$\widetilde{V_K}(t-1, r_{t-1}, y_{t-1})$ and $\widetilde{V_L}(t-1, r_{t-1}, y_{t-1})$ will be continuous in r_{t-1} if their option values $E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right]$ and $E\left[\widetilde{V_L}(t, r_t, y_t \mid r_{t-1})\right]$ will be continuous in r_{t-1}. The option values will be continues in r_{t-1} if for every sequence (r_{t-1}^n) such that $lim(r_{t-1}^n) = r_{t-1}$ we can show that

$$\lim_{r_{t-1}^n \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}^n\right] = E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right] \text{ and}$$

$$\lim_{r_{t-1}^n \to r_{t-1}} E\left[\widetilde{V_L}(t, r_t, y_t) \mid r_{t-1}^n\right] = E\left[\widetilde{V_L}(t, r_t, y_t) \mid r_{t-1}\right].$$

Since $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l)$ are independent of r_t,

$$\lim_{r_{t-1}^n \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}^n\right] =$$

$$= \int\int \lim_{r_{t-1}^n \to r_{t-1}} \left[\widetilde{V_K}(t, g_t^k r_{t-1}^n, g_t^l g_T^k r_{t-1}^n)\right] dF_{g^k}(u^k|T) dF_{g^l}(u^l) =$$

$$= \int\int \left[\widetilde{V_K}(t, g_t^k r_{t-1}, g_t^l g_t^k r_{t-1})\right] dF_{g^k}(u^k|T) dF_{g^l}(u^l).$$

The last equality follows because $\widetilde{V_K}(t, r_t, y_t)$ is continuous in r_{T-1}. ($y_T = g_T^l g_T^k r_{T-1}$ and $r_T = g_T^k r_{T-1}$ are both continuous in r_{T-1}).

The proof for

$$\lim_{r_{t-1}^n \to r_{t-1}} E\left[\widetilde{V_L}(t, r_t, y_t) \mid r_{t-1}^n\right] = E\left[\widetilde{V_L}(t, r_t, y_t) \mid r_{t-1}\right] \text{ is analogue.}$$

(iii)

In $t = T$ the option value is always 0. The option value in $t = T - 1$ is at least 0 (by definition $\widetilde{V_K}(T, r_T)$ and $\widetilde{V_L}(T, r_T, y_T)$ are always at least 0), so must be its expected value. Since the renewal fees are increasing with age, $\widetilde{V_L}(T-1, r, y) \geq \widetilde{V_L}(T, r, y)$ and $\widetilde{V_K}(T-1, r) \geq \widetilde{V_K}(T, r)$. By assumption, $F_{g^l}(u^l)$ does not change with patent age and $F_{g^k}(u^k \mid t)$ is increasing with t making higher growth rates less likely. The increasing renewal fees and the last assumption guarantee that the property also holds for the general case:

Assume that $\widetilde{V}^L(t+1, r, y) \leq \widetilde{V}^L(t, r, y) \Rightarrow \widetilde{V_L}(t+1, r, y) \leq \widetilde{V_L}(t, r, y)$.

Thus,

$$E\left[\widetilde{V_L}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] \leq E\left[\widetilde{V_L}(t, g^k_t r, g^l_t g^k_t r)\right].$$

Then,

$$\widetilde{V}^L(t, r, y) = -\tfrac{f_t}{2} + y + \beta E\left[\widetilde{V_L}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] \leq$$
$$\leq -\tfrac{f_{t-1}}{2} + y + \beta E\left[\widetilde{V_L}(t, g^k_t r, g^l_t g^k_t r)\right] = \widetilde{V}^L(t-1, r, y).$$

Assume that $\widetilde{V}^K(t+1, g^k r) \leq \widetilde{V}^K(t, g^k r)$.

We know that

$$\widetilde{V}^L(t+1, g^k r, g^l g^k r) \leq \widetilde{V}^L(t, g^k r, g^l g^k r) \Rightarrow \widetilde{V_K}(t+1, g^k r, g^l g^k r) \leq \widetilde{V_K}(t, g^k r, g^l g^k r).$$

Thus, $E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] \leq E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right]$.

Since $f_{t-1} < f_t$,

$$\widetilde{V}^K(t,r,y) = -f_t + r + E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] <$$

$$< -f_{t-1} + r + E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right] = \widetilde{V}^K(t-1,r,y). \quad \blacksquare$$

Proof of Corollary 1.1

Proof. Once LOR has been declared the patentee can only choose between the strategies (L) and (X) and will choose (X) if $g^l_t < \hat{g}^{l-}_t(r_t)$ and $r_t \in [0, r^{max}]$. As long as LOR has not yet been declared the patentee has the opportunity to choose not only between (L) and (X), but also (K). Thus, he will choose (X) only if $g^l_t(r) < \hat{g}^{l-}_t(r_t)$ and $r_t < \hat{r} < r^{max}$. This means that there must exist at least one point (g^l_t, r_t) in the (r, g^l)-space, where a patent owner of a patent endorsed LOR would let his patent expire and a patent owner of a patent with full protection would not. ■

Proof of Proposition 1.1

Proof.

(i)

In this scenario the patentee is indifferent between (L) and (X). We know that the value function $\widetilde{V}^L(.)$ is weakly increasing in the returns r_t . Thus, if the per period returns increase, the cut-off value $\hat{g}^{l-}_t$ must decrease to keep the equality in $\widetilde{V}^L(.) = 0$.

(ii)

The patent owner has to choose between (K) and (L). Consider the last period T:

$$\hat{g}^{l+}_T(r_T) = 1 - \frac{f_T}{2r_T} \text{ => increasing in } r_T.$$

Consider period t:

$$\widetilde{V}^K(.) - \widetilde{V}^L(.) = -\frac{f_t}{2} + r_t - \hat{g}^{l+}_t r_t +$$

$$+\beta\left\{E\left[\widetilde{V_K}(t+1, g^k_{t+1}r_t, g^l_{t+1}g^k_{t+1}r_t)\right] - E\left[\widetilde{V_L}(t+1, g^k_{t+1}r_t, g^l_{t+1}g^k_{t+1}r_t)\right]\right\} = 0.$$

Solved for $\hat{g}_t^{l+}$:

$$\hat{g}_t^{l+} = -\frac{f_t}{2r} + 1 + \beta \left\{ \frac{E\left[\widetilde{V_K}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right]}{r_t} \right\}.$$

Taking the derivative with respect to r:

$$\frac{\partial \hat{g}_t^{l+}}{\partial r_t} = \frac{f_t}{2r_t^2} +$$

$$+\beta \left\{ \frac{\frac{\partial\left\{E\left[\widetilde{V_K}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right]\right\}}{\partial r_t} - \frac{E\left[\widetilde{V_K}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right]}{r_t}}{r_t} \right\}.$$

This means that as long as the difference in option values from both regimes, $E\left[\widetilde{V_K}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right]$, is convexly increasing in r_t, $\frac{\partial \hat{g}_t^{l+}}{\partial r_t} > 0$ will hold. ■

Proof of Proposition 1.2

Proof. $\hat{r}_t$ is defined as $\widetilde{V}^K(t, \hat{r}_t) = 0$ and $\hat{r}_{t+1}$ as $\widetilde{V}^K(t+1, \hat{r}_{t+1}) = 0$. From Lemma 1.1 we know that $\widetilde{V}^K(.)$ is a weakly increasing in r_t and decreasing in t. So, it must be that $\hat{r}_{t+1} \geq \hat{r}_t$ to keep equality. ■

Proof of Proposition 1.3

Proof.

(i)

The patent owner is indifferent between (L) and (X). We know from Lemma 1.1 that $\widetilde{V}^L(t, r_t, y_t)$ is increasing in returns and decreasing in age. Thus, if we take the same returns $r_t = r_{t+1} = r$ in two consecutive periods, $\hat{g}_t^{l-}(r)$,which is defined as

$$\widetilde{V}^L(t, r, \hat{g}_t^{l-} r) = \hat{g}_t^{l-} r - \tfrac{1}{2} f_t + \beta E\left[\widetilde{V_L}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] = 0,$$

must be at least as large as $\hat{g}_{t-1}^{l-}(r)$.

(ii)

In this case the patent owner is indifferent between (L) and (K) if $g_t^l = \hat{g}_t^{l+}$.

For the last period it is sufficient to show that for a fixed $r_t = r_{t+1} = r$ and $y_t = y_{t+1} = y$, $\widetilde{V}^K(T, r) - \widetilde{V}^L(T, r, y) \leq \widetilde{V}^K(T-1, r) - \widetilde{V}^L(T-1, r, y)$.

This is equivalent to:

$$-\tfrac{f_T}{2} \leq -\tfrac{f_{T-1}}{2} + \beta \left\{ E\left[\widetilde{V_K}(T, g_T^k r, g_T^l g_T^k r)\right] - E\left[\widetilde{V_L}(T, g_T^k r, g_T^l g_T^k r)\right]\right\}.$$

Since after keeping a patent (K) in period t the patentee always has the possibility to declare LOR (L) in the next period, $\widetilde{V_K}(T, r, y) \geq \widetilde{V_L}(T, r, y)$,

and $E\left[\widetilde{V_K}(T, r, y)\right] \geq E\left[\widetilde{V_L}(T, r, y)\right]$ (the option value of strategy L is included in the option value of strategy K).

Since f_{T-1} is also smaller than f_T the inequality must be fulfilled.

For the general result one has to show that

$$\widetilde{V}^K(t, r) - \widetilde{V}^L(t, r, y) \leq \widetilde{V}^K(t-1, r) - \widetilde{V}^L(t-1, r, y)\ .$$

Assume that $\widetilde{V}^K(t+1, r) - \widetilde{V}^L(t+1, r, y) \leq \widetilde{V}^K(t, r) - \widetilde{V}^L(t, r, y)$.

From Lemma 1.1 we know that $\widetilde{V}^K(t+1,r) \leq \widetilde{V}^K(t,r)$ and $\widetilde{V}^L(t+1,r,y) \leq \widetilde{V}^L(t,r,y)$, and thus,

$$max\left\{\widetilde{V}^K(t+1,r),\widetilde{V}^L(t+1,r,y),0\right\} - max\left\{\widetilde{V}^L(t+1,r,y),0\right\} \leq$$

$$\leq max\left\{\widetilde{V}^K(t,r),\widetilde{V}^L(t,r,y),0\right\} - max\left\{\widetilde{V}^L(t,r,y),0\right\}$$

$$\Rightarrow E\left[\widetilde{V_K}(t+1,g^k_{t+1}r,g^l_{t+1}g^k_{t+1}r) - \widetilde{V_L}(t+1,g^k_{t+1}r,g^l_{t+1}g^k_{t+1}r)\right] \leq$$

$$\leq E\left[\widetilde{V_K}(t,g^k_t r,g^l_t g^k_t r) - \widetilde{V_L}(t,g^k_t r,g^l_t g^k_t r)\right] \text{ (since } \widetilde{V_K}(.) \geq \widetilde{V_L}(.) \text{ for all } t)$$

$$\Rightarrow E\left[\widetilde{V_K}(t+1,g^k_{t+1}r,g^l_{t+1}g^k_{t+1}r)\right] - E\left[\widetilde{V_L}(t+1,g^k_{t+1}r,g^l_{t+1}g^k_{t+1}r)\right] \leq$$

$$\leq E\left[\widetilde{V_K}(t,g^k_t r,g^l_t g^k_t r)\right] - E\left[\widetilde{V_L}(t,g^k_t r,g^l_t g^k_t r)\right]$$

$$\Rightarrow \widetilde{V}^K(t,r) - \widetilde{V}^L(t,r,y) \leq \widetilde{V}^K(t-1,r) - \widetilde{V}^L(t-1,r,y).$$

Intuition: By declaring LOR in period $t-1$ the agent loses the option value of strategy (K) for $a-(t-1)$ periods. However, if he chose (L) in period t, he would give up the option of choosing (K) for only $a-t$ periods. The earlier LOR is declared, the higher will be the loss in option value from not being able to choose (K) anymore. Or, putting it differently, the option value of choosing (K) instead of (L) is decreasing with t, since once LOR has been declared you can never choose (K) again but not vice versa. Furthermore, the savings in maintenance fees from declaring LOR are non-decreasing with t. This means that $\hat{g}^{l+}_t(r)$ is decreasing with t for a given r. ■

1.7.2 Descriptive Statistics

Descriptive Statistics with a Single Patent as the Unit of Observation (Cohorts 1983-1998)

Variable	N	Mean	Std. Dev.	Min	Max
LOR	776,519	0.04675	0.21111	0	1
N_IPC	774,382	4.40897	3.20675	1	169
N_INV	767,215	2.24690	1.59214	1	40
N_CIT_7y	776,519	2.42785	4.20978	0	286
N_CIT_5y	776,519	1.75108	3.15256	0	218
FAM_SIZE	776,519	6.66823	5.96992	1	255
OPPOSITION	776,519	0.05565	0.22924	0	1
SMALL_CLASS	774,382	0.00236	0.04856	0	1
PORTFOL_SIZE	732,748	277.627	670.028	1	5,520
IPC4_C4	739,144	0.19855	0.12219	0.02913	1
IPC4_SHARE	730,931	0.02518	0.05018	0.00021	1
IPC4_PORTFOL	730,931	0.38823	0.37982	0.00018	1
EPO	776,519	0.68502	0.46451	0	1
NON-PROFIT ORGANIZATION & UNIVERSITY	764,012	0.03152	0.17473	0	1
INDIVIDUAL INVENTOR	764,012	0.09713	0.29613	0	1
SMALL CORPORATION	764,012	0.30234	0.45927	0	1
MEDIUM CORPORATION	764,012	0.29063	0.45405	0	1
LARGE CORPORATION	764,012	0.27838	0.44820	0	1
ELECTRICAL ENGINEERING	774,098	0.21673	0.41201	0	1
INSTRUMENTS	774,098	0.15877	0.36546	0	1
CHEMISTRY & PHARMA.	774,098	0.19895	0.39921	0	1
PROCESS ENGINEERING	774,098	0.15971	0.36634	0	1
MECHANICAL ENGINEERING	774,098	0.19087	0.39299	0	1

Variable	N	Mean	Std. Dev.	Min	Max
CONSUMER & CONSTR. GOODS	774,098	0.07498	0.26335	0	1
APPLCT_DE	776,519	0.33245	0.47109	0	1
APPLCT_JP	776,519	0.19058	0.39276	0	1
APPLCT_US	776,519	0.18540	0.38862	0	1
APPLCT_FR	776,519	0.05887	0.23538	0	1
APPLCT_NL_BE	776,519	0.03098	0.17325	0	1
APPLCT_NONE	776,519	0.04155	0.19955	0	1
APPLCT_REST	776,519	0.16018	0.36677	0	1
APPL_YR_1983	776,519	0.04561	0.20863	0	1
APPL_YR_1984	776,519	0.04971	0.21734	0	1
APPL_YR_1985	776,519	0.05039	0.21875	0	1
APPL_YR_1986	776,519	0.05261	0.22326	0	1
APPL_YR_1987	776,519	0.05408	0.22618	0	1
APPL_YR_1988	776,519	0.05809	0.23392	0	1
APPL_YR_1989	776,519	0.06033	0.23809	0	1
APPL_YR_1990	776,519	0.06606	0.24838	0	1
APPL_YR_1991	776,519	0.06467	0.24595	0	1
APPL_YR_1992	776,519	0.06641	0.24899	0	1
APPL_YR_1993	776,519	0.06718	0.25034	0	1
APPL_YR_1994	776,519	0.06889	0.25326	0	1
APPL_YR_1995	776,519	0.06991	0.25499	0	1
APPL_YR_1996	776,519	0.07257	0.25943	0	1
APPL_YR_1997	776,519	0.07599	0.26498	0	1
APPL_YR_1998	776,519	0.07751	0.26739	0	1

Correlation Table with one Single Patent as the Unit of Observation (Cohorts 1983-1998)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) LOR	1.0000											
(2) N_IPC	-0.0223	1.0000										
(3) N_INV	-0.0084	0.1262	1.0000									
(4) N_CIT_7y	-0.0120	0.1686	0.1252	1.0000								
(5) N_CIT_5y	-0.0116	0.1672	0.1301	0.9496	1.0000							
(6) FAM_SIZE	-0.0932	0.2425	0.1564	0.3450	0.3290	1.0000						
(7) OPPOSITION	-0.0076	-0.0022	0.0031	0.0954	0.0889	0.0326	1.0000					
(8) SMALL_CLASS	-0.0069	-0.0114	-0.0103	-0.0098	-0.0098	-0.0020	-0.0014	1.0000				
(9) PORTFOL_SIZE	0.1011	-0.0053	0.0686	0.0166	0.0222	-0.0561	-0.0344	-0.0122	1.0000			
(10) IPC4_C4	0.0566	-0.0178	0.0299	0.0073	0.0149	-0.0452	-0.0163	0.1227	0.1695	1.0000		
(11) IPC4_SHARE	0.0129	-0.0226	-0.0249	-0.0339	-0.0317	-0.0556	0.0165	0.0383	0.2631	0.2246	1.0000	
(12) IPC4_PORTFOL	-0.1214	-0.0599	-0.1933	-0.0252	-0.0315	-0.0101	0.0339	0.0196	-0.3498	-0.1413	-0.1310	1.0000

Descriptive Statistics with One Decision Period as the Unit of Observation (Cohorts 1983-1998)

Decision to Declare the Willingness to License (LOR)

Variable	N	Mean	Std. Dev.	Min	Max
LOR	5,424,860	0.00591	0.07663	0	1
N_IPC	5,424,860	4.41710	3.15769	1	169
N_INV	5,424,860	2.23282	1.56220	1	40
N_CIT	5,424,860	3.13924	5.46988	0	549
FAM_SIZE	5,424,860	6.46198	5.73404	1	255
OPPOSITION	5,424,860	0.06258	0.24220	0	1
SMALL_CLASS	5,424,860	0.00244	0.04934	0	1
PORTFOL_SIZE	5,424,860	265.665	636.922	1	5,520
IPC4_C4	5,424,860	0.19815	0.12222	0.02912	1
IPC4_SHARE	5,424,860	0.02575	0.05063	0.00021	1
IPC4_PORTFOL	5,424,860	0.38665	0.37697	0.00018	1
EPO	5,424,860	0.62273	0.48470	0	1
NOGRANT_YEAR	5,424,860	0.11730	0.32178	0	1
NON-PROFIT ORGANIZATION & UNIVERSITY	5,424,860	0.02923	0.16844	0	1
INDIVIDUAL INVENTOR	5,424,860	0.09421	0.29211	0	1
SMALL CORPORATION	5,424,860	0.30746	0.46144	0	1
MEDIUM CORPORATION	5,424,860	0.29588	0.45644	0	1
LARGE CORPORATION	5,424,860	0.27322	0.44561	0	1
ELECTRICAL ENGINEERING	5,424,860	0.20829	0.40609	0	1
INSTRUMENTS	5,424,860	0.15881	0.36550	0	1
CHEMISTRY & PHARMA.	5,424,860	0.19023	0.39248	0	1
PROCESS ENGINEERING	5,424,860	0.16436	0.37060	0	1
MECHANICAL ENGINEERING	5,424,860	0.20320	0.40238	0	1

Decision to Declare the Willingness to License (LOR)

Variable	N	Mean	Std. Dev.	Min	Max
CONSUMER & CONSTR. GOODS	5,424,860	0.07510	0.26356	0	1
APPLCT_DE	5,424,860	0.35265	0.47780	0	1
APPLCT_JP	5,424,860	0.20484	0.40359	0	1
APPLCT_US	5,424,860	0.16869	0.37447	0	1
APPLCT_FR	5,424,860	0.05701	0.23187	0	1
APPLCT_NL_BE	5,424,860	0.02771	0.16415	0	1
APPLCT_NONE	5,424860	0.04159	0.19965	0	1
APPLCT_REST	5,424,860	0.14750	0.35461	0	1
AGE_3	5,424,860	0.04182	0.20017	0	1
AGE_4	5,424,860	0.04997	0.21788	0	1
AGE_5	5,424,860	0.07059	0.25613	0	1
AGE_6	5,424,860	0.08980	0.28589	0	1
AGE_7	5,424,860	0.10056	0.30075	0	1
AGE_8	5,424,860	0.10267	0.30353	0	1
AGE_9	5,424,860	0.09971	0.29961	0	1
AGE_10	5,424,860	0.09430	0.29225	0	1
AGE_11	5,424,860	0.07952	0.27054	0	1
AGE_12	5,424,860	0.06546	0.24733	0	1
AGE_13	5,424,860	0.05315	0.22433	0	1
AGE_14	5,424,860	0.04263	0.20202	0	1
AGE_15	5,424,860	0.03363	0.18026	0	1
AGE_16	5,424,860	0.02599	0.15910	0	1
AGE_17	5,424,860	0.01960	0.13860	0	1
AGE_18	5,424,860	0.01431	0.11875	0	1
AGE_19	5,424,860	0.00984	0.09873	0	1
AGE_20	5,424,860	0.00647	0.08016	0	1
YEAR_1986	5,424,860	0.00289	0.05365	0	1
YEAR_1987	5,424,860	0.00619	0.07845	0	1
YEAR_1988	5,424,860	0.01049	0.10187	0	1
YEAR_1989	5,424,860	0.01553	0.12364	0	1
YEAR_1990	5,424,860	0.02101	0.14343	0	1
YEAR_1991	5,424,860	0.02656	0.16079	0	1
YEAR_1992	5,424,860	0.03150	0.17468	0	1
YEAR_1993	5,424,860	0.03639	0.18725	0	1
YEAR_1994	5,424,860	0.04243	0.20157	0	1

Decision to Declare the Willingness to License (LOR)

Variable	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
YEAR_1995	5,424,860	0.04859	0.21502	0	1
YEAR_1996	5,424,860	0.05441	0.22682	0	1
YEAR_1997	5,424,860	0.05948	0.23652	0	1
YEAR_1998	5,424,860	0.06394	0.24465	0	1
YEAR_1999	5,424,860	0.06816	0.25201	0	1
YEAR_2000	5,424,860	0.07103	0.25688	0	1
YEAR_2001	5,424,860	0.06955	0.25439	0	1
YEAR_2002	5,424,860	0.07024	0.25555	0	1
YEAR_2003	5,424,860	0.06924	0.25387	0	1
YEAR_2004	5,424,860	0.06496	0.24645	0	1
YEAR_2005	5,424,860	0.06021	0.23787	0	1
YEAR_2006	5,424,860	0.05561	0.22916	0	1
YEAR_2007	5,424,860	0.05099	0.21998	0	1
YEAR_2008	5,424,860	0.00060	0.02442	0	1

Decision to Let the Patent Expire (EXP)

Variable	N	Mean	Std. Dev.	Min	Max
EXP	7,316,518	0.05990	0.23730	0	1
N_IPC	7,316,518	4.50045	3.31813	1	169
N_INV	7,316,518	2.30022	1.62398	1	40
N_CIT	7,316,518	2.94235	5.42165	0	549
FAM_SIZE	7,316,518	7.01173	6.27967	1	255
OPPOSITION	7,316,518	0.06109	0.23949	0	1
SMALL_CLASS	7,316,518	0.00231	0.04805	0	1
PORTFOL_SIZE	7,316,518	275.871	628.940	1	5,520
IPC4_C4	7,316,518	0.20005	0.12269	0.02913	1
IPC4_SHARE	7,316,518	0.02590	0.05073	0.00021	1
IPC4_PORTFOL	7,316,518	0.37785	0.37508	0.00018	1
EPO	7,316,518	0.70892	0.45426	0	1
NOGRANT_YEAR	7,316,518	0.32661	0.46897	0	1
WITH_LOR	7,316,518	0.02461	0.15494	0	1
NON-PROFIT ORGANIZATION & UNIVERSITY	7,316,518	0.03083	0.17285	0	1
INDIVIDUAL INVENTOR	7,316,518	0.08589	0.28020	0	1
SMALL CORPORATION	7,316,518	0.29908	0.45786	0	1
MEDIUM CORPORATION	7,316,518	0.29416	0.45567	0	1
LARGE CORPORATION	7,316,518	0.29004	0.45378	0	1
ELECTRICAL ENGINEERING	7,316,518	0.22672	0.41871	0	1
INSTRUMENTS	7,316,518	0.16317	0.36952	0	1
CHEMISTRY & PHARMA.	7,316,518	0.20286	0.40213	0	1
PROCESS ENGINEERING	7,316,518	0.15412	0.36106	0	1
MECHANICAL ENGINEERING	7,316,518	0.18458	0.38795	0	1
CONSUMER & CONSTR. GOODS	7,316,518	0.06856	0.25271	0	1

Decision to Let the Patent Expire (EXP)

Variable	N	Mean	Std. Dev.	Min	Max
APPLCT_DE	7,316,518	0.31082	0.46283	0	1
APPLCT_JP	7,316,518	0.21742	0.41249	0	1
APPLCT_US	7,316,518	0.19679	0.39757	0	1
APPLCT_FR	7,316,518	0.05730	0.23241	0	1
APPLCT_NL_BE	7,316,518	0.03118	0.17380	0	1
APPLCT_NONE	7,316,518	0.03296	0.17854	0	1
APPLCT_REST	7,316,518	0.15353	0.36050	0	1
AGE_3	7,316,518	0.09874	0.29831	0	1
AGE_4	7,316,518	0.09843	0.29790	0	1
AGE_5	7,316,518	0.09763	0.29681	0	1
AGE_6	7,316,518	0.09557	0.29400	0	1
AGE_7	7,316,518	0.09169	0.28858	0	1
AGE_8	7,316,518	0.08645	0.28103	0	1
AGE_9	7,316,518	0.08055	0.27215	0	1
AGE_10	7,316,518	0.07453	0.26263	0	1
AGE_11	7,316,518	0.06237	0.24182	0	1
AGE_12	7,316,518	0.05124	0.22049	0	1
AGE_13	7,316,518	0.04166	0.19982	0	1
AGE_14	7,316,518	0.03355	0.18006	0	1
AGE_15	7,316,518	0.02658	0.16085	0	1
AGE_16	7,316,518	0.02066	0.14225	0	1
AGE_17	7,316,518	0.01568	0.12423	0	1
AGE_18	7,316,518	0.01150	0.10660	0	1
AGE_19	7,316,518	0.00794	0.08875	0	1
AGE_20	7,316,518	0.00524	0.07217	0	1
YEAR_1986	7,316,518	0.00516	0.07162	0	1
YEAR_1987	7,316,518	0.01032	0.10105	0	1
YEAR_1988	7,316,518	0.01559	0.12389	0	1
YEAR_1989	7,316,518	0.02075	0.14253	0	1
YEAR_1990	7,316,518	0.02606	0.15932	0	1
YEAR_1991	7,316,518	0.03172	0.17525	0	1
YEAR_1992	7,316,518	0.03751	0.19000	0	1
YEAR_1993	7,316,518	0.04266	0.20210	0	1
YEAR_1994	7,316,518	0.04750	0.21271	0	1
YEAR_1995	7,316,518	0.05204	0.22211	0	1
YEAR_1996	7,316,518	0.05654	0.23097	0	1

Decision to Let the Patent Expire (EXP)

Variable	N	Mean	Std. Dev.	Min	Max
YEAR_1997	7,316,518	0.06068	0.23874	0	1
YEAR_1998	7,316,518	0.06498	0.24649	0	1
YEAR_1999	7,316,518	0.06948	0.25426	0	1
YEAR_2000	7,316,518	0.07375	0.26136	0	1
YEAR_2001	7,316,518	0.06990	0.25498	0	1
YEAR_2002	7,316,518	0.06587	0.24805	0	1
YEAR_2003	7,316,518	0.06090	0.23916	0	1
YEAR_2004	7,316,518	0.05485	0.22769	0	1
YEAR_2005	7,316,518	0.04931	0.21650	0	1
YEAR_2006	7,316,518	0.04432	0.20580	0	1
YEAR_2007	7,316,518	0.03966	0.19516	0	1
YEAR_2008	7,316,518	0.00047	0.02176	0	1

Correlation Tables with One Decision Period as the Unit of Observation (Cohorts 1983-1998)

Decision to Declare the Willingness to License (LOR)

N = 5,424,860	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
(1) LOR	1.0000											
(2) N_IPC	-0.0074	1.0000										
(3) N_INV	-0.0023	0.1235	1.0000									
(4) N_CIT	-0.0056	0.1748	0.1127	1.0000								
(5) FAM_SIZE	-0.0304	0.2466	0.1415	0.3362	1.0000							
(6) OPPOSITION	-0.0057	-0.0022	-0.0004	0.1043	0.0261	1.0000						
(7) PORTFOL_SIZE	0.0382	0.0020	0.0859	0.0020	-0.0537	-0.0371	1.0000					
(8) IPC4_C4	0.0204	-0.0192	0.0403	-0.0068	-0.0454	-0.0181	0.1746	1.0000				
(9) IPC4_SHARE	0.0119	-0.0133	0.0501	0.0081	-0.0126	-0.0085	0.3499	0.5602	1.0000			
(10) IPC4_PORTFOL	-0.0429	-0.0646	-0.2064	-0.0174	-0.0203	0.0359	-0.3509	-0.1434	-0.1253	1.0000		
(11) SMALL_CLASS	-0.0024	-0.0122	-0.0119	-0.0094	-0.0012	-0.0007	-0.0110	0.1238	0.2227	0.0186	1.0000	
(12) AGE	0.0015	0.0592	0.0628	0.2560	0.1541	0.0433	-0.0211	0.0086	0.0166	-0.0223	-0.0027	1.0000

Decision to Let the Patent Expire (EXP)

N = 7,316,518	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
(1) EXP	1.0000												
(2) N_IPC	-0.0124	1.0000											
(3) N_INV	-0.0255	0.1244	1.0000										
(4) N_CIT	-0.0114	0.1614	0.1091	1.0000									
(5) FAM_SIZE	-0.0407	0.2431	0.1479	0.3328	1.0000								
(6) OPPOSITION	-0.0169	-0.0007	0.0024	0.1032	0.0371	1.0000							
(7) WITH_LOR	0.0317	-0.0187	-0.0118	0.0078	-0.0744	-0.0081	1.0000						
(8) PORTFOL_SIZE	-0.0057	-0.0057	0.0790	-0.0015	-0.0621	-0.0399	0.0761	1.0000					
(9) IPC4_C4	-0.0086	-0.0216	0.0312	-0.0096	-0.0576	-0.0198	0.0411	0.1827	1.0000				
(10) IPC4_SHARE	-0.0071	-0.0153	0.0460	0.0060	-0.0227	-0.0074	0.0229	0.3576	0.5630	1.0000			
(11) IPC4_PORTFOL	0.0081	-0.0521	-0.1910	-0.0073	0.0085	0.0371	-0.0865	-0.3584	-0.1455	-0.1278	1.0000		
(12) SMALL_CLASS	0.0025	-0.0119	-0.0110	-0.0084	-0.0010	-0.0003	-0.0046	-0.0118	0.1198	0.2155	0.0182	1.0000	
(13) AGE	0.1642	0.0185	0.0164	0.2518	0.0279	0.0388	0.1390	-0.0120	0.0021	0.0135	-0.0129	-0.0014	1.0000

1.7.3 Supplementary Regressions

Determinants of the Probability to Observe a Declaration of the Willingness to License (LOR) – EPO vs. DPMA

LOR[a]	EPO		DPMA	
	(a)	(b)	(a)	(b)
log(N_CIT)	-0.034 (0.011)**		-0.012 (0.011)	
N_CIT				
1		-0.028 (0.025)		-0.049 (0.022)*
2		-0.061 (0.027)*		0.000 (0.025)
3		-0.091 (0.031)**		-0.032 (0.030)
4		-0.076 (0.034)*		-0.033 (0.035)
5		-0.083 (0.039)*		-0.043 (0.042)
6		-0.076 (0.044)†		-0.044 (0.050)
7		-0.096 (0.051)†		-0.046 (0.057)
8≤		-0.141 (0.032)***		-0.021 (0.034)
log(FAM_SIZE)	-0.521 (0.020)***		-0.381 (0.012)***	
FAM_SIZE				
2		-0.309 (0.117)**		-0.238 (0.025)***
3		-0.196 (0.090)*		-0.362 (0.027)***
4		-0.324 (0.088)***		-0.412 (0.028)***
5		-0.392 (0.088)***		-0.550 (0.034)***
6		-0.510 (0.088)***		-0.722 (0.045)***
7		-0.589 (0.090)***		-0.796 (0.061)***
8		-0.598 (0.092)***		-0.837 (0.078)***
9		-0.764 (0.096)***		-0.906 (0.099)***
10		-0.987 (0.104)***		-1.228 (0.144)***
11≤		-1.153 (0.095)***		-1.260 (0.088)***
OPPOSITION	-0.185 (0.044)***	-0.162 (0.044)***	-0.214 (0.035)***	-0.209 (0.035)***
log(N_INV)	-0.041 (0.014)**	-0.033 (0.014)*	-0.124 (0.015)***	-0.120 (0.015)***
log(N_IPC)	0.026 (0.016)	0.030 (0.016)†	0.015 (0.015)	0.015 (0.015)
AGE				
4	1.230 (0.720)†	1.246 (0.720)†	-0.247 (0.043)***	-0.247 (0.043)***
5	1.735 (0.707)*	1.759 (0.707)*	0.309 (0.039)***	0.310 (0.039)***
6	1.915 (0.706)**	1.945 (0.707)**	0.204 (0.042)***	0.205 (0.042)***
7	2.104 (0.706)**	2.141 (0.706)**	0.633 (0.040)***	0.631 (0.040)***
8	2.160 (0.706)**	2.202 (0.706)**	0.572 (0.041)***	0.573 (0.042)***
9	2.195 (0.706)**	2.239 (0.706)**	0.707 (0.042)***	0.709 (0.042)***
10	2.387 (0.706)***	2.435 (0.706)***	0.915 (0.042)***	0.920 (0.042)***
11	2.188 (0.706)**	2.242 (0.707)**	0.981 (0.044)***	0.992 (0.044)***
12	2.255 (0.707)**	2.315 (0.707)**	1.021 (0.047)***	1.036 (0.047)***
13	2.162 (0.707)**	2.230 (0.707)**	1.092 (0.051)***	1.109 (0.051)***
14	2.169 (0.707)**	2.244 (0.707)**	1.030 (0.057)***	1.045 (0.057)***
15	2.321 (0.707)**	2.399 (0.707)***	1.091 (0.061)***	1.112 (0.061)***
16	2.356 (0.708)***	2.434 (0.708)***	1.061 (0.069)***	1.085 (0.069)***
17	2.196 (0.709)**	2.273 (0.709)**	0.929 (0.082)***	0.961 (0.082)***
18	2.152 (0.710)**	2.222 (0.710)**	0.828 (0.099)***	0.868 (0.100)***
19	2.042 (0.712)**	2.105 (0.712)**	0.834 (0.113)***	0.882 (0.113)***
20	1.957 (0.717)**	2.011 (0.717)**	0.907 (0.132)***	0.963 (0.133)***

LOR[a]	EPO		DPMA	
	(a)	(b)	(a)	(b)
APPLCT_TYPE				
INDIV. INVENTOR	0.408 (0.147)**	1.354 (0.163)***	0.484 (0.074)***	0.813 (0.086)***
SMALL CORP.	0.294 (0.135)*	1.143 (0.152)***	-0.284 (0.071)***	0.131 (0.084)
MEDIUM CORP.	1.218 (0.129)***	1.184 (0.133)***	0.481 (0.060)***	0.447 (0.064)***
LARGE CORP.	1.858 (0.132)***	1.384 (0.129)***	1.000 (0.059)***	0.810 (0.059)***
TECH_AREA				
INSTRUMENTS	-0.237 (0.023)***	-0.114 (0.026)***	-0.340 (0.025)***	-0.212 (0.027)***
CHEM.&PHARMA.	-1.749 (0.040)***	-1.665 (0.042)***	-1.066 (0.045)***	-0.962 (0.046)***
PROCESS ENG.	-0.997 (0.036)***	-0.896 (0.039)***	-0.843 (0.032)***	-0.654 (0.035)***
MECHANIC. ENG.	0.063 (0.024)**	0.155 (0.027)***	-0.187 (0.020)***	-0.071 (0.022)**
CONS.&CONSTR.	-0.810 (0.061)***	-0.662 (0.063)***	-0.234 (0.035)***	-0.077 (0.038)*
log(PORTFOL_SIZE)	0.054 (0.011)***		0.061 (0.011)***	
PORTFOL_SIZE				
2-		0.044 (0.120)		-0.046 (0.067)
3-		0.126 (0.118)		-0.056 (0.074)
6-		0.507 (0.121)***		-0.030 (0.083)
11-		0.848 (0.133)***		0.100 (0.090)
19-		1.168 (0.138)***		0.259 (0.095)**
34-		1.226 (0.141)***		0.454 (0.097)***
62-		1.838 (0.140)***		0.852 (0.098)***
106-		2.044 (0.143)***		0.933 (0.101)***
180-		2.247 (0.149)***		1.097 (0.107)***
360-		2.363 (0.151)***		0.110 (0.112)
652-		1.970 (0.153)***		0.710 (0.112)***
1179-		2.238 (0.155)***		0.908 (0.117)***
IPC4_SHARE	-5.394 (0.228)***		-3.955 (0.264)***	
0.07%-		0.081 (0.079)		-0.111 (0.059)
0.12%-		-0.105 (0.078)		-0.156 (0.058)**
0.18%-		-0.003 (0.077)		-0.223 (0.057)***
0.25%-		-0.103 (0.075)		-0.262 (0.057)***
0.35%-		-0.021 (0.075)		-0.215 (0.057)***
0.46%-		-0.140 (0.076)†		-0.275 (0.057)***
0.62%-		-0.147 (0.074)*		-0.267 (0.057)***
0.84%-		-0.074 (0.073)		-0.163 (0.057)**
1.15%-		-0.176 (0.074)*		-0.181 (0.057)***
1.59%-		-0.287 (0.074)***		-0.273 (0.058)***
2.29%-		-0.223 (0.074)**		-0.191 (0.058)***
3.36%-		-0.502 (0.076)***		-0.217 (0.059)***
5.25%-		-0.665 (0.078)***		-0.586 (0.062)***
9.75%-		-0.935 (0.082)***		-0.893 (0.068)***

LOR[a]	**EPO**		**DPMA**	
	(a)	**(b)**	**(a)**	**(b)**
IPC4_PORTFOL	-0.454 (0.060)***		-0.863 (0.046)***	
0.98%-		0.079 (0.030)**		0.063 (0.031)
2.17%-		0.036 (0.033)		0.004 (0.033)
3.84%-		0.019 (0.036)		-0.013 (0.035)
6.08%-		0.030 (0.037)		0.021 (0.039)
9.09%-		-0.066 (0.041)		0.014 (0.043)
13.11%-		0.068 (0.045)		-0.169 (0.048)***
18.75%-		-0.008 (0.053)		-0.521 (0.058)***
25.00%-		0.307 (0.055)***		-0.577 (0.059)***
33.33%-		0.260 (0.053)***		-0.469 (0.056)***
50.00%-		0.077 (0.072)		-0.800 (0.070)***
62.50%-		0.118 (0.073)		-0.595 (0.066)***
100.00%		-0.145 (0.104)		-0.843 (0.081)***
IPC4_C4	1.502 (0.077)***		1.181 (0.076)***	
6.25%-		-0.427 (0.081)***		-0.047 (0.060)
7.95%-		-0.043 (0.075)		0.074 (0.057)
9.95%-		0.161 (0.072)*		-0.003 (0.057)
11.67%-		-0.026 (0.073)		0.134 (0.058)*
13.43%-		0.078 (0.071)		0.194 (0.057)***
14.87%-		0.218 (0.069)**		0.282 (0.055)***
16.43%-		0.276 (0.067)***		0.336 (0.053)***
18.25%-		0.387 (0.067)***		0.482 (0.053)***
20.15%-		0.358 (0.067)***		0.421 (0.055)***
22.25%-		0.505 (0.066)***		0.555 (0.053)***
24.85%-		0.469 (0.066)***		0.517 (0.054)***
28.02%-		0.495 (0.066)***		0.500 (0.054)***
31.89%-		0.361 (0.067)***		0.401 (0.055)***
41.37%-		0.383 (0.066)***		0.524 (0.057)***
control variables: *EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS*				
log pseudolikelihood	-84,179.9	-83,594.8	-88,073.5	-87,025.8
Pseudo R2	0.141	0.147	0.092	0.103
Observations	3,378,131	3,378,131	2,046,637	2,046,637

[a]Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Determinants of the Probability to Observe a Declaration of the Willingness to License (LOR) – ALL

LOR[a]	ALL					
	(a)	(b)	(c)	(d)	(e)	(f)
log(N_CIT)	-0.031 (0.008)***		-0.036 (0.008)***			
N_CIT						
1		-0.038 (0.016)*		-0.037 (0.016)*		
2		-0.032 (0.018)†		-0.032 (0.018)†		
3		-0.065 (0.021)**		-0.064 (0.021)**		
4		-0.057 (0.025)*		-0.059 (0.025)*		
5		-0.063 (0.028)*		-0.065 (0.028)*		
6		-0.062 (0.033)†		-0.060 (0.033)†		
7		-0.077 (0.038)*		-0.080 (0.038)*		
8≤		-0.088 (0.023)***		-0.083 (0.023)***		
log(FAM_SIZE)	-0.406 (0.010)***		-0.417 (0.010)***			
FAM_SIZE						
2		-0.252 (0.024)***		-0.254 (0.024)***		
3		-0.375 (0.022)***		-0.357 (0.022)***		
4		-0.441 (0.022)***		-0.434 (0.022)***		
5		-0.521 (0.022)***		-0.521 (0.022)***		
6		-0.634 (0.025)***		-0.644 (0.025)***		
7		-0.714 (0.029)***		-0.734 (0.029)***		
8		-0.736 (0.034)***		-0.763 (0.034)***		
9		-0.900 (0.043)***		-0.935 (0.043)***		
10		-1.138 (0.056)***		-1.183 (0.056)***		
11≤		-1.296 (0.039)***		-1.362 (0.039)***		
OPPOSITION	-0.195 (0.028)***	-0.179 (0.028)***	-0.193 (0.028)***	-0.190 (0.028)***		
log(N_INV)	-0.084 (0.010)***	-0.080 (0.010)***	-0.069 (0.010)***	-0.065 (0.010)***		
log(N_IPC)	0.018 (0.011)	0.023 (0.011)*	0.022 (0.011)*	0.023 (0.011)*		
AGE						
4	-0.250 (0.042)***	-0.250 (0.042)***	-0.255 (0.042)***	-0.255 (0.042)***		
5	0.260 (0.037)***	0.258 (0.037)***	0.253 (0.037)***	0.252 (0.037)***		
6	0.239 (0.037)***	0.236 (0.037)***	0.232 (0.037)***	0.229 (0.037)***		
7	0.573 (0.036)***	0.571 (0.036)***	0.563 (0.036)***	0.560 (0.036)***		
8	0.585 (0.037)***	0.586 (0.037)***	0.573 (0.036)***	0.570 (0.037)***		
9	0.680 (0.037)***	0.683 (0.037)***	0.665 (0.037)***	0.662 (0.037)***		
10	0.889 (0.037)***	0.893 (0.037)***	0.869 (0.037)***	0.866 (0.037)***		
11	0.810 (0.039)***	0.820 (0.039)***	0.788 (0.039)***	0.784 (0.039)***		
12	0.863 (0.040)***	0.877 (0.040)***	0.836 (0.040)***	0.832 (0.040)***		
13	0.845 (0.042)***	0.860 (0.042)***	0.817 (0.042)***	0.813 (0.042)***		
14	0.818 (0.045)***	0.834 (0.045)***	0.789 (0.045)***	0.784 (0.045)***		
15	0.929 (0.046)***	0.948 (0.047)***	0.897 (0.046)***	0.891 (0.046)***		
16	0.937 (0.050)***	0.956 (0.050)***	0.902 (0.050)***	0.895 (0.050)***		
17	0.787 (0.058)***	0.808 (0.058)***	0.746 (0.058)***	0.739 (0.058)***		
18	0.718 (0.067)***	0.740 (0.067)***	0.672 (0.067)***	0.663 (0.067)***		
19	0.652 (0.078)***	0.677 (0.079)***	0.604 (0.078)***	0.593 (0.078)***		
20	0.638 (0.096)***	0.663 (0.096)***	0.585 (0.095)***	0.571 (0.096)***		

LOR[a]	**ALL**					
	(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**
APPLCT_TYPE						
INDIV. INVENTOR	0.451 (0.064)***	1.035 (0.074)***	-0.170 (0.057)**	-0.161 (0.057)**	0.508 (0.063)***	1.056 (0.073)***
SMALL CORP.	-0.165 (0.060)**	0.438 (0.072)***	-0.605 (0.055)***	-0.606 (0.055)***	-0.187 (0.060)**	0.410 (0.071)***
MEDIUM CORP.	0.657 (0.053)***	0.661 (0.057)***	0.617 (0.053)***	0.610 (0.053)***	0.613 (0.053)***	0.641 (0.057)***
LARGE CORP.	1.217 (0.054)***	0.963 (0.053)***	1.334 (0.052)***	1.322 (0.052)***	1.210 (0.054)***	0.942 (0.053)***
TECH_AREA						
INSTRUMENTS	-0.292 (0.017)***	-0.180 (0.018)***	-0.343 (0.017)***	-0.345 (0.017)***	-0.308 (0.017)***	-0.191 (0.018)***
CHEM.&PHARMA.	-1.551 (0.030)***	-1.445 (0.031)***	-1.614 (0.029)***	-1.568 (0.030)***	-1.710 (0.029)***	-1.630 (0.030)***
PROCESS ENG.	-0.915 (0.024)***	-0.793 (0.026)***	-1.049 (0.024)***	-1.041 (0.024)***	-0.969 (0.024)***	-0.845 (0.026)***
MECHANIC. ENG.	-0.107 (0.015)***	-0.031 (0.017)†	-0.166 (0.015)***	-0.168 (0.015)***	-0.111 (0.015)***	-0.025 (0.017)
CONS.&CONSTR.	-0.384 (0.029)***	-0.244 (0.031)***	-0.536 (0.029)***	-0.528 (0.029)***	-0.380 (0.029)***	-0.242 (0.031)***
log(PORTFOL_SIZE)	0.058 (0.008)***				0.048 (0.008)***	
PORTFOL_SIZE						
2-		-0.035 (0.059)				-0.097 (0.058)†
3-		-0.013 (0.062)				-0.102 (0.062)
6-		0.192 (0.066)**				0.075 (0.067)
11-		0.406 (0.073)***				0.267 (0.073)***
19-		0.634 (0.076)***				0.487 (0.076)***
34-		0.779 (0.078)***				0.633 (0.078)***
62-		1.249 (0.079)***				1.110 (0.079)***
106-		1.382 (0.081)***				1.237 (0.081)***
180-		1.556 (0.085)***				1.424 (0.085)***
360-		1.187 (0.087)***				1.069 (0.087)***
652-		1.192 (0.088)***				1.041 (0.088)***
1179-		1.426 (0.090)***				1.295 (0.090)***
IPC4_SHARE	-4.679 (0.171)***				-4.841 (0.172)***	
0.07%-		-0.027 (0.047)				-0.018 (0.047)
0.12%-		-0.129 (0.046)**				-0.115 (0.046)*
0.18%-		-0.123 (0.046)**				-0.107 (0.046)*
0.25%-		-0.189 (0.045)***				-0.181 (0.045)***
0.35%-		-0.122 (0.045)**				-0.110 (0.045)*
0.46%-		-0.202 (0.045)***				-0.198 (0.045)***
0.62%-		-0.201 (0.045)***				-0.198 (0.045)***
0.84%-		-0.110 (0.044)*				-0.108 (0.044)*
1.15%-		-0.174 (0.045)***				-0.170 (0.044)***
1.59%-		-0.266 (0.045)***				-0.274 (0.045)***
2.29%-		-0.194 (0.045)***				-0.194 (0.045)***
3.36%-		-0.348 (0.046)***				-0.354 (0.046)***
5.25%-		-0.609 (0.048)***				-0.618 (0.048)***
9.75%-		-0.867 (0.051)***				-0.891 (0.051)***

LOR[a]	ALL					
	(a)	(b)	(c)	(d)	(e)	(f)
IPC4_PORTFOL	-0.707 (0.037)***				-0.718 (0.037)***	
0.98%-		0.064 (0.022)**				0.058 (0.022)**
2.17%-		0.013 (0.023)				0.011 (0.023)
3.84%-		0.000 (0.025)				-0.007 (0.025)
6.08%-		0.020 (0.027)				0.013 (0.027)
9.09%-		-0.022 (0.029)				-0.032 (0.029)
13.11%-		-0.035 (0.032)				-0.048 (0.032)
18.75%-		-0.231 (0.039)***				-0.253 (0.039)***
25.00%-		-0.117 (0.040)**				-0.135 (0.040)***
33.33%-		-0.095 (0.039)*				-0.124 (0.038)**
50.00%-		-0.381 (0.050)***				-0.416 (0.050)***
62.50%-		-0.259 (0.048)***				-0.300 (0.048)***
100.00%		-0.476 (0.062)***				-0.530 (0.062)***
IPC4_C4	1.383 (0.054)***				1.402 (0.054)***	
6.25%-		-0.199 (0.048)***				-0.211 (0.048)***
7.95%-		0.028 (0.045)				0.036 (0.045)
9.95%-		0.052 (0.045)				0.055 (0.045)
11.67%-		0.049 (0.045)				0.048 (0.045)
13.43%-		0.129 (0.044)**				0.137 (0.044)**
14.87%-		0.240 (0.043)***				0.252 (0.042)***
16.43%-		0.300 (0.041)***				0.314 (0.041)***
18.25%-		0.433 (0.041)***				0.459 (0.041)***
20.15%-		0.387 (0.042)***				0.413 (0.042)***
22.25%-		0.518 (0.041)***				0.541 (0.041)***
24.85%-		0.483 (0.041)***				0.500 (0.041)***
28.02%-		0.505 (0.041)***				0.525 (0.041)***
31.89%-		0.369 (0.042)***				0.377 (0.042)***
41.37%-		0.470 (0.042)***				0.494 (0.042)***
control variables: *EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS*						
log pseudolikelihood	-173,348.0	-172,229.3	-9,230.5	-6,426.6	-174357.6	-173287.8
Pseudo R2	0.117	0.123	0.116	0.155	0.112	0.118
Observations	5,424,860	5,424,860	372,196	656,116	5,424,860	5,424,860

[a]Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Determinants of the Probability to Observe a Declaration of the Willingness to License (LOR) – Market and Applicant Characteristics

LOR[a]	(1)		(2)		(3)		(4)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
APPLCT_TYPE								
INDIV. INVENTOR	0.077 (0.061)	0.959 (0.073)***	0.464 (0.063)***	1.048 (0.073)***	-0.076 (0.057)	-0.059 (0.057)	0.412 (0.060)***	0.487 (0.061)***
SMALL CORP.	-0.466 (0.059)***	0.350 (0.071)***	-0.218 (0.060)***	0.425 (0.071)***	-0.597 (0.055)***	-0.592 (0.055)***	-0.279 (0.057)***	-0.190 (0.058)**
MEDIUM CORP.	0.581 (0.053)***	0.571 (0.057)***	0.624 (0.053)***	0.664 (0.057)***	0.565 (0.053)***	0.546 (0.053)***	0.594 (0.053)***	0.606 (0.053)***
LARGE CORP.	1.165 (0.055)***	0.870 (0.053)***	1.253 (0.054)***	0.967 (0.053)***	1.282 (0.052)***	1.254 (0.052)***	1.303 (0.052)***	1.241 (0.053)***
TECH_AREA								
INSTRUMENTS	-0.348 (0.017)***	-0.364 (0.017)***	-0.342 (0.017)***	-0.362 (0.017)***	-0.356 (0.017)***	-0.216 (0.018)***	-0.318 (0.017)***	-0.208 (0.018)***
CHEM.&PHARMA.	-1.750 (0.029)***	-1.800 (0.030)***	-1.787 (0.029)***	-1.812 (0.030)***	-1.758 (0.029)***	-1.655 (0.029)***	-1.729 (0.029)***	-1.639 (0.030)***
PROCESS ENG.	-1.079 (0.024)***	-1.110 (0.024)***	-1.029 (0.024)***	-1.049 (0.024)***	-1.102 (0.024)***	-0.950 (0.025)***	-0.990 (0.024)***	-0.878 (0.025)***
MECHANIC. ENG.	-0.149 (0.016)***	-0.179 (0.016)***	-0.139 (0.015)***	-0.156 (0.016)***	-0.167 (0.015)***	-0.075 (0.016)***	-0.131 (0.015)***	-0.061 (0.016)***
CONS.&CONSTR.	-0.504 (0.029)***	-0.490 (0.029)***	-0.440 (0.029)***	-0.426 (0.030)***	-0.526 (0.029)***	-0.423 (0.029)***	-0.406 (0.029)***	-0.337 (0.030)***
log(PORTFOL_SIZE)	0.049 (0.006)***		0.029 (0.008)***					
PORTFOL_SIZE								
2-		-0.042 (0.046)		-0.129 (0.058)*				
3-		0.135 (0.040)***		-0.150 (0.062)*				
6-		0.389 (0.042)***		0.015 (0.067)				
11-		0.631 (0.049)***		0.195 (0.073)**				
19-		0.866 (0.052)***		0.405 (0.076)***				
34-		1.039 (0.052)***		0.550 (0.078)***				
62-		1.518 (0.052)***		1.020 (0.078)***				
106-		1.658 (0.053)***		1.136 (0.080)***				
180-		1.824 (0.059)***		1.316 (0.085)***				
360-		1.463 (0.060)***		0.943 (0.087)***				
652-		1.410 (0.060)***		0.899 (0.088)***				
1179-		1.526 (0.059)***		1.102 (0.089)***				

LOR[a]	(1)		(2)		(3)		(4)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
IPC4_SHARE			-3.066 (0.156)***				-4.450 (0.155)***	
0.07%-				0.018 (0.047)				0.004 (0.047)
0.12%-				-0.110 (0.046)*				-0.074 (0.046)
0.18%-				-0.075 (0.045)				-0.054 (0.046)
0.25%-				-0.137 (0.045)**				-0.106 (0.045)*
0.35%-				-0.052 (0.045)				-0.017 (0.045)
0.46%-				-0.124 (0.045)**				-0.081 (0.045)†
0.62%-				-0.109 (0.044)*				-0.075 (0.044)†
0.84%-				0.008 (0.044)				0.035 (0.043)
1.15%-				-0.043 (0.044)				-0.025 (0.043)
1.59%-				-0.126 (0.044)**				-0.114 (0.043)**
2.29%-				-0.017 (0.044)				-0.028 (0.043)
3.36%-				-0.140 (0.045)**				-0.168 (0.043)***
5.25%-				-0.362 (0.046)***				-0.404 (0.044)***
9.75%-				-0.572 (0.049)***				-0.625 (0.046)***
IPC4_PORTFOL			-0.771 (0.036)***				-0.826 (0.032)***	
0.98%-				0.035 (0.021)				0.047 (0.021)*
2.17%-				-0.011 (0.023)				-0.031 (0.022)
3.84%-				-0.030 (0.025)				-0.078 (0.024)**
6.08%-				-0.014 (0.026)				-0.098 (0.025)***
9.09%-				-0.074 (0.029)*				-0.168 (0.027)***
13.11%-				-0.101 (0.032)**				-0.195 (0.030)***
18.75%-				-0.313 (0.038)***				-0.434 (0.037)***
25.00%-				-0.198 (0.039)***				-0.361 (0.037)***
33.33%-				-0.203 (0.038)***				-0.385 (0.035)***
50.00%-				-0.504 (0.050)***				-0.754 (0.042)***
62.50%-				-0.394 (0.048)***				-0.640 (0.044)***
100.00%				-0.651 (0.062)***				-0.848 (0.038)***

LOR[a]	**(1)**		**(2)**		**(3)**		**(4)**	
	(a)	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**
IPC4_C4					0.245 (0.048)***		1.365 (0.054)***	
6.25%-						-0.243 (0.048)***		-0.220 (0.048)***
7.95%-						-0.023 (0.045)		-0.003 (0.045)
9.95%-						-0.014 (0.044)		0.018 (0.045)
11.67%-						-0.026 (0.044)		0.014 (0.045)
13.43%-						0.072 (0.043)†		0.116 (0.044)**
14.87%-						0.169 (0.042)***		0.225 (0.042)***
16.43%-						0.221 (0.040)***		0.287 (0.041)***
18.25%-						0.340 (0.040)***		0.431 (0.041)***
20.15%-						0.267 (0.040)***		0.379 (0.041)***
22.25%-						0.363 (0.040)***		0.514 (0.040)***
24.85%-						0.288 (0.040)***		0.460 (0.041)***
28.02%-						0.279 (0.040)***		0.486 (0.041)***
31.89%-						0.090 (0.040)*		0.329 (0.041)***
41.37%-						0.063 (0.041)		0.470 (0.042)***
control variables: ***AGE, EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS***								
log pseudolikelihood	-175437.3	-174477.8	-174651.5	-173738.5	-175448.6	-175174.2	-174377.7	-174032.5
Pseudo R2	0.107	0.111	0.111	0.115	0.107	0.108	0.112	0.114
Observations	5,424,860	5,424,860	5,424,860	5,424,860	5,424,860	5,424,860	5,424,860	5,424,860

[a] Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Determinants of the Probability to Observe a Decision to Let the Patent Expire (EXP) – EPO vs. DPMA

EXP[a]	EPO		DPMA	
	(a)	(b)	(a)	(b)
log(N_CIT)	-0.274 (0.003)***		-0.202 (0.004)***	
N_CIT				
1		-0.109 (0.006)***		-0.108 (0.008)***
2		-0.211 (0.007)***		-0.191 (0.009)***
3		-0.293 (0.007)***		-0.238 (0.010)***
4		-0.353 (0.009)***		-0.290 (0.012)***
5		-0.417 (0.010)***		-0.316 (0.014)***
6		-0.484 (0.011)***		-0.346 (0.017)***
7		-0.531 (0.013)***		-0.412 (0.020)***
8≤		-0.753 (0.008)***		-0.544 (0.012)***
log(FAM_SIZE)	-0.222 (0.004)***		0.001 (0.004)	
FAM_SIZE				
2		0.138 (0.031)***		-0.013 (0.009)
3		0.213 (0.026)***		0.006 (0.010)
4		0.199 (0.025)***		0.048 (0.010)***
5		0.210 (0.025)***		0.071 (0.011)***
6		0.166 (0.025)***		0.058 (0.013)***
7		0.105 (0.025)***		0.064 (0.016)***
8		0.064 (0.026)*		0.026 (0.019)
9		0.017 (0.026)		-0.010 (0.023)
10		-0.025 (0.026)		-0.020 (0.028)
11≤		-0.154 (0.025)***		-0.118 (0.017)***
OPPOSITION	-0.545 (0.011)***	-0.533 (0.011)***	-0.293 (0.011)***	-0.295 (0.011)***
log(N_INV)	-0.043 (0.004)***	-0.041 (0.004)***	-0.053 (0.005)***	-0.048 (0.005)***
log(N_IPC)	0.030 (0.004)***	0.030 (0.004)***	0.012 (0.005)*	0.015 (0.006)**
AGE				
4	1.424 (0.158)***	1.421 (0.158)***	0.365 (0.027)***	0.364 (0.027)***
5	1.931 (0.157)***	1.923 (0.157)***	0.786 (0.025)***	0.784 (0.025)***
6	2.275 (0.157)***	2.263 (0.157)***	1.251 (0.024)***	1.250 (0.024)***
7	2.520 (0.157)***	2.507 (0.157)***	1.464 (0.024)***	1.464 (0.024)***
8	2.729 (0.157)***	2.716 (0.157)***	1.499 (0.024)***	1.501 (0.024)***
9	2.859 (0.157)***	2.849 (0.157)***	1.538 (0.024)***	1.542 (0.024)***
10	3.010 (0.157)***	3.002 (0.157)***	1.558 (0.025)***	1.563 (0.025)***
11	3.132 (0.157)***	3.125 (0.157)***	1.637 (0.025)***	1.644 (0.025)***
12	3.201 (0.157)***	3.196 (0.157)***	1.682 (0.025)***	1.690 (0.025)***
13	3.258 (0.157)***	3.254 (0.157)***	1.694 (0.026)***	1.703 (0.026)***
14	3.342 (0.157)***	3.340 (0.157)***	1.779 (0.026)***	1.789 (0.026)***
15	3.437 (0.157)***	3.438 (0.157)***	1.844 (0.027)***	1.855 (0.027)***
16	3.544 (0.157)***	3.548 (0.157)***	1.905 (0.028)***	1.919 (0.028)***
17	3.701 (0.157)***	3.709 (0.157)***	1.972 (0.029)***	1.990 (0.029)***
18	3.877 (0.157)***	3.890 (0.157)***	2.167 (0.030)***	2.188 (0.030)***
19	4.024 (0.157)***	4.040 (0.157)***	2.326 (0.031)***	2.352 (0.031)***
20	4.381 (0.158)***	4.397 (0.158)***	2.689 (0.033)***	2.720 (0.033)***
WITH_LOR	0.066 (0.012)***	0.067 (0.012)***	0.069 (0.011)***	0.048 (0.011)***

EXP[a]	**EPO**		**DPMA**	
	(a)	**(b)**	**(a)**	**(b)**
APPLCT_TYPE				
INDIV. INVENTOR	0.062 (0.015)***	0.049 (0.015)**	0.033 (0.020)†	0.007 (0.021)
SMALL CORP.	-0.073 (0.013)***	-0.068 (0.013)***	-0.205 (0.018)***	-0.214 (0.020)***
MEDIUM CORP.	-0.048 (0.012)***	-0.037 (0.013)**	-0.167 (0.016)***	-0.191 (0.018)***
LARGE CORP.	0.027 (0.015)†	-0.038 (0.017)*	-0.139 (0.018)***	-0.157 (0.021)***
TECH_AREA				
INSTRUMENTS	-0.008 (0.007)	0.001 (0.007)	0.039 (0.010)***	0.036 (0.010)***
CHEM.&PHARMA.	0.142 (0.006)***	0.162 (0.007)***	0.184 (0.011)***	0.196 (0.012)***
PROCESS ENG.	0.090 (0.007)***	0.127 (0.008)***	0.194 (0.010)***	0.226 (0.011)***
MECHANIC. ENG.	0.030 (0.007)***	0.054 (0.008)***	0.081 (0.009)***	0.093 (0.009)***
CONS.&CONSTR.	0.127 (0.010)***	0.159 (0.010)***	0.100 (0.011)***	0.117 (0.012)***
log(PORTFOL_SIZE)	-0.025 (0.003)***		-0.020 (0.004)***	
PORTFOL_SIZE				
2-		-0.132 (0.012)***		-0.097 (0.014)***
3-		-0.185 (0.013)***		-0.143 (0.016)***
6-		-0.232 (0.015)***		-0.150 (0.018)***
11-		-0.223 (0.017)***		-0.149 (0.021)***
19-		-0.239 (0.019)***		-0.189 (0.024)***
34-		-0.275 (0.020)***		-0.221 (0.025)***
62-		-0.256 (0.020)***		-0.218 (0.027)***
106-		-0.247 (0.021)***		-0.290 (0.028)***
180-		-0.232 (0.024)***		-0.281 (0.033)***
360-		-0.377 (0.025)***		-0.458 (0.034)***
652-		-0.257 (0.026)***		-0.531 (0.035)***
1179-		-0.209 (0.027)***		-0.265 (0.037)***
IPC4_SHARE	-0.545 (0.056)***		-0.009 (0.084)	
0.07%-		0.010 (0.011)		-0.031 (0.016)*
0.12%-		0.013 (0.011)		-0.002 (0.016)
0.18%-		-0.011 (0.011)		-0.017 (0.016)
0.25%-		-0.011 (0.012)		-0.017 (0.016)
0.35%-		-0.007 (0.012)		-0.028 (0.016)†
0.46%-		-0.010 (0.012)		-0.039 (0.016)*
0.62%-		-0.018 (0.012)		-0.027 (0.017)
0.84%-		-0.035 (0.012)**		-0.007 (0.017)
1.15%-		-0.028 (0.013)*		-0.022 (0.017)
1.59%-		-0.072 (0.013)***		-0.009 (0.018)
2.29%-		-0.086 (0.013)***		0.001 (0.019)
3.36%-		-0.056 (0.014)***		0.025 (0.019)
5.25%-		-0.038 (0.014)**		0.008 (0.020)
9.75%-		-0.065 (0.016)***		0.012 (0.023)

EXP[a]	**EPO**		**DPMA**	
	(a)	**(b)**	**(a)**	**(b)**
IPC4_PORTFOL	-0.100 (0.010)***		-0.094 (0.013)***	
0.98%-		-0.037 (0.011)***		-0.045 (0.016)**
2.17%-		-0.036 (0.011)**		-0.084 (0.016)***
3.84%-		-0.068 (0.012)***		-0.098 (0.017)***
6.08%-		-0.079 (0.012)***		-0.164 (0.018)***
9.09%-		-0.053 (0.012)***		-0.177 (0.019)***
13.11%-		-0.121 (0.012)***		-0.246 (0.019)***
18.75%-		-0.124 (0.014)***		-0.268 (0.021)***
25.00%-		-0.101 (0.014)***		-0.272 (0.021)***
33.33%-		-0.166 (0.014)***		-0.271 (0.020)***
50.00%-		-0.185 (0.016)***		-0.285 (0.022)***
62.50%-		-0.204 (0.016)***		-0.324 (0.022)***
100.00%		-0.256 (0.018)***		-0.341 (0.024)***
IPC4_C4	0.073 (0.020)***		0.023 (0.029)	
6.25%-		0.061 (0.011)***		0.082 (0.015)***
7.95%-		0.037 (0.012)**		0.065 (0.015)***
9.95%-		0.022 (0.012)†		0.072 (0.015)***
11.67%-		0.095 (0.012)***		0.073 (0.015)***
13.43%-		0.101 (0.012)***		0.093 (0.016)***
14.87%-		0.136 (0.011)***		0.109 (0.016)***
16.43%-		0.100 (0.012)***		0.089 (0.015)***
18.25%-		0.089 (0.012)***		0.068 (0.016)***
20.15%-		0.060 (0.012)***		0.073 (0.016)***
22.25%-		0.066 (0.012)***		0.076 (0.016)***
24.85%-		0.074 (0.012)***		0.079 (0.016)***
28.02%-		0.083 (0.012)***		0.078 (0.017)***
31.89%-		0.076 (0.012)***		0.060 (0.017)***
41.37%-		0.038 (0.013)**		0.074 (0.018)***
control variables: *EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS*				
log pseudolikelihood	-945,350.3	-944,373.1	-488,468.4	-487,945.8
Pseudo R2	0.141	0.142	0.114	0.115
Observations	5,186,822	5,186,822	2,128,796	2,128,796

[a] Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Determinants of the Probability to Observe a Decision to Let the Patent Expire (EXP) – ALL

EXP[a]	ALL					
	(a)	(b)	(c)	(d)	(e)	(f)
log(N_CIT)	-0.254 (0.002)***		-0.255 (0.002)***			
N_CIT						
1		-0.107 (0.005)***		-0.108 (0.005)***		
2		-0.202 (0.005)***		-0.205 (0.005)***		
3		-0.272 (0.006)***		-0.276 (0.006)***		
4		-0.329 (0.007)***		-0.334 (0.007)***		
5		-0.381 (0.008)***		-0.387 (0.008)***		
6		-0.437 (0.009)***		-0.443 (0.009)***		
7		-0.491 (0.011)***		-0.496 (0.011)***		
8≤		-0.686 (0.007)***		-0.695 (0.007)***		
log(FAM_SIZE)	-0.122 (0.003)***		-0.123 (0.003)***			
FAM_SIZE						
2		-0.044 (0.008)***		-0.048 (0.008)***		
3		-0.023 (0.008)**		-0.027 (0.008)***		
4		0.011 (0.007)		0.003 (0.007)		
5		0.036 (0.007)***		0.024 (0.007)***		
6		-0.006 (0.008)		-0.017 (0.008)*		
7		-0.062 (0.008)***		-0.072 (0.008)***		
8		-0.104 (0.009)***		-0.115 (0.009)***		
9		-0.153 (0.010)***		-0.165 (0.010)***		
10		-0.192 (0.011)***		-0.205 (0.011)***		
11≤		-0.325 (0.008)***		-0.343 (0.008)***		
OPPOSITION	-0.434 (0.008)***	-0.428 (0.008)***	-0.434 (0.008)***	-0.430 (0.008)***		
log(N_INV)	-0.048 (0.003)***	-0.043 (0.003)***	-0.047 (0.003)***	-0.044 (0.003)***		
log(N_IPC)	0.028 (0.003)***	0.035 (0.003)***	0.029 (0.003)***	0.032 (0.003)***		
AGE						
4	0.392 (0.026)***	0.384 (0.026)***	0.392 (0.026)***	0.383 (0.026)***		
5	0.829 (0.024)***	0.816 (0.024)***	0.830 (0.024)***	0.814 (0.024)***		
6	1.217 (0.023)***	1.200 (0.023)***	1.217 (0.023)***	1.198 (0.023)***		
7	1.434 (0.023)***	1.416 (0.023)***	1.434 (0.023)***	1.413 (0.023)***		
8	1.573 (0.023)***	1.555 (0.023)***	1.573 (0.023)***	1.551 (0.023)***		
9	1.670 (0.023)***	1.653 (0.023)***	1.670 (0.023)***	1.647 (0.023)***		
10	1.777 (0.023)***	1.761 (0.023)***	1.777 (0.023)***	1.754 (0.023)***		
11	1.884 (0.023)***	1.867 (0.023)***	1.884 (0.023)***	1.860 (0.023)***		
12	1.945 (0.023)***	1.929 (0.023)***	1.946 (0.023)***	1.921 (0.023)***		
13	1.989 (0.023)***	1.972 (0.023)***	1.989 (0.023)***	1.964 (0.023)***		
14	2.075 (0.024)***	2.057 (0.024)***	2.075 (0.024)***	2.050 (0.024)***		
15	2.161 (0.024)***	2.144 (0.024)***	2.162 (0.024)***	2.136 (0.024)***		
16	2.254 (0.024)***	2.238 (0.024)***	2.255 (0.024)***	2.228 (0.024)***		
17	2.385 (0.025)***	2.369 (0.025)***	2.385 (0.024)***	2.358 (0.025)***		
18	2.565 (0.025)***	2.551 (0.025)***	2.566 (0.025)***	2.538 (0.025)***		
19	2.711 (0.026)***	2.697 (0.026)***	2.712 (0.026)***	2.683 (0.026)***		
20	3.067 (0.026)***	3.053 (0.026)***	3.068 (0.026)***	3.038 (0.026)***		
WITH_LOR	0.036 (0.008)***	0.032 (0.008)***	0.041 (0.008)***	0.052 (0.008)***	0.085 (0.008)***	0.066 (0.008)***

EXP[a]			ALL			
	(a)	(b)	(c)	(d)	(e)	(f)
APPLCT_TYPE						
INDIV. INVENTOR	0.055 (0.012)***	0.043 (0.012)***	0.054 (0.011)***	0.064 (0.011)***	0.118 (0.011)***	0.098 (0.012)***
SMALL CORP.	-0.127 (0.010)***	-0.124 (0.011)***	-0.121 (0.010)***	-0.125 (0.010)***	-0.115 (0.010)***	-0.096 (0.011)***
MEDIUM CORP.	-0.105 (0.010)***	-0.100 (0.010)***	-0.111 (0.010)***	-0.122 (0.010)***	-0.096 (0.010)***	-0.073 (0.010)***
LARGE CORP.	-0.057 (0.012)***	-0.097 (0.013)***	-0.108 (0.010)***	-0.128 (0.010)***	-0.017 (0.012)	-0.079 (0.013)***
TECH_AREA						
INSTRUMENTS	0.004 (0.006)	0.011 (0.006)†	0.000 (0.006)	0.006 (0.006)	-0.030 (0.006)***	-0.023 (0.006)***
CHEM.&PHARMA.	0.135 (0.006)***	0.177 (0.006)***	0.138 (0.005)***	0.172 (0.005)***	0.059 (0.005)***	0.076 (0.006)***
PROCESS ENG.	0.121 (0.006)***	0.158 (0.006)***	0.115 (0.006)***	0.127 (0.006)***	0.098 (0.006)***	0.132 (0.006)***
MECHANIC. ENG.	0.044 (0.005)***	0.059 (0.006)***	0.044 (0.005)***	0.048 (0.005)***	0.039 (0.005)***	0.052 (0.006)***
CONS.&CONSTR.	0.095 (0.007)***	0.126 (0.008)***	0.087 (0.007)***	0.102 (0.007)***	0.116 (0.007)***	0.133 (0.008)***
log(PORTFOL_SIZE)	-0.018 (0.002)***				-0.029 (0.002)***	
PORTFOL_SIZE						
2-		-0.113 (0.009)***				-0.150 (0.009)***
3-		-0.165 (0.010)***				-0.226 (0.010)***
6-		-0.196 (0.012)***				-0.282 (0.012)***
11-		-0.188 (0.013)***				-0.282 (0.013)***
19-		-0.211 (0.015)***				-0.305 (0.015)***
34-		-0.244 (0.015)***				-0.341 (0.015)***
62-		-0.227 (0.016)***				-0.323 (0.016)***
106-		-0.245 (0.017)***				-0.351 (0.016)***
180-		-0.235 (0.019)***				-0.323 (0.019)***
360-		-0.371 (0.020)***				-0.464 (0.020)***
652-		-0.329 (0.020)***				-0.423 (0.020)***
1179-		-0.201 (0.021)***				-0.289 (0.021)***
IPC4_SHARE	-0.405 (0.047)***				-0.509 (0.047)***	
0.07%-		-0.006 (0.009)				0.004 (0.009)
0.12%-		0.010 (0.009)				0.029 (0.009)**
0.18%-		-0.012 (0.009)				0.005 (0.009)
0.25%-		-0.011 (0.009)				0.006 (0.009)
0.35%-		-0.013 (0.009)				0.012 (0.009)
0.46%-		-0.019 (0.010)†				0.004 (0.010)
0.62%-		-0.018 (0.010)†				0.001 (0.010)
0.84%-		-0.022 (0.010)*				0.001 (0.010)
1.15%-		-0.022 (0.010)*				-0.002 (0.010)
1.59%-		-0.047 (0.011)***				-0.031 (0.010)**
2.29%-		-0.052 (0.011)***				-0.032 (0.011)**
3.36%-		-0.025 (0.011)*				-0.012 (0.011)
5.25%-		-0.020 (0.012)†				0.000 (0.012)
9.75%-		-0.032 (0.013)*				-0.021 (0.013)

EXP[a]			**ALL**			
	(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**
IPC4_PORTFOL	-0.093 (0.008)***				-0.120 (0.008)***	
0.98%-		-0.040 (0.009)***				-0.053 (0.009)***
2.17%-		-0.051 (0.009)***				-0.067 (0.009)***
3.84%-		-0.078 (0.010)***				-0.095 (0.009)***
6.08%-		-0.104 (0.010)***				-0.121 (0.010)***
9.09%-		-0.091 (0.010)***				-0.115 (0.010)***
13.11%-		-0.164 (0.010)***				-0.195 (0.010)***
18.75%-		-0.174 (0.012)***				-0.220 (0.011)***
25.00%-		-0.159 (0.012)***				-0.209 (0.011)***
33.33%-		-0.200 (0.011)***				-0.254 (0.011)***
50.00%-		-0.218 (0.013)***				-0.283 (0.013)***
62.50%-		-0.242 (0.013)***				-0.313 (0.013)***
100.00%		-0.276 (0.014)***				-0.367 (0.014)***
IPC4_C4	0.077 (0.017)***				0.152 (0.017)***	
6.25%-		0.064 (0.009)***				0.066 (0.009)***
7.95%-		0.043 (0.009)***				0.053 (0.009)***
9.95%-		0.035 (0.009)***				0.041 (0.009)***
11.67%-		0.082 (0.009)***				0.087 (0.009)***
13.43%-		0.089 (0.009)***				0.105 (0.009)***
14.87%-		0.121 (0.009)***				0.137 (0.009)***
16.43%-		0.088 (0.009)***				0.106 (0.009)***
18.25%-		0.075 (0.009)***				0.103 (0.009)***
20.15%-		0.063 (0.010)***				0.096 (0.010)***
22.25%-		0.065 (0.010)***				0.093 (0.010)***
24.85%-		0.074 (0.010)***				0.103 (0.010)***
28.02%-		0.083 (0.010)***				0.117 (0.010)***
31.89%-		0.068 (0.010)***				0.093 (0.010)***
41.37%-		0.042 (0.010)***				0.090 (0.010)***
control variables: *EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS*						
log pseudolikelihood	-1,438,580.74	-1,436,712.2	-1,438,741.2	-1,437,860.2	-1,451,364.9	-1,449,969.5
Pseudo R2	0.133	0.134	0.133	0.133	0.125	0.126
Observations	7,316,518	7,316,518	7,316,518	7,708,015	7,316,518	7,316,518

[a]Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Determinants of the Probability to Observe a Decision to Let the Patent Expire (EXP) – Market and Applicant Characteristics

EXP[a]	(1)		(2)		(3)		(4)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
WITH_LOR	0.093 (0.008)***	0.082 (0.008)***	0.087 (0.008)***	0.069 (0.008)***	0.092 (0.008)***	0.090 (0.008)***	0.084 (0.008)***	0.075 (0.008)***
APPLCT_TYPE								
INDIV. INVENTOR	0.096 (0.011)***	0.072 (0.012)***	0.117 (0.011)***	0.100 (0.012)***	0.129 (0.011)***	0.127 (0.011)***	0.156 (0.011)***	0.155 (0.011)***
SMALL CORP.	-0.123 (0.010)***	-0.114 (0.011)***	-0.114 (0.010)***	-0.091 (0.011)***	-0.097 (0.010)***	-0.101 (0.010)***	-0.080 (0.010)***	-0.061 (0.010)***
MEDIUM CORP.	-0.098 (0.010)***	-0.098 (0.010)***	-0.093 (0.010)***	-0.066 (0.010)***	-0.108 (0.010)***	-0.114 (0.010)***	-0.110 (0.010)***	-0.091 (0.010)***
LARGE CORP.	-0.054 (0.011)***	-0.107 (0.013)***	-0.012 (0.012)	-0.073 (0.013)***	-0.100 (0.010)***	-0.103 (0.010)***	-0.093 (0.010)***	-0.122 (0.011)***
TECH_AREA								
INSTRUMENTS	-0.038 (0.006)***	-0.031 (0.006)***	-0.036 (0.006)***	-0.037 (0.006)***	-0.034 (0.006)***	-0.026 (0.006)***	-0.024 (0.006)***	-0.024 (0.006)***
CHEM.&PHARMA.	0.057 (0.005)***	0.073 (0.005)***	0.050 (0.005)***	0.061 (0.005)***	0.061 (0.005)***	0.065 (0.006)***	0.067 (0.005)***	0.073 (0.006)***
PROCESS ENG.	0.087 (0.006)***	0.099 (0.006)***	0.090 (0.006)***	0.095 (0.006)***	0.092 (0.006)***	0.121 (0.006)***	0.107 (0.006)***	0.135 (0.006)***
MECHANIC. ENG.	0.036 (0.005)***	0.047 (0.005)***	0.034 (0.005)***	0.032 (0.005)***	0.039 (0.005)***	0.049 (0.005)***	0.049 (0.005)***	0.059 (0.006)***
CONS.&CONSTR.	0.102 (0.007)***	0.110 (0.007)***	0.108 (0.007)***	0.103 (0.007)***	0.107 (0.007)***	0.121 (0.007)***	0.127 (0.007)***	0.149 (0.008)***
log(PORTFOL_SIZE)	-0.013 (0.002)***		-0.030 (0.002)***					
PORTFOL_SIZE								
2-		-0.099 (0.007)***		-0.153 (0.009)***				
3-		-0.138 (0.007)***		-0.232 (0.010)***				
6-		-0.149 (0.008)***		-0.294 (0.011)***				
11-		-0.117 (0.009)***		-0.296 (0.013)***				
19-		-0.116 (0.011)***		-0.323 (0.014)***				
34-		-0.128 (0.011)***		-0.362 (0.015)***				
62-		-0.089 (0.011)***		-0.347 (0.015)***				
106-		-0.102 (0.012)***		-0.379 (0.016)***				
180-		-0.063 (0.015)***		-0.352 (0.019)***				
360-		-0.186 (0.015)***		-0.498 (0.019)***				
652-		-0.135 (0.015)***		-0.459 (0.020)***				
1179-		0.010 (0.015)		-0.333 (0.021)***				

EXP[a]	(1)		(2)		(3)		(4)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
IPC4_SHARE			-0.299 (0.040)***				-0.689 (0.045)***	
0.07%-				0.015 (0.009)†				-0.013 (0.009)
0.12%-				0.041 (0.009)***				0.004 (0.009)
0.18%-				0.021 (0.009)*				-0.020 (0.009)*
0.25%-				0.026 (0.009)**				-0.028 (0.009)**
0.35%-				0.036 (0.009)***				-0.025 (0.009)**
0.46%-				0.031 (0.009)***				-0.035 (0.009)***
0.62%-				0.031 (0.009)***				-0.046 (0.009)***
0.84%-				0.034 (0.009)***				-0.050 (0.010)***
1.15%-				0.035 (0.010)***				-0.060 (0.010)***
1.59%-				0.011 (0.010)				-0.092 (0.010)***
2.29%-				0.013 (0.010)				-0.097 (0.010)***
3.36%-				0.037 (0.010)***				-0.076 (0.010)
5.25%-				0.051 (0.011)***				-0.064 (0.011)
9.75%-				0.032 (0.012)**				-0.086 (0.012)
IPC4_PORTFOL			-0.125 (0.008)***				-0.061 (0.006)***	
0.98%-				-0.059 (0.009)***				-0.047 (0.009)***
2.17%-				-0.075 (0.009)***				-0.058 (0.009)***
3.84%-				-0.105 (0.009)***				-0.081 (0.009)***
6.08%-				-0.132 (0.010)***				-0.106 (0.009)***
9.09%-				-0.128 (0.010)***				-0.098 (0.009)***
13.11%-				-0.210 (0.010)***				-0.175 (0.010)***
18.75%-				-0.240 (0.011)***				-0.189 (0.011)***
25.00%-				-0.229 (0.011)***				-0.178 (0.010)***
33.33%-				-0.275 (0.011)***				-0.216 (0.010)***
50.00%-				-0.307 (0.012)***				-0.197 (0.010)***
62.50%-				-0.340 (0.012)***				-0.268 (0.011)***
100.00%				-0.396 (0.013)***				-0.141 (0.010)***

EXP[a]	(1)		(2)		(3)		(4)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
IPC4_C4					0.026 (0.014)†		0.166 (0.017)***	
6.25%-						0.064 (0.009)***		0.073 (0.009)***
7.95%-						0.054 (0.009)***		0.069 (0.009)***
9.95%-						0.037 (0.009)***		0.056 (0.009)***
11.67%-						0.081 (0.009)***		0.105 (0.009)***
13.43%-						0.097 (0.009)***		0.122 (0.009)***
14.87%-						0.124 (0.009)***		0.151 (0.009)***
16.43%-						0.095 (0.009)***		0.122 (0.009)***
18.25%-						0.088 (0.009)***		0.120 (0.009)***
20.15%-						0.081 (0.009)***		0.116 (0.010)***
22.25%-						0.070 (0.009)***		0.111 (0.010)***
24.85%-						0.078 (0.009)***		0.122 (0.010)***
28.02%-						0.084 (0.009)***		0.135 (0.010)***
31.89%-						0.066 (0.009)***		0.116 (0.010)***
41.37%-						0.026 (0.009)**		0.102 (0.010)***
control variables: ***AGE, EPO, YEAR, APPLCT_CTRY, NOGRANT_YEAR, SMALL_CLASS***								
log pseudolikelihood	-1,451,624.9	-1,451,061.7	-1,451,407.2	-1,450,137.9	-1,451,646.8	-1,451,485.9	-1,451,448.1	-1,450,592.7
Pseudo R2	0.125	0.125	0.125	0.126	0.125	0.125	0.125	0.125
Observations	7,316,518	7,316,518	7,316,518	7,316,518	7,316,518	7,316,518	7,316,518	7,316,518

[a] Robust standard errors in parenthesis.

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Chapter 2

The License of Right, Compulsory Licensing and the Value of Exclusivity

2.1 Introduction

By definition a patent is an exclusion right over an invention granted by society for a limited period of time. In exchange, the patent applicant is obliged to disclose all technical information on the claimed invention to society. If the patent protects exactly one product and knowledge is not cumulative, the following economic trade-off ensues: On the one hand, the protection against competition from others should increase the incentives of the inventor to invest in innovative activities and the obligation to disclose his invention should promote the dissemination of knowledge (dynamic efficiency). On the other hand, the right to exclude others may create temporary monopoly power and impose a welfare loss on society (static inefficiency).

However, recent theoretical as well as empirical economic literature has recognized that at least two of the assumptions on which the traditional economic trade-off described above is based on may often fail in reality. Most of the innovation activities are inherently cumulative (Scotchmer 1991) and products are often covered by multiple patent rights (Heller and Eisenberg 1998). In this case two additional opposed welfare effects arise.[65] On the one hand, patents may even increase competition by helping to establish a market for knowledge. They can be traded as an input good as well as facilitating entry of new competitors hence improving static efficiency. On the other hand, in the new

[65]See Hall and Harhoff (2012) for an extensive discussion.

setting the exclusivity right gets a new leverage. If an inventor is excluded from the use of patents his invention builds on, or if the access to all complementary patents needed for commercialization is denied, he will not be able to appropriate any returns. To reduce the fragmentation threat firms may even increase their "defensive" patenting activities (Ziedonis 2004) creating an even denser net of patent rights. This behavior can considerably hamper dynamic efficiency. Already existing knowledge will remain underused and inventors can be discouraged to invest in the combination of new ideas and inventions. Thus, the question arises how to reduce the economic distortions created by the exclusive right conferred by a patent while maintaining the positive incentive effects to inventors.

One possible approach to tackle the problem is to increase access to patented inventions by reducing the exclusivity rights of patentees. Alongside private solutions–such as standards, clearing houses, and patent pools where patent owners transfer their rights into a bundle which can be licensed by others–several institutional initiatives have been discussed.[66] Two prominent examples are Compulsory Licensing (CL) and Licenses of Right (LOR). Both systems are based on the idea of transforming the patent right from an absolute permission rule with a right to exclude others (Merges 1996) into a liability rule, where the patent owner has only a right to reasonable remuneration, i.e., licensing revenues. The CL system requires the patent owner by law to make licenses available to any party requesting a license. Although it clearly reduces the degree of exclusivity CL may considerably reduce the profits from patent protection and diminish the incentives to engage in innovative activities. In contrast, LOR is a system where the patent may, at the request of its owner, be transformed into a liability rule. However, it is rather unlikely that patentees would voluntarily give up their right to exclude others, unless the legislator provides appropriate incentives. To be able to analyze both systems economically and derive possible welfare statements it is necessary to know the distribution of the returns from patent protection. But even more important is to know which part of the value can be attributed to the right to exclude others and which part can be sustained with only a right to reasonable remuneration.

Hence, the aim of this paper will be twofold. First, we will present a framework for estimating the distribution of the value of exclusivity using German patent data. Second, we will use the estimation results to evaluate the welfare effects of the LOR system as implemented in Germany. We will further calculate the patent owners' losses in private value associated with the introduction of a CL system.

The License of Right or "Willingness to License" was introduced on October 01, 1936 into the German patent system. It is stated in Sec. 23 of the German Patent Act that "[i]f the applicant for a patent or the person recorded as patentee [...] declares to the Patent

[66] See Schovsbo (2009) for an overview.

Office in writing that he is prepared to allow anyone to use the invention in return for reasonable compensation, the annual [maintenance] fees falling due after receipt of the declaration shall be reduced to one half [...]."[67]

In Germany, License of Right is declared for almost 6% of all granted patent applications. However, the usage rates differ highly across technology areas as well as across applicant types. In the area of electrical engineering LOR is declared for over 11% of all patents whereas in the area of chemistry and biotechnology the usage rate is 1.3%. More than 12% of patents filed by large corporations and only less than 2% of patents filed by small corporations are endorsed LOR when they expire.

Assuming rational behavior, the patent applicant will only declare LOR if his expected returns from patent protection without the right to exclude net of the reduced renewal fees will exceed the expected returns from full patent protection net of the regular renewal fees. The difference between the returns from full patent protection and the returns from patent protection without the right to exclude others is what we define as the value of exclusivity. We will use the decision to declare LOR taken by the patent owner to identify the distribution of the value of exclusivity for German patents.

To perform the estimations we will develop a model of patent renewal and LOR declaration. This model extends the traditional patent renewal models first developed in Pakes and Schankerman (1984), Pakes (1986), and Schankerman and Pakes (1986). The traditional patent renewal models are discrete choice models which incorporate a patentee's optimal decision when to let his patent expire in order to estimate the distribution of the private value of patent protection. Given that for each additional year of patent protection the patentee has to pay renewal fees, he will only maintain patent protection as long as these yearly fees do not exceed his expected returns from having a patent. We extend this framework and allow for a third option, the declaration of LOR. Similar to the German provision, if the patentee chooses the third option, the maintenance fees will be reduced, and he will lose the right to exclude others. Thus, the decision to declare or not to declare LOR ought to contain information about the private value of exclusivity. The model is subsequently estimated using a simulated general method of moments estimator (SGMM).

Subsequently, we employ the estimated parameters to evaluate the effects of two hypothetical policy changes. First, we consider the abolishment of the LOR option from the German patent system. From this experiment we learn about the effects of LOR on the private value of patent protection and on the German patent office's revenues. Patent

[67] If the parties are unable to agree on a compensation scheme it can be assessed by the Patent Division at the written request of one of the parties. This makes the provision enforceable for the patent owner as well as the potential licensee.

maintenance fees are usually one of the main sources of patent office finance. In our second experiment we introduce a compulsory licensing requirement for all patents from the application day on. This allows us to estimate the costs imposed on the patent holders by a CL system.

The outline of the paper is as follows. In the next section we develop the patent renewal model incorporating the decision to declare LOR. Section 3 presents the estimation strategy and the stochastic specification. The data are described in Section 4. In Section 5 and Section 6 we discuss the estimation results and its implications. Section 7 concludes.

2.2 The Model

In this section we present a model that incorporates the decision of a patentee to renew patent protection as well as the decision to declare the willingness to license (LOR). The model builds on the observation that patentees have to pay renewal fees if they want to keep patent protection. The majority of granted patents is usually not renewed to the statutory patent term and expires prior to maturity. Assuming maximizing behavior of the patent owners the decision to pay the maintenance fees and renew patent protection must depend on the current returns as well as expected future returns. A patentee can choose between two protection regimes, the full patent protection with an exclusion right and the license of right regime. A LOR declaration reduces the future renewal fees but in turn removes the right to exclude others leaving only a right to reasonable remuneration.[68]

Below we will explain the general set-up of the model, describe the patent system, describe how patentees derive value from patent protection, and their information structure. In the next step we will state the patentees' maximization problem and describe the solution of the model. Subsequently, we perform comparative statics to shed more light on the properties of the model.

2.2.1 General Set-up

Patent system An agent can acquire a patent with full protection, which allows him to exclude others from the patented invention. Keeping patent protection–we will call it strategy (K)–is not free of charge and the agent must pay renewal fees $c_t = f_t$ at the beginning of each period $t \in 1, ..., T$. T is the maximum number of years a patent

[68]Serrano (2011) has also extended the traditional model to incorporate a third decision, namely the decision to transfer the patent right. He uses it to estimate the costs associated with a technology transfer and the option value of the possibility to transfer patents.

is allowed to be renewed. If he decides not to pay the fees the patent will expire (X) forever. As is common in most patent systems, the fees are rising with a patent's maturity, $f_t \leq f_{t+1}$. Alternatively, the patentee can switch to the License of Right regime which we will call strategy (L). Contrary to the full protection regime, it prohibits excluding others from the invention but maintains the right to reasonable remuneration through licensing. In turn, the patent owner is only required to pay half of the statutory renewal fees, $c_t = \frac{1}{2}f_t$. We further assume that once LOR has been declared, the patentee can never return to full patent protection. He can either renew within the LOR regime (L) or let the patent expire (X).

We also assume that each patent belongs to exactly one agent. Furthermore, all agents are rational in the sense that in the beginning of each period they will choose the regime that will maximize their expected profits given the available information.

Evolution of returns We assume that a patent generates returns z_t in each year t which depend on the type of patent protection. Returns are 0 if the patent expires, $z_t = 0$. The per period returns in case of full patent protection, $z_t = r_t$, differ from those of a patent endorsed LOR by a multiplicative factor g_t^l such that $z_t = y_t = g_t^l r_t$. The factor g_t^l represents the fraction of the returns which can be realized by a patent without the right to exclude others. This means in turn that $(1 - g_t^l)r_t$ corresponds to the returns that can be derived from exclusivity. We allow g_t^l to exceed 1. It might well be that the commitment to non-exclusive licensing may even increase the patentee's revenues.[69]

The yearly returns are not constant and evolve over time in the following way:

- In the beginning of a patent's life an initial return from full patent protection, r_1, is assigned to each patent. Let r_1 be drawn i.i.d. from a continuous distribution F_{IR} on a positive domain.
- The returns from full patent protection in the following years, r_t, $t \in 2, ..., T$, change over a patent's life cycle. We assume that they evolve from the previous period such that $r_t = g_t^k r_{t-1}$, where $g_t^k \in \left[0, B^k\right]$ is the growth rate of returns in case of full patent protection.[70] A growth rate $g_t^k < 1$ represents a depreciation, whereas $g_t^k > 1$ represents an increase of the revenues from full patent protection. The growth rates are drawn i.i.d. from continuous distributions with the cumulative density functions $F_{g^k}(u^k|t) = Pr\left[g_t^k \leq u^k\right]$, $t \in 2, ..., T$. We assume that the probability to have a high growth rate g_t^k and to discover a way to increase the returns compared to

[69] See discussion in Chapter 1.

[70] This stochastic specification fulfills the Markov property. This means that the returns in future periods are independent of past periods' returns.

the previous year decreases with the patent's maturity in the sense of first-order stochastic dominance: $(F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1))$.[71]

- The shares of returns which can be realized in a LOR regime $g_t^l \in \left[0, B^l\right]$, $t \in 1, ..., T$, are drawn i.i.d. from yet other distributions with the cumulative density functions $F_{g^l}(u^l|t) = Pr\left[g_t^l \leq u^l\right]$, $t \in 1, ..., T$. Furthermore, we assume that the probability to have a high LOR growth rate is also decreasing with the patent's age throughout all periods in the sense of first-order stochastic dominance: $F_{g^l}(u^l \mid t) \leq F_{g^l}(u^l \mid t{+}1)$.[72]
- We assume that the patentee has perfect information about the distributions of all future growth rates in all regimes but that the per period returns z_t, i.e, the growth rates g_t^k and g_t^l, are revealed to him only in the beginning of each period t.

Maximization problem The agent has to choose the strategy with the highest expected value in the beginning of each period, since this is when the renewal fees are due. His value functions in each regime will consist of returns and costs from the current period as well as the option value of his choices in future periods. We define $\widetilde{V_K}(t, r_t, y_t)$ as the value function of the patentee's optimal strategy in year t if the patent has been renewed with full patent protection (K) in all previous periods. In this case the patent owner can choose between all three strategies, (K), (L), and (X). Similarly, $\widetilde{V_L}(t, y_t)$ is the value function of the patentee's optimal strategy in year t if LOR, i.e., strategy (L), has been declared in one of the previous periods and strategy (K) in all periods preceding the declaration. In this case he can only choose between strategy (L) and (X) for the following year.

Consider now a patent in the beginning of year t, $t < T$, which has been renewed with full patent protection in all previous periods. The patentee has three choices. He can either keep full patent protection (K), declare LOR (L), or let his patent expire (X). If he decides not to pay the renewal fees in this period and lets his patent expire (X) his returns from this strategy, $\widetilde{V}^X(t)$, will be 0:[73]

$$\widetilde{V}^X(t) = 0$$

If the agent decides instead to renew the patent with full patent protection (K) his value

[71]Usually, the application and usage of an invention is determined early in a patent's life. The probability to discover new uses in later periods should hence decrease over time.

[72]This is just a simplifying assumption. Nevertheless, in the estimations below we will allow for the possibility that the probability to have a higher LOR growth rate may increase with a patent's age. We will test the assumption using German patent data.

[73]$\widetilde{V}^i(.)$, $i = K, L, X$ denotes the value function in case the patentee would choose strategy i. It does not mean that this is his optimal strategy in the corresponding year.

function will consist of the returns in the current period r_t, net of the renewal fees f_t, plus the discounted option value of having the full strategy choice–strategies (X), (K), and (L)–in the subsequent period. The option value will be a function of the current returns r_t. With β as the discount factor between the periods we get the following value function for strategy (K):

$$\widetilde{V}^K(t, r_t) = r_t - f_t + \beta E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] \tag{2.1}$$

with

$$E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] = \int\int \widetilde{V_K}(t+1, u^k r_t, u^l u^k r_t) dF_{g^k}(u^k \mid t) dF_{g^l}(u^l \mid t)$$

and

$$\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) = max\left\{\widetilde{V}^K(t+1, r_{t+1}), \widetilde{V}^L(t+1, y_{t+1}), \widetilde{V}^X(t+1)\right\}$$

If instead he decides to declare LOR (L), his current returns from patent protection will equal $y_t = g_t^l r_t$. The renewal fees for all following years will be reduced by half. He will also lose the right to return to the full protection regime (K). The patentee will only be able to renew his right to reasonable remuneration (L) or to let the patent expire (X). We assume that once the declaration has been made the LOR growth rate g_t^l, which is the share of profits without the right to exclude, remains constant in the following periods. This means that if LOR has been declared in year a and the patent is allowed to expire in year b, it must be that $g_t^l = g_a^l$ for all periods $t \in \{a, a+1, ..., b\}$. The LOR growth rate varies only as long as LOR has not yet been declared. The justification for this assumption is that a declaration may go along with the conclusion of licensing agreements. This means that the potential for non-exclusive licensing will be determined at this stage for all future periods. The option value $E\left[\widetilde{V_L}(t+1, y_{t+1}) \mid r_t, g_t^l\right]$, will now depend on the current returns r_t from full patent protection as well as the LOR growth rate g_t^l from the period of declaration. Thus, the value function for a patentee who chooses to declare LOR (L) is:

$$\begin{aligned}\widetilde{V}^L(t, y_t) &= y_t - \tfrac{1}{2}f_t + \beta E\left[\widetilde{V_L}(t+1, y_{t+1}) \mid r_t, g_t^l\right] \\ &= g_t^l r_t - \tfrac{1}{2}f_t + \beta E\left[\widetilde{V_L}(t+1, g_t^l r_{t+1}) \mid r_t\right]\end{aligned} \tag{2.2}$$

with

$$E\left[\widetilde{V_L}(t+1, g_t^l r_{t+1}) \mid r_t\right] = \int \widetilde{V_L}(t+1, g_t^l u^k r_t) dF_{g^k}(u^k \mid t)$$

and

$$\widetilde{V_L}(t+1, y_{t+1}) = max\left\{\widetilde{V}^L(t+1, y_{t+1}), \widetilde{V}^X(t+1)\right\}$$

Now that we have stated the value functions we will describe the solution to the maximization problem. Since the maximum number of years a patent can be renewed is finite, $T < \infty$, the option value in the last period is always 0 independent of the protection regime. Thus, the model can be solved by backward recursion determining an agent's optimal decision in each period.

The agent's optimal decision in each year t is fully determined by the size of the per period returns r_t and the LOR growth rate g_t^l (and thus y_t). Dependent on whether these returns will exceed certain threshold values or not, the patentee will either choose to keep full patent protection (K), to declare LOR (L), or to let it expire (X):

- $\{\hat{r}_t\}_{t=1}^T$: patent returns that make the agent indifferent between keeping a patent with full patent protection (K) in year t and letting it expire (X). It is defined by $\widetilde{V}^K(t, \hat{r}_t) = 0$.[74]
- $\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^T$: growth rates that make the agent indifferent between declaring LOR (L) and letting a patent expire (X) in year t. It depends on the level of returns r_t from full patent protection and is defined by $\widetilde{V}^L\left(t, \hat{g}_t^{l-} r_t\right) = 0$.
- $\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^T$: growth rates that make the agent indifferent between declaring LOR (L) and keeping full patent protection (K). It depends on the level of per period returns r_t from full patent protection and is defined by $\widetilde{V}^K(t, r_t) = \widetilde{V}^L\left(t, \hat{g}_t^{l+} r_t\right)$.

The following lemma guarantees that these threshold values exist and are unique.

Lemma 2.1. *The value functions $\widetilde{V}^K(t, r_t)$ and $\widetilde{V}^L(t, y_t)$, with $t = 1, ..., T$, are*

(i) increasing and (ii) continuous in the current returns r_t and y_t,

(iii) and non-increasing in t.

[74]Remember that $\widetilde{V}^X(t) = 0$ throughout all periods.

Proof. See Appendix 2.8.1. ■

All three vectors of cut-off functions define the strategy space for a patent owner in each year. Consider a patent that has been renewed with full protection up to period t. The patentee can now choose between all three strategies: (K), (L), and (X). As one can see in Figure 2.1 the cut-off functions $\hat{r}_t$, $\hat{g}_t^{l+}(r_t)$, and $\hat{g}_t^{l-}(r_t)$ divide the (r_t, g_t^l)-space in exactly three regions. Letting the patent expire (X) will be the optimal strategy if and only if the current per period returns r_t as well as the LOR growth rate g_t^l will both be lower than their corresponding threshold values $\hat{r}_t$ and $\hat{g}_t^{l-}(r_t)$ (the region in the lower left corner in Figure 2.1). In this case renewal in any regime, (L) or (X), would not justify the costs of renewal. If in turn the current per period returns from full patent protection are high enough, $r_t \geq \hat{r}_t$, renewal will be optimal in any case. The agent will renew with full patent protection (K) as long as the LOR growth rate is not too high, $g_t^l < \hat{g}_t^{l+}(r_t)$. These patents are located in the lower right part of the figure. A declaration of the willingness to license (L) will be the optimal strategy if the LOR growth rate is high enough, such that $g_t^l \geq \hat{g}_t^{l+}(r_t)$. We call this the commitment motive for LOR declaration. By committing to license non-exclusively and simultaneously reducing all future renewal fees the patentee can improve his expected profits. In this case he will declare LOR instead of keeping full patent protection. These patents are located in the upper right part of the figure. Patentees can also declare LOR out of the cost-saving motive. These are all patents which are situated in the upper left part of the figure. If the current per period returns are too low, $r_t < \hat{r}_t$, such that renewal with full patent protection will never be optimal, the patentee may still declare LOR. As long as he can sustain a sufficient part of the returns without the exclusion right, i.e., $g_t^l \geq \hat{g}_t^{l-}(r_t)$, the reduction in future renewal fees can turn the LOR declaration into a profitable strategy.

Consider now a patent that has been renewed up to period t and for which LOR was declared in year a, with $a < t$. The patentee has only two options, he can either renew the patent endorsed LOR (L) or let it expire (X). In this case $\hat{y}_t = g_a^l r_t$ are the minimum revenues that a patent endorsed LOR has to generate in this period for the patentee to keep patent protection.[75] We can rewrite $\hat{y}_t$ as a function in the (r_t, g_t^l)-space. Thus, given per period returns r_t, all patents already endorsed LOR with growth rates $g_a^l \leq \hat{g}_t^{l-}(r_t)$ will not be renewed (see Figure 2.2).

2.2.2 Comparative Statics

This section analyzes how the returns from patent protection r_t–we call it selection effect– and the age of a patent t–we call it horizon effect–determine the agent's strategy space.

[75] $\hat{y}_t$ is defined in $\widetilde{V}^L(t, \hat{y}_t) = 0$.

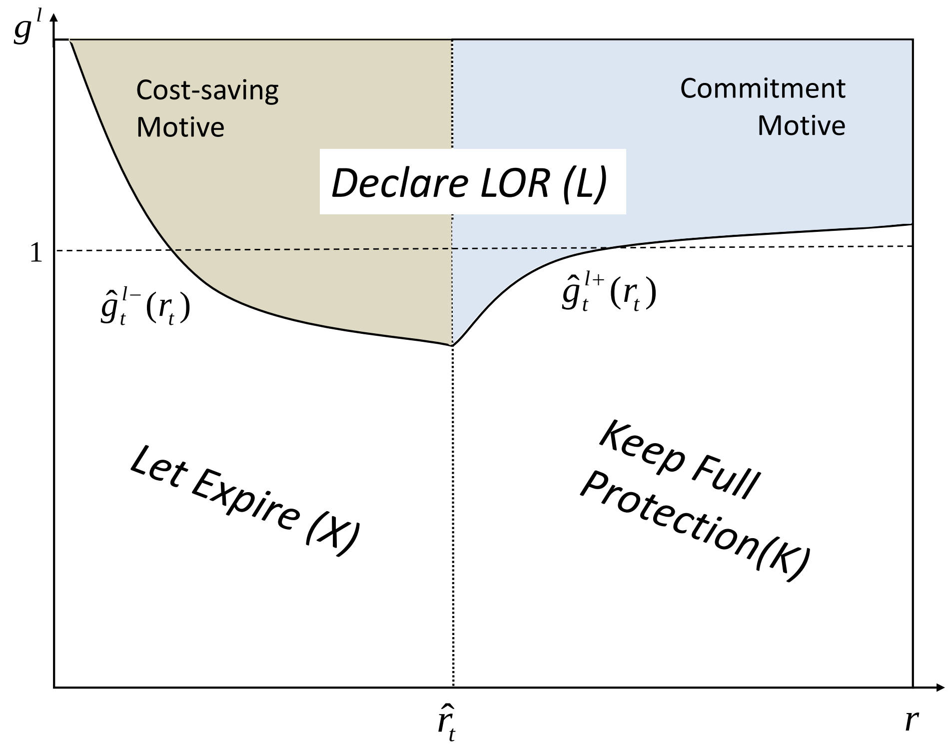

Figure 2.1: Strategy Space of a Patent with Full Protection

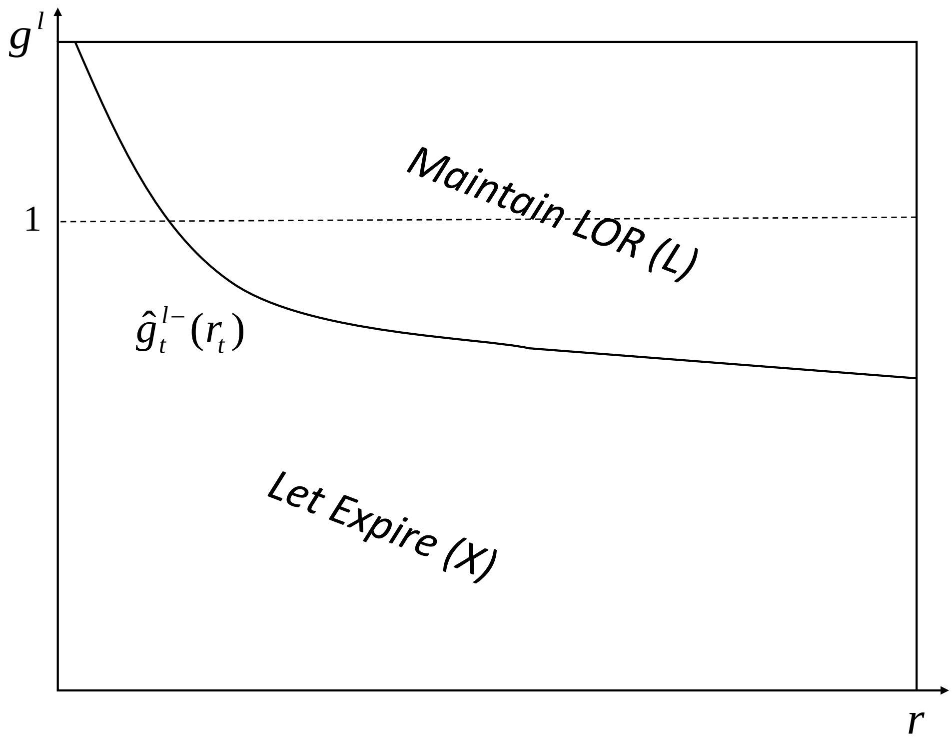

Figure 2.2: Strategy Space of a Patent Endorsed LOR

Selection effect The selection effect tells us how the probability to observe a declaration of LOR varies with changes in returns from full patent protection r_t.

Proposition 2.1. *If it holds that*[76]

$$1+\beta\frac{\partial\left\{E\left[\widetilde{V_K}(t+1,g^k_{t+1}r_t,g^l_{t+1}g^k_{t+1}r_t)\right]-E\left[\widetilde{V_L}(t+1,\hat{g}^{l+}_t(r_t)g^k_{t+1}r_t)\right]\right\}}{\partial r}>\hat{g}^{l+}_t(r_t)$$

then

(i) $\hat{g}^{l-}_t(r_t)$ *will be decreasing in* r_t *and*

(ii)$\hat{g}^{l+}_t(r_t)$ *will be increasing in* r_t.

Proof. See Appendix 2.8.1. ■

Assume that an agent has renewed his patent up to period t. There are two cases to be considered. If $r_t < \hat{r}_t$ the patentee has to decide whether to declare LOR (L) or to let it expire (X). He will only declare LOR if the current returns from a patent endorsed LOR, $y_t = g^l_t r_t$, and the option value $E\left[\widetilde{V_L}(t+1,\hat{g}^{l+}_t g^k_{t+1}r_t)\right]$, are high enough to cover the renewal fees $\frac{f_t}{2}$. We know from Lemma 2.1 that the option value is non-decreasing in per period returns r_t. Thus, the higher r_t, the lower can be the share of returns realized during the LOR regime, g^l_t, such that the agent will still be willing to renew the patent. This is why the threshold value functions $\hat{g}^{l-}_t(r_t)$ are decreasing in r_t in the respective region (see Figure 2.3). If the returns from full patent protection are high enough, $r_t \geq \hat{r}_t$, the agent will choose between strategy (K) and strategy (L). Now, the higher the per period returns r_t, the less important will be the reduction in renewal fees relative to the potential reduction in expected (future) returns due to the loss of exclusivity. Therefore, a high growth rate g^l_t is needed for the patentee to choose LOR for valuable patents. This is represented by an increasing function $\hat{g}^{l+}_t(r_t)$ in Figure 2.3. To sum up, if the returns in case of full patent protection with the right to exclude others are relatively low, the probability of observing a declaration $Pr(g^l_t \geq \hat{g}^{l-}_t(r_t) \mid r_t < \hat{r}_t)$ in year t will be increasing in r_t. If instead the patent is able to generate relatively high returns in case of full patent protection, the probability of declaration $Pr(g^l_t \geq \hat{g}^{l+}_t(r_t) \mid r_t \geq \hat{r}_t)$ will be decreasing in r_t.

Horizon effect In our model, by assumption not only the renewal fees but also the probability distributions vary with t. Consequently, the patent age should have an impact

[76]We have checked this assumption for the stochastic specifications which we use for the structural estimations. Simulations have shown that this condition is always satisfied at reasonable parameter values.

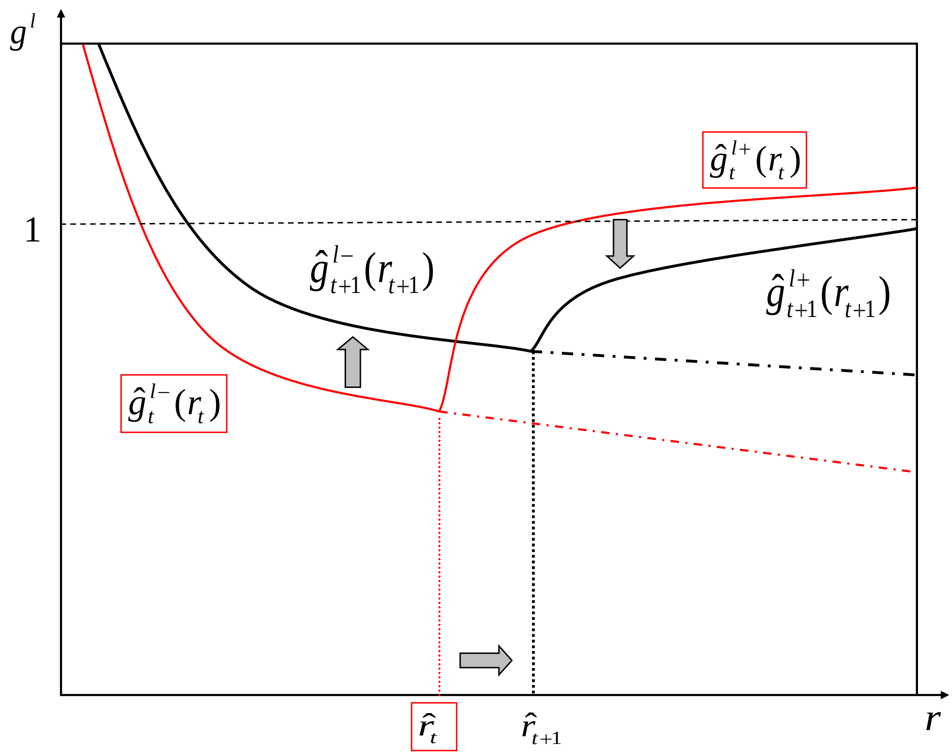

Figure 2.3: Selection and Horizon Effect

on both the decision to declare LOR (L), the decision to keep full patent protection (K), or to let the patent expire (X). This is reflected in the following propositions.

Proposition 2.2. *The cut-off values $\hat{r}_t$ are non-decreasing in t.*

Proof. See Appendix 2.8.1. ■

The threshold value $\hat{r}_t$ is only relevant for patents that have kept full protection throughout all previous periods. It divides these patents into two categories. Those that would certainly have been dropped (patents with $r_t < \hat{r}_t$) and those that would certainly have been renewed with full protection (patents with $r_t \geq \hat{r}_t$), if the LOR system had not existed. Given that the renewal fees are increasing and the option value decreasing with t, the minimum returns, $\hat{r}_t$, needed to belong to the second category, will also increase with t (see Figure 2.3).

Proposition 2.3. *Given r_t,*

(i) $\hat{g}_t^{l-}(r_t)$ is non-decreasing in t and

(ii) the effect of t on $\hat{g}_t^{l+}(r_t)$ is ambiguous.

Proof. See Appendix 2.8.1. ■

Let us consider patents with relatively low returns from full patent protection ($r_t < \hat{r}_t$). For younger patents the renewal fees are lower and the option value higher than for older patents. Thus, the minimum LOR growth rate needed for the agent to renew a younger patent should be equal or even lower than the one needed for an older patent. This shifts the cut-off value function $\hat{g}_t^{l-}(r)$ upwards for older patents (see Figure 2.3).

For patents with higher per period returns ($r_t \geq \hat{r}_t$) the horizon effect is ambiguous and depends on the exact specification of the distributions of the growth rates. There are several countervailing effects. On the one hand, $\hat{g}_t^{l+}(r)$ should decrease as patents get older, since the maintenance fees are rising with a patent's maturity, and so is the cost difference between both regimes. Furthermore, the older the patent, the smaller will be the loss in option value (the patentee is giving up option (K)) in case of a declaration. On the other hand, $F_{g^l}(u^l \mid t)$ is decreasing in t, reducing the chance for older patents to draw a high LOR growth rate g_t^l. Thus, $\hat{g}_t^{l+}(r)$ may nevertheless increase with t.[77]

To sum up, patent age influences not only the probability of expiration but also the probability to observe a LOR declaration. For patents with relatively low returns from full patent protection, the probability of observing a declaration $Pr(g_t^l \geq \hat{g}_t^{l-}(r_t) \mid r_t < \hat{r}_t)$ will decrease with t. If instead the returns are high, the probability $Pr(g_t^l \geq \hat{g}_t^{l+}(r_t) \mid r_t \geq \hat{r}_t)$ may either increase or decrease with t. The probability of expiration in year t is defined as $Pr(g_t^l < \hat{g}_t^{l-}(r_t) \wedge r_t < \hat{r}_t)$ for patents not endorsed LOR and $P(g_t^l < \hat{g}_t^{l-}(r_t))$ for patents already endorsed LOR. We know from Proposition 2.2 and Proposition 2.3 that $\hat{r}_t$ and $\hat{g}_t^{l-}$ are both increasing with age t. Therefore, these probabilities must increase with a patent's maturity.

2.3 Estimation

2.3.1 Estimation Strategy

In the first step of the structural estimation we assign a stochastic specification to our structural model which will depend on a vector of parameters ω. In general, the stochastic specification we assign to our model will determine the process how the growth rates evolve over time as well as the distribution of initial returns. Although in theory a solution to the problem described above can be found analytically, it is hardly possible in practice due to the high complexity of the model. Thus, we are using a weighted simulated minimum distance estimator (SGMM) $\hat{\omega}_N$ developed by McFadden (1989) and Pakes and

[77]Simulation results have shown that for the stochastic specification we use for estimation the condition for $\hat{g}_t^{l+}(r)$ to be decreasing in t is always satisfied.

Polland (1989) and already applied by Lanjouw (1998) and Serrano (2011). To estimate the vector of the true parameters ω_0 we will use legal events data on German patent applications. According to Lanjouw (1998) it is advantageous to fit hazard probabilities instead of mortality rates or other statistical moments.[78] The estimator is the argument that minimizes the norm of the distance between the vector of true and simulated hazard proportions:

$$A(\omega)\left\|h_N - \eta_N(\omega)\right\| \tag{2.3}$$

$$\text{with } \hat{\omega}_N = arg\,\min_{\omega} A(\omega)\left\|h_N - \eta_N(\omega)\right\|$$

- h_N is the vector of sample or true hazard proportions,
- $\eta_N(\omega)$ is the vector of simulated hazard proportions (predicted by the model),
- $A(\omega) = diag\left(\frac{\sqrt{n_j/N}}{h_j}\right)$ is the weighting matrix. n_j is the number of patents in the sample for the relevant age-cohort j and h_j is the corresponding sample hazard. N is the sample size.[79]

In particular, h_N consists of three types of hazard proportions:

- $HR^X_{NoLOR}(t)$ is the percentage of patents that expire in year t given that they were active and not endorsed LOR in the previous period $t-1$,
- $HR^L(t)$ is the percentage of patents which declare LOR in year t given that they were active and not endorsed LOR in the previous period $t-1$, and
- $HR^X_{LOR}(t)$ is the percentage of patents that expire in year t given that they were active and endorsed LOR in the previous period $t-1$.

In order to calculate the hazard rates predicted by the model for a parameter set ω, in the first step we will calculate the cut-off value functions $\{\hat{r}_t\}_{t=1}^T$, $\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^T$ and

[78] In this way we are avoiding the selection bias caused by patents which were dropped during the grant proceedings which might take more than 10 years.

[79] We follow previous patent renewal studies and use a diagonal matrix that weights each moment according to the number of observations in each sample hazard to improve the efficiency of the estimator. Since the hazard proportions of LOR declarations are at least ten times smaller than the hazard proportions of expiration, we further divide each element in the diagonal matrix by its corresponding sample hazard. This will give more weight to the distance between the sample and true hazard proportions of declaration $HR^L(t)$. This will improve the estimation efficiency of the parameters that determine the distribution of the LOR growth rates.

$\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^{T}$. Then, we proceed recursively by first calculating the value functions in the last period, $\widetilde{V}^K(T, r_T)$ and $\widetilde{V}^L(T, y_T)$, and the corresponding cut-off functions $\hat{r}_T$, $\hat{g}_T^{l+}(r_T)$ and $\hat{g}_T^{l+}(r_T)$. Subsequently, using these cut-off functions, we approximate the value functions for the year $T-1$. The cut-off value $\hat{r}_T$ is easily computed. However, to calculate the cut-off functions $\hat{g}_{T-1}^{l+}(r_{T-1})$ and $\hat{g}_{T-1}^{l-}(r_{T-1})$ we must equate the respective value functions on an M-point grid of points $\overrightarrow{r} \equiv \{r_1 < r_2 < ... < r_M\}$ and approximate the function at all points via interpolation.[80] We then proceed in the same recursive manner until the first year. Once we have calculated the cut-off functions for all periods, we simulate S populations of granted patents.[81] Each population consists of $3 \cdot N$ patents. For each one we take pseudo random draws from the initial distribution and from the distributions of both types of growth rates, g_t^k ($t \in 2, ..., T$) and g_t^l ($t \in 1, ..., T$). Afterwards, we pass the initial draws through the stochastic process, compare them with the cut-off values in each period and calculate the vector of simulated hazard proportions. We then average the simulated moments over S populations. The vector of the average simulated hazard proportions $\eta_N(\omega)$ is then inserted into the objective function (2.3). The objective function is minimized using global optimization algorithms for non-smooth problems implemented in MATLAB.[82] The standard errors are calculated using parametric bootstrap described in Appendix 2.8.3.

2.3.2 Stochastic Specification

Similar to previous patent renewal studies (Pakes 1986; Schankerman and Pakes 1986; Deng 2011; Serrano 2011) we assume that the initial returns r_1 of all granted patents are lognormally distributed with mean μ_{IR} and variance σ_{IR}:

$$log(r_1) \sim Normal(\mu_{IR}, \sigma_{IR}) \tag{2.4}$$

With probability $1 - \theta$ a patent can become obsolete in the beginning of each period, which corresponds to an extreme form of value depreciation.

We follow the specification in Schankerman and Pakes (1986) and Serrano (2011) to model the distributions of the growth rates for the returns from full patent protection, g_t^k. We assume a constant growth rate, or more precisely a constant rate of value depreciation,

[80] For all calculations we have used MATLAB (matrix laboratory), a numerical computing environment developed by MathWorks.

[81] We set $S = 5$.

[82] Since the objective function is supposed to be non-smooth we apply the Simulated Annealing algorithm and the Genetic algorithm in the first step. Both are probabilistic search algorithms (see description of the Global Optimization Toolbox for MATLAB). In the second step we apply a Nelder-Mead-type search algorithm called *fminsearch* to find the local minimum.

$g_t^k = \delta < 1$. We refer to this as the deterministic approach, since the growth rate for all future periods will be determined already in the first period.[83]

The growth rates associated with the LOR regime, g_t^l, are drawn from an exponential distribution:

$$q^l(g^l \mid t) = \frac{1}{\sigma_t^l} exp(-\frac{g^l}{\sigma_t^l}) \tag{2.5}$$

We allow the standard deviation of these distributions to change monotonically with a patent's age t, $\sigma_t^l = (\phi^l)^t \sigma_0^l$. The parameter ϕ^l is not bounded and may exceed 1. This allows us to test whether the probability to have a high LOR growth rate is decreasing with a patent's age.

We fix the discount factor $\beta = 0.95$ to ease the computational burden. Thus, our vector ω consists of six structural parameters:

$$\mu_{IR}, \sigma_{IR},\ \theta,\ \phi^l, \sigma_0^l,\ \delta$$

2.3.3 Identification

The structural parameters are identified by the size of and the variation in renewal fees, both across ages and different regimes, as well as the highly non-linear form of the model. Different parameter values imply different cut-off values, which in turn imply different aggregate behavior, and thus different hazard proportions. Nevertheless, since our model is based on the assumption that patentees will renew patent protection as long as the expected returns exceed the corresponding renewal fees, we are unable to directly identify the right tail of the patent value distribution. The value of patents which are renewed until the statutory patent term is only indirectly identified by the functional form assumptions for the distributions of initial returns and the growth rates.

All structural parameters are jointly estimated. The parameters ϕ^l and σ_0^l determine the distribution of the LOR growth rates and are identified by the variation in all three types of hazard proportions, $HR_{NoLOR}^X(t)$, $HR^L(t)$, and $HR_{LOR}^X(t)$. If σ_0^l is small, fewer declarations will be made throughout all ages. Patents endorsed LOR will expire earlier, increasing the drop out proportions for intermediate ages and decreasing them for higher

[83] We also estimate a model with a different specification for the distributions of the growth rates for the returns from full patent protection, g_t^k, where we explicitly allow for learning. This more stochastic approach follows closely the model specification in Pakes (1986), Lanjouw (1998), and Deng (2011) and is presented in Appendix 2.8.4.

ages. Furthermore, more patent owners of patents not endorsed LOR will choose not to declare LOR and let their patents expire. ϕ^l particularly determines the shape of the $HR^L(t)$ curve. For relatively low values of ϕ^l the hazard proportions are sharply decreasing with patent age, whereas for relatively high values of ϕ^l (values close to or above one) they may be increasing throughout all patent ages.

The parameter θ is identified by the proportions of expiration, $HR^X_{NoLOR}(t)$ and $HR^X_{LOR}(t)$. Contrary to all other parameters, θ shifts the entire curves up or down and determines the size of the proportions especially early in the life of a patent, when renewal fees are relatively low. Given the renewal fees schedule, the parameter δ and the parameters that determine the initial distribution of returns, μ_{IR} and σ_{IR}, are jointly identified by the variation in all three types of hazard rates. In particular, higher values of σ_{IR} imply a more skewed distribution of patent returns which cause higher dropout rates for intermediate ages and lower dropout rates for higher ages, when renewal fees are highest. Lower values of σ_{IR} have the opposite effect. δ mainly determines the variation in hazard proportions when patents get closer to their expiration date.

2.4 Data

We use data on German patent applications provided by the German Patent and Trademark Office (DPMA) updated as of Dec. 24, 2008.[84] This data set contains information on all legal events, especially about patent renewals and declarations of the willingness to license according to Sec. 23 of the German Patent Act. For estimation, we use granted patent applications with effect in Germany from cohorts 1983-1988 for which we observe the full patent term.[85] Since we do not explicitly model the application and examination stages which precede the patent stage, we do not consider renewal and declaration decisions in the years the patent has not been granted. Usually high lump-sum costs are involved in both stages and the patent system offers several additional options to the patent applicants, too. One of them is the possibility to defer the examination of the patent for up to seven years. Another one is to stop or accelerate examination during

[84]Due to legal provisions, the DPMA has to announce the publication of certain legal documents and events, e.g., publications of patent applications, patent grants, translations of European and PCT patent claims, as well as their changes. The announcement itself is made by a notice that appears in the weekly published Patent Gazette. Information used for the publication in the Patent Gazette is stored in the PU-Band, tagged with the date the particular event was announced in the Patent Gazette (on average 3 months after the event). The first entry in the data we use dates back to 31 March 1981.

[85]Besides truncation issues, the reason for not choosing younger cohorts was a legal amendment in 1992 which allowed applicants to withdraw the LOR declaration as long as there had not been any request for a license. This option is not incorporated in our model. Nevertheless, in the chosen cohorts willingness to license was withdrawn only in 10 cases, which leaves our model assumption of the declaration being irrevocable still justifiable.

the grant procedure. The consequence of these additional costs and options which are not captured by our model is that they could create a selection effect in the data even in the periods after grant. At any age, the probability of observing an expiration decision is likely to differ between patents which have just been granted and those that had been granted many years ago. The same applies to the probability to observe the decision to declare LOR. To avoid these biases in the calculation of the sample hazard proportions we have excluded the decisions in the first two years after grant, too.[86]

After excluding patents which expired within the first two years after they had been granted (12% of all granted patents) we were left with 211,869 patents divided in six cohorts. LOR has been declared for 12,878 (6.08%) of them. For 3,557 patents the LOR declaration was made when the patent application has still been pending or within the first two years after grant. These LOR declarations were not considered for the calculation of the hazard proportions. For 35,410 (16.7%) patents, protection has been renewed for the full patent term.

The weighted sample hazard proportions obtained for patent ages 5 to 20 (respectively 6 to 20) are presented in Figures 2.4-2.6.[87] The theoretical model predicts that the hazard proportions of expiration for patents endorsed, as well as for patents not endorsed LOR should be monotonically increasing in patent age due to the selection effect. However, this is not the case for some intermediate ages. Furthermore, there is a sharp increase for older ages. The explanation is easily found by looking at the disaggregated hazard proportions of expiration. For each cohort there are two kinks in the elsewise monotonically increasing curves which can be attributed to the events surrounding the dot-com bubble in Germany. The sharp decline in hazard proportions in 1998 can be associated with the emergence of the New Economy, whereas the jump in 2002 can be associated with its burst. Both events significantly affected the overall economic development in Germany. To capture the impact of these shocks we allow the obsolescence rate $1-\theta$ to differ in 1998 ($1-\theta_{1998}$) and 2002 ($1-\theta_{2002}$). We assume that both shocks were unexpected by the patent owners.[88] The hazard proportions of LOR declarations follow an inverted-U-shaped curve. They increase from 0.53% in year 5 to 0.81% in year 13, decrease for the following years, and reach the minimum in year 20 with 0.37%.

The patent renewal fee schedule for the time span under consideration is provided in Appendix 2.8.2. There was one major change to the fee structure in Jan. 1, 2000. The renewal fee for each year was increased by 15%. Following Lanjouw (1998) we assume

[86]The hazard proportions did not change considerably when we excluded the first three or four years after grant.

[87]Since patent examination takes at least two years and due to subsetting we do not observe hazard proportions for the first 4, respectively 5 years.

[88]Alternatively, we could have implemented these shocks as a change in the distribution of the growth rates. However, this would considerably complicate the model and increase the computational burden.

that the changes were anticipated by the patentees such that they always have correct expectations about the renewal fee schedule that they will face in the future.[89]

2.5 Estimation Results

The estimation results are presented in Table 2.1.[90] We begin with a discussion of the overall fit of the model and then turn to the interpretation of the parameter estimates. In the previous literature two measures were used to evaluate how well the estimated model fits the data. First, one can look at how well the curves of the simulated hazard proportions, calculated using the estimated parameters, mimic the curves of the true hazard rates. In Figures 2.4-2.6 we plot the true and the weighted simulated hazard rates for the cohorts 1983-1988. As expected, the model fits the curves of hazard proportions particularly well for ages which received the highest weight in the estimation. However, it fails to capture the rather sharp increase in the hazards of expiration in the final ages. Regarding the hazard proportions of declaration, the model slightly underestimates them but captures the decrease for higher ages reasonably well. Another performance indicator is the fraction of the variation in the true hazard rates that can be explained by the model. Therefore, we calculate the Mean Square Error (MSE) defined as the sum of squared residuals divided by the number of age-cohort cells. A low MSE relative to the variance in the sample hazard proportions suggests a good fit. With a MSE value of 9.23 e^{-4} the model is able to explain 83.23% of the overall variation in the hazard proportions.[91]

Depreciation dynamics The distribution of the initial returns is determined by the parameters μ_{IR} and σ_{IR}. The mean initial return was 16,019€ (1,417€).[92] The distribution was skewed with a median initial return of 5,714€ (348€). The parameters δ and θ together determine the depreciation of the value of patent protection over time. The obsolescence rate, defined as $1 - \theta$, was 7.60%, meaning that 50.91% of all patents became worthless to their owners after ten years. Additionally, we confirm the finding

[89] To avoid solving the dynamic optimization problem for each cohort separately we decided to calculate a single renewal fee schedule as a weighted average of the renewal fee schedules of all cohorts. We are aware that this simplification may potentially bias our estimates.

[90] We provide the estimation of the stochastic model with learning in Appendix 2.8.4. The main results do not differ significantly.

[91] The unweighted MSE is somewhat higher than reported in other patent renewal studies where the explained variation typically exceeds 90%. This is reasonable, since we have used a different weighting scheme. The weighting matrix $A(\omega)$ in the objective function was constructed such that hazard proportions of LOR declaration have received relatively higher weights. The reported MSE does not take this weighting scheme into account.

[92] All monetary values are in units of 2002€ calculated for cohort 1983. Standard errors are reported in parentheses.

Parameter	Model 1	(s.e.)[†]
β (fixed)	0.950	
μ_{IR}	8.286	(0.0630)
σ_{IR}	1.435	(0.0239)
θ	0.924	(0.0006)
θ_{1998}	0.985	(0.0011)
θ_{2002}	0.835	(0.0020)
δ	0.968	(0.0030)
ϕ^l	0.973	(0.0002)
σ_0^l	0.204	(0.0009)
Age-Cohort Cells	282	
Sample Size	211,869	
Simulation Size	635,607	
MSE_{All}[‡]	0.000923	
$Var_{All}(h_N)$	0.0055	
$1 - MSE_{All}/Var_{All}(h_N)$	0.8323	

[†]Calculated using parametric bootstrap.

[‡]Calculated as the sum of squared residuals divided by the number of age-cohort cells.

Table 2.1: Parameter Estimates

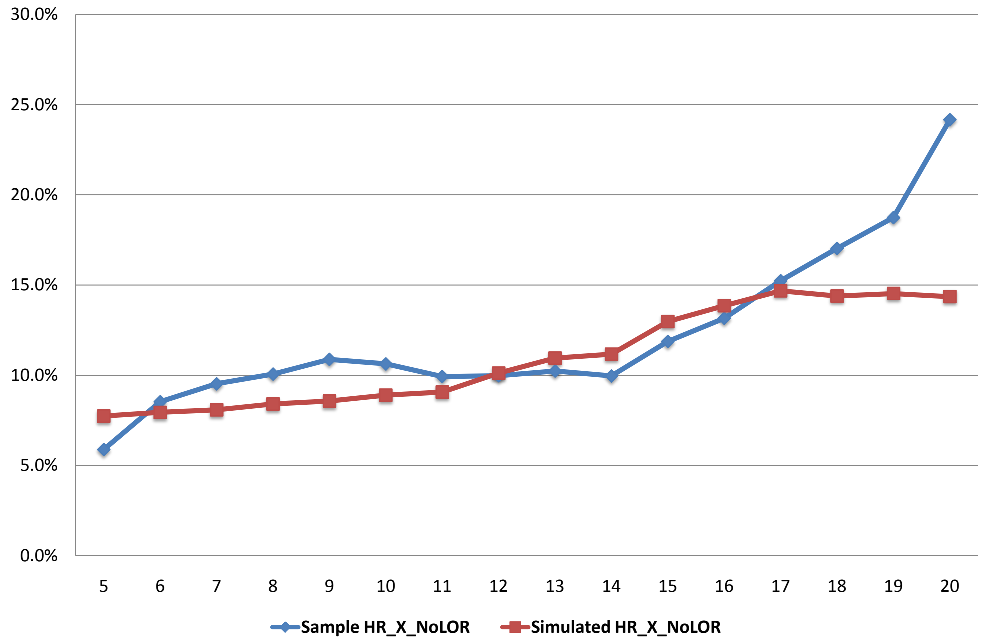

Figure 2.4: Hazard Proportions of Expiration for Patents Not Endorsed LOR

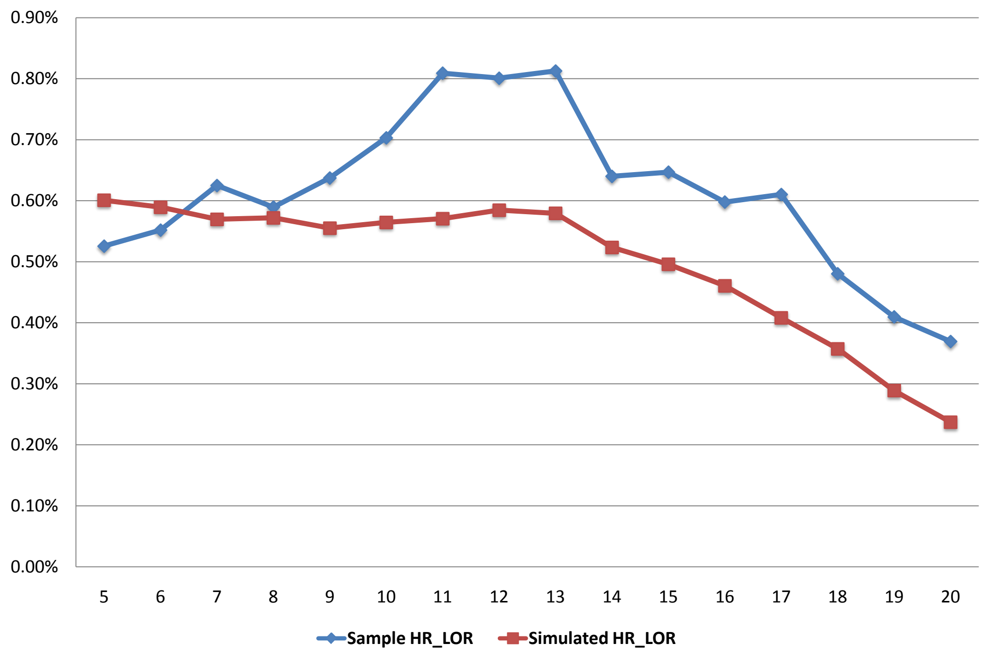

Figure 2.5: Hazard Proportions of LOR Declaration

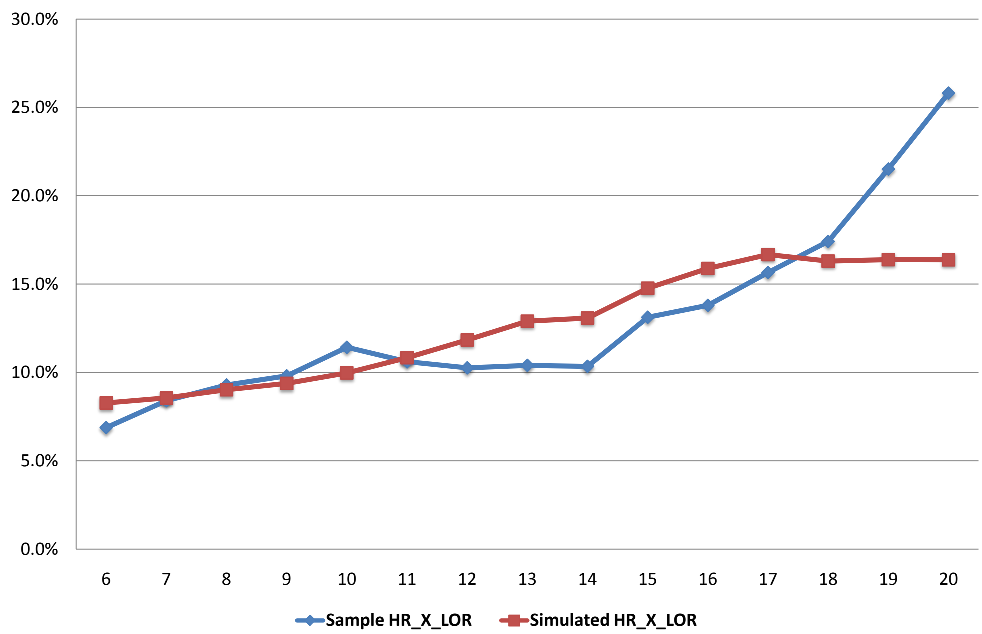

Figure 2.6: Hazard Proportions of Expiration for Patents Endorsed LOR

by Schankerman (1998) that economic shocks, positive as well as negative, significantly influence the value of patents. The estimated obsolescence rates for the years 1998 and 2002, $1-\theta_{1998}$ and $1-\theta_{2002}$, are higher, respectively lower. In 1998, during the economic upturn, only 1.52% of patents and in 2002, when the economic crisis became most severe, as many as 16.49% of patents were considered obsolete. If the patents did not become obsolete the returns depreciated by 3.2% each year. This is a relatively small value. However, the obsolescence rate already accounts for a large part of the overall depreciation in patent value.

Distribution of the value of exclusivity One of the major contributions of this paper is the estimation of the distribution of the value of exclusivity. This was defined as 1 minus the fraction of returns from patent protection that remain if the patentee declares LOR, maintaining only a right to reasonable remuneration. The estimated parameters ϕ^l and σ_0^l determine this distribution across all German patents. One can see in Table 2.2 that in the first year, 2.23% of the patent owners would still be able to realize 75% of the returns from full patent protection even if they gave up exclusivity. For 0.63% of the patents the returns could even be increased if they waived their exclusive right. The declaration of the LOR is a binding commitment to make licenses available at a reasonable fee. This commitment may increase the diffusion of the technology, and hence the licensing revenues. Especially if the setup costs required for using a technology are high, a guarantee that licenses will be available at a reasonable price could foster the demand for the technology (Shepard 1987; Farrell and Gallini 1988).

Since ϕ^l is smaller than 1, the probabilities to draw relatively high LOR growth rates are decreasing with patent age. For patents still alive at age 20 the likelihood of being able to realize higher returns after declaring LOR than with full patent protection falls to only 0.02% and the likelihood of being able to realize 75% of the returns, to 0.16%. As many as 1.38% of the patents would still be able to retain at least 50% of the returns if they gave up exclusivity. In reverse, this means that exclusivity becomes relatively more important for returns appropriation with patent age. The older the patent the bigger is the fraction of returns which is associated with the right to exclude others and foreclose competition. Although returns to patent protection decrease with patent age, patents' contribution to static inefficiency, i.e., welfare losses, increases in relative terms. Older patents are likely to be more detrimental to the society. This result confirms previous findings (e.g., Cornelli and Schankerman 1999; Baudry and Dumont 2009) that the optimal patent renewal fees should be sharply increasing towards the end of patent life to minimize the social cost.

Age	$Pr(g_t^l \geq 1.00)$	$Pr(g_t^l \geq 0.75)$	$Pr(g_t^l \geq 0.50)$
1	0.63% (0.0144)†	2.23% (0.0383)	7.93% (0.0907)
2	0.55% (0.0125)	2.01% (0.0345)	7.39% (0.0847)
3	0.47% (0.0108)	1.80% (0.0310)	6.87% (0.0789)
4	0.41% (0.0094)	1.61% (0.0278)	6.37% (0.0735)
5	0.35% (0.0081)	1.43% (0.0249)	5.90% (0.0684)
6	0.30% (0.0069)	1.27% (0.0222)	5.45% (0.0635)
...	...	...	...
18	0.03% (0.0009)	0.23% (0.0049)	1.74% (0.0248)
19	0.02% (0.0007)	0.19% (0.0043)	1.55% (0.0229)
20	0.02% (0.0006)	0.16% (0.0037)	1.38% (0.0211)

†Standard errors in parentheses.

Table 2.2: Evolution of LOR Growth Rates

2.6 Implications

2.6.1 The Value of Patent Rights

We use the estimated parameters to calculate the distribution of the value of patent rights for patents from cohort 1983. To do this, we draw a population of 500,000 patents from the initial distribution and pass them through the model. We then use German deflation factors to calculate the discounted present value of the stream of returns, net of discounted renewal fees for each patent.

In Table 2.3 we report the distributions at three different ages, at age 1, which corresponds to the overall value of patent protection, at age 5, and at age 10. For the distribution of the overall patent value we distinguished between the value of patents for which LOR has been declared and patents which have never been endorsed LOR. As already reported in previous studies, we observe that the distribution is very skewed with most of the value generated by only a small fraction of patents. The average patent value was 122,925€ with 50% being worth less than 32,845€. Only 5% of the patents were worth more than 493,017€ and for 1% the value even exceeded 1,392,057€. The distribution gets more skewed at age 5 and even more so at age 10 after many patents have become obsolete.

We estimate somewhat higher patent values compared to previous patent renewal studies. Using patent data for cohorts 1950-1979 Pakes (1986) reports a mean value per German patent of 46,560€. Lanjouw (1998), using patents from cohorts 1953-80 in four technological areas, reports somewhat lower average values for patents in computers and textiles, and higher values for patents in engines and pharmaceuticals. However, both studies were using stochastic models which allowed for learning. The only study directly comparable

	at Age 10	at Age 5	at Age 1		
Percentile	All		All	No LOR	Endorsed LOR
50	0	9,838	32,845	33,383	26,366
(s.e.)	(0)	(396)	(1,730)	(1,775)	(1,239)
75	12,781	50,402	103,687	105,982	71,885
(s.e.)	(466)	(2440)	(6,199)	(6,348)	(4,290)
90	65,505	159,192	277,082	281,885	198,308
(s.e.)	(2,909)	(9115)	(18,933)	(19,248)	(15,263)
95	136,858	299,285	493,017	499,854	362,173
(s.e.)	(7,052)	(19022)	(36,531)	(37,096)	(30,341)
99	455,827	900,290	1,392,057	1,400,844	1,236,523
(s.e.)	(30,200)	(70386)	(122,695)	(123,907)	(115,550)
99.9	1,599,868	2,987,310	4,468,806	4,469,337	4,418,714
(s.e.)	(131,764)	(285310)	(473,114)	(481,255)	(483,024)
Mean	29,260	69,026	122,925	124,601	96,898
(s.e.)	(1,738)	(4,673)	(9,236)	(9,379)	(7,472)

Table 2.3: Value Distributions in 2002€

to ours is Schankerman and Pakes (1986). Using the same data as in Pakes (1986) but a deterministic model they estimate a mean patent value at age 5 of 55,069€ for the 1970 cohort. According to our results, the average value of patent protection at age 5 for the 1983 cohort was higher, with 69,026€. We have used a sample of German patents from cohorts 1983-1988 for estimation. There are several explanations for the discrepancy. Schankerman (1998) and Schankerman and Pakes (1986) indicate that patent values have been increasing over time. Furthermore, data on German patents used for estimation in previous studies preceded the German reunification in 1990 whereas our data almost exclusively cover the post-reunification era. The increased market size should have had a significant effect on the private value of German patent rights.

Patents endorsed LOR are on average less valuable than patents which have never been endorsed LOR. This confirms the result in Chapter 1 where we have used regression analysis to show that a declaration is less likely for patents of presumably higher value. The average value of a patent endorsed LOR was 96,898€, 22.23% lower than the average value of a patent never endorsed LOR. The median value was 26,366€ and 10% of all patents for which LOR has been declared were even worth more than 198,308€. Since LOR can be declared throughout the whole patent life, we subtract the returns generated before the LOR declaration and calculate the distribution of the value from patent protection which has been generated during the LOR regime. This distribution looks even more skewed with a mean value of 62,312€ and a median value of 8,474€ (see Table 2.4). 10% of patents endorsed LOR were even able to accumulate more than 130,074€ in net returns during the LOR regime. The result is surprising, since the common opinion is that

LOR is declared only for patents which are peripheral or have already become worthless to their owners. Our estimates, however, suggest that a substantial part of the value of patents for which LOR had been declared, on average 64.31%, has been generated after the declaration.

Percentile	50	75	90	95	99	99.9	Mean
Value	8,474	39,279	130,074	255,510	886,023	3,188,420	62,312
(s.e.)	(472)	(2,337)	(9,171)	(19,981)	(86,983)	(384,581)	(4,777)

Table 2.4: Value Realized During the LOR Regime in 2002€

2.6.2 Counterfactual Analysis

License of right We perform a counterfactual policy experiment where we ban the possibility to declare LOR from the patent system. We then look at how the overall value provided by the German patent system would change, as well as the consequences for the revenues of the German patent office. According to our calculations, the option value of the LOR system is positive. The value of all patents in the simulated cohort falls by 0.51% (0.02%), once we exclude the option to declare LOR from the model. The mean patent value drops by 620€ (52€). However, the amount of total renewal fees paid by the patentees increases by 2.21% (0.05%). Hence, the LOR system is associated with costs for the German patent office. Nevertheless, these costs correspond to only 12.16% of the additional private value it creates. Overall, the results indicate that a license of right provision can contribute to a better functioning of a patent system. It increases access to patented inventions without depriving patent owners of their returns. Although it encourages to maintain patent protection for a longer period, licenses are available at reasonable terms to any third party. Furthermore, the legislator can design the LOR incentive structure in a way as to discourage welfare decreasing declarations.

Of the 500,000 simulated patents for cohort 1983, 6.05% (0.05%) have declared LOR. The average declaration in the sample data was 6.08%. Now, we divide patents endorsed LOR according to the motives of declaration. A declaration is assigned to the cost-saving motive if the primary reason for the declaration was to profit from the cost reduction such that the patent would not have been renewed otherwise. These declarations can be considered as unambiguously welfare decreasing. A declaration is assigned to the commitment motive if the choice for the patentee was either to renew with full patent protection or to declare LOR. In this case the patent would have existed even without the possibility to declare LOR at least for one more year, maintaining the right to exclude others. Instead, the patentee commits to license his invention non-exclusively. These declarations can potentially be welfare increasing. According to the simulation results presented in

Age	1-5	6-10	11-15	16-20	1-20
Cost-Saving Motive	0.30%	4.07%	12.51%	19.75%	4.41%
Commitment Motive	99.70%	95.93%	87.49%	80.25%	95.59%
(s.e.)	(0.05%)	(0.30%)	(0.58%)	(1.05%)	(0.18%)

Table 2.5: Motive for LOR Declaration

Table 2.5, only less than 4.41% of all declarations were unambiguously welfare decreasing. In contrast, 95.59% of the declarations were made because the patentee expected higher profits in the LOR regime compared to the regime with full patent protection. However, this division is not constant for all patent ages. In the first 5 years, 99.70% of all declarations could be assigned to the commitment motive. This is not surprising since the renewal fees in the first five years are almost negligible. In contrast, of all declarations made in the last five years of the statutory patent term, only 80.25% could be assigned to the commitment motive and 19.75% to the cost-saving motive. Since the renewal fees in Germany are increasing progressively, they are highest in this five-year period. The corollary from this result is that the present cost structure that guarantees a 50% fee reduction for all declarations might not be welfare optimizing. To improve welfare one could decrease the fee reduction rate for late LOR declarations and increase it for early ones. The older the patent for which LOR is declared the lower should be the subsidy. This would incentivize early declarations and discourage welfare decreasing declarations for older patents.[93]

Compulsory licensing In our second counterfactual experiment we measure the cost of compulsory licensing (CL) requirements for the patent owners. We adapt our model and oblige every patent to declare LOR on the day of application, making licensing compulsory. Again, using the estimated parameters for German patent data we calculate the patent value assuming a 50% reduction in renewal fees. Compared to the present patent system in Germany the introduction of the compulsory licensing requirement for all patents would lead to a decrease in overall value by 81.00% (0.17%) or 99,572€ (7,344€) on average. We are aware that this result might overstate the real losses. First, patentees facing a compulsory licensing could adjust their strategies, e.g., by protecting their invention via secrecy, and avoid the burden of compulsory licensing. For example they may intensify the use of other means of IP protection like trade secrets or design patents. Secondly, our results depend on the functional form assumption for the distribution of the growth rates in case of LOR. We have chosen an exponential probability distribution

[93]Theoretically, one could use the model developed in this article and the estimated parameters to calculate the welfare optimizing fee structure. The results would highly depend on the employed welfare function. These welfare function should relate the welfare derived from an invention protected by a patent with full patent protection to the welfare derived from the same invention protected by a patent without the exclusive right and to the welfare without any patent protection. We leave this to future research.

which is a constantly decreasing function. This makes very low LOR growth rates, and hence low returns in case of CL very probable. Nevertheless, the results indicate that making licensing compulsory to all patent holders may deprive the system of much of its incentive power. Contrary to license of right it might not be advisable to apply compulsory licensing to the patent system as a whole. However, it can be beneficial to society to require licenses being available at reasonable terms for standard-related patents for interoperability purposes.[94] The same applies to patents in cumulative innovation fields. In some cases providing access to patented technology that follow-on inventions build upon might benefit welfare by far more than the losses in private value from patent protection if exclusivity is removed.

2.7 Conclusion

The main empirical findings can be summarized as follows. We confirm the result from previous patent renewal studies that the distribution of the private value from patent protection is very skewed. Additionally, we estimate that the distribution of the value of exclusivity is very skewed, too. We define the value of exclusivity as those returns that the patent owner would forfeit by giving up his right to exclude others in return for only a right to reasonable remuneration. We show that less than 7.93% of all patents would be able to maintain at least 50% of the returns from patent protection if they gave up exclusivity in the first year, and only 2.23% would be able to maintain at least 75%. Interestingly, a small fraction of patents, estimated to be around 0.63%, can even profit from a commitment to make licenses available to everyone. Furthermore, the value of exclusivity becomes more important with patent age. The older the patent the lower is the probability that the patentee will be able to retain a larger part of his revenues without the possibility to exclude others.

Moreover, the model allowed us to identify declarations which were unambiguously welfare decreasing. We estimate for the 1983 cohort of patents that 4.41% of all declarations were made only because of the 50% reduction in maintenance fees. Without the LOR option these patents would not have been renewed. The fraction of such declarations was almost negligible for young patents but has increased rapidly for older ones.

On average, patents endorsed LOR were by 22.23% less valuable to their owners than patents never endorsed LOR. However, a major part of the value of patents endorsed LOR has been generated during the LOR regime.

[94] Hilty and Geiger (2005) propose a mandatory license of right declaration for patents in component technologies such as the software sector.

Future research should look at the differences between technological areas. We know that LOR is mostly never used in discrete technologies like chemistry or biotechnology whereas it is widely used in complex technologies. LOR was declared for almost 11.41% of patents in electrical engineering and 8.02% in mechanical engineering. For some subclasses of these technology fields the numbers were even higher. The results would show how the distribution of the value of exclusivity differs across different complex technologies. Besides, the higher usage rates could help to improve the identification of the model parameters.

The results from the counterfactual experiments which we have performed using the estimated parameters show very useful insights, too. Although, as we argue, the estimated loss in private returns from patent protection of 81.00% that would follow an introduction of a compulsory licensing system constitutes only an upper bound, the sheer number is astonishing. Compulsory licensing would have considerably undermined the incentive effect of the patent system.

The possibility to declare LOR in the German patent system has somewhat different implications. Without this option, the private returns from patent protection of all patents would have fallen by 0.51%. However, the renewal fees collected by the German patent office would have risen by 2.21%. A LOR system is costly to implement for the patent office but these costs are only a fraction of the additional private value created in the patent system. The model and the estimated distributions could further be used to precisely assess the effects on the social welfare as well as to determine the welfare optimizing design of the LOR system. Certainly, the findings should differ across technology areas.

The basic trade-off is that on the one hand the LOR system provides incentives to open the access to patented inventions. On the other hand, the reduction in renewal fees, which are increasing with a patent's maturity, might result in too strong incentives to maintain patent protection. We observe that on average LOR was declared 8.5 years after the application date and the patents were renewed for additional 6 years, resulting in longer-living patents (2.5 years longer compared to patents without LOR).

Consider a simple model. Assume for simplicity the patentee has full information about all future returns from patent protection at the filing date. Without the possibility to declare LOR the patent owner would choose to let his patent expire at time $\overline{T}^{NL}$. Alternatively, the patent owner can also opt to declare LOR. The LOR regime is associated with an optimal time T for the declaration and an optimal time $\overline{T}^{L}$ for the expiration (see Figure 2.7). The difference $\overline{T}^{NL} - T$ denotes the period when the welfare effect from LOR will be positive, since exclusivity will be removed. The difference $\overline{T}^{L} - \overline{T}^{NL}$ denotes the period when the welfare effect will be negative, since patent protection would have been extended. Even if during this period the patent were endorsed LOR, a situation without

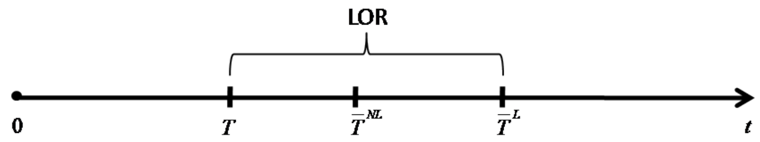

Figure 2.7: Time Line

any protection would increase welfare.

If the patentee indeed chooses to declare LOR he will do it earlier (T decreases) and let the patent expire later ($\overline{T}^L$ increases) the higher will be his returns from patent protection during the LOR regime and the higher the reduction in renewal fees. Assuming a welfare function for the different regimes of protection–no patent protection, patent protection with exclusivity, patent protection without exclusivity (LOR)–such that one could relate the welfare increasing effects to the welfare decreasing effects, one ought to be able to calculate the welfare optimizing fee reduction rate (currently 0.5). If the government sets only a low discount rate it will only attract patents with a positive welfare contribution into the LOR regime. However, the discount rate will be too low for the patent owners to choose the optimal time of declaration. Many patentees will choose too declare later than socially optimal, or choose not to declare LOR at all. On the other hand, if the government sets a high discount rate it will allow patents with a higher welfare contribution to choose the socially optimal time for the declaration. However, it would also encourage patents with negative welfare contributions into the LOR regime. The optimal discount rate should balance those effects.

In this setting one could also analyze whether there are other applicable incentive mechanisms besides a uniform discount rate which could discourage patents with negative welfare contribution to declare LOR, but maintain the incentives for patents with a positive one. One possibility is to design individual contracts for each patent owner combining high discount rates for early declarations with an early commitment to non-exclusive licensing, and low discount rates for declarations for older patents. A practical implementation would be to reduce the discount rate with the age of the patent at declaration. This mechanism could possibly ensure that patent owners take welfare optimizing decisions.

2.8 Appendix

2.8.1 Proofs

Proof of Lemma 2.1

For the proof of parts *(i)* and *(ii)* it suffices to show the properties for $\widetilde{V}^L(t, y_t)$ and $\widetilde{V}^K(t, r_t)$ in r_t. For a given LOR growth rate g_t^l the same properties apply for y_t.

Let a be the year of declaration (if chosen). Remember, $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l \mid t)$ are independent of returns and $y_t = g_a^l r_t = g_a^l g_t^k r_{t-1}$.

Proofs are done by induction.

(i)

Let's look at the last period $t = T$:

$\widetilde{V}^K(T, r_T) = r_T - f_T$ and $\widetilde{V}^L(T, y_T) = y_T - \frac{f_T}{2} = g_a^l r_T - \frac{f_T}{2}$ are clearly increasing in r_T.

Now, let's look at the periods $t < T$:

Assume that for an arbitrary $r < r'$: $\widetilde{V}^L(t+1, g_a^l g_{t+1}^k r) < \widetilde{V}^L(t+1, g_a^l g_{t+1}^k r')$.

Then, $\widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r) \leq \widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r')$

and $E\left[\widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r)\right] \leq E\left[\widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r')\right]$.

Then,

$\widetilde{V}^L(t, g_a^l r) = -\frac{f_t}{2} + g_a^l r + \beta E\left[\widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r)\right] <$

$< -\frac{f_t}{2} + g_a^l r' + \beta E\left[\widetilde{\widetilde{V}_L}(t+1, g_a^l g_{t+1}^k r')\right] = \widetilde{V}^L(t, g_a^l r')$.

Now, assume that for $r < r'$: $\widetilde{V}^K(t+1, g^k_{t+1}r) < \widetilde{V}^K(t+1, g^k_{t+1}r')$.

We know from above that $\widetilde{V}^L(t+1, g^l_t g^k_{t+1}r) < \widetilde{V}^L(t+1, g^l_t g^k_{t+1}r')$.

This means that $\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_t g^k_{t+1}r) \leq \widetilde{V_K}(t+1, g^k_{t+1}r', g^l_t g^k_{t+1}r')$

and $E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_t g^k_{t+1}r)\right] \leq E\left[\widetilde{V_K}(t+1, g^k_{t+1}r', g^l_t g^k_{t+1}r')\right]$.

Then,

$$\widetilde{V}^K(t,r) = -f_t + r + \beta E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_t g^k_{t+1}r)\right] <$$
$$< -f_t + r' + \beta E\left[\widetilde{V_K}(t+1, g^k_{t+1}r', g^l_t g^k_{t+1}r')\right] = \widetilde{V}^K(t,r').$$

(ii)

$\widetilde{V}^L(T, y_T)$ and $\widetilde{V}^K(T, r_T)$ are clearly continuous in r_T. To prove continuity in r_t for all t assume that $\widetilde{V_K}(t, r_t, y_t)$ and $\widetilde{V_L}(t, y_t)$ are continuous in r_t for an arbitrary t.

$\widetilde{V_K}(t-1, r_{t-1}, y_{t-1})$ and $\widetilde{V_L}(t-1, y_{t-1})$ will be continuous in r_{t-1} if $\widetilde{V}^K(t-1, r_{t-1})$ and $\widetilde{V}^L(t-1, y_{t-1})$ are continuous in r_{t-1}. In turn, $\widetilde{V}^K(t-1, r_{t-1})$ and $\widetilde{V}^L(t-1, y_{t-1})$ will be continuous in r_{t-1} if their option values $E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right]$ and $E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g^l_a\right]$ are continuous in r_{t-1}.

The option values will be continuous in r_{t-1} if for every sequence (r^n_{t-1}), such that $lim(r^n_{t-1}) = r_{t-1}$, we can show that

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r^n_{t-1}\right] = E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right] \text{ and}$$

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_L}(t, y_t) \mid r^n_{t-1}, g^l_a\right] = E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g^l_a\right].$$

Since $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l \mid t)$ are independent of r_t, it must be that

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r^n_{t-1}\right] =$$

$$= \int\int \lim_{r^n_{t-1} \to r_{t-1}} \left[\widetilde{V_K}(t, g^k_t r^n_{t-1}, g^l_t g^k_t r^n_{t-1})\right] dF_{g^k}(du^k \mid t) dF_{g^l}(du^l \mid t) =$$

$$= \int\int \left[\widetilde{V_K}(t, g^k_t r_{t-1}, g^l_t g^k_t r_{t-1})\right] dF_{g^k}(du^k \mid t) dF_{g^l}(du^l \mid t).$$

The last equality follows because $\widetilde{V_K}(t, r_t, y_t)$ is continuous in r_{t-1} (remember that $y_t = g^l_t g^k_t r_{t-1}$ and $r_t = g^k_t r_{t-1}$ are both continuous in r_{t-1}).

The proof for

$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_L}(t, y_t) \mid r^n_{t-1}, g^l_a\right] = E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g^l_a\right]$ is identical.

(iii):

In $t = T$ the option value is always 0. The option value in $t = T - 1$ must be at least 0 since the patentee has always the choice to let the patent expire (X). Let's hold r and g^l fixed. Since the renewal fees are increasing in t, it must be that $\widetilde{V}^K(T-1, r) \geq \widetilde{V}^K(T, r)$ and $\widetilde{V}^L(T-1, y) \geq \widetilde{V}^L(T, y)$.

By assumption, $F_{g^l}(u^l \mid t)$ and $F_{g^k}(u^k \mid t)$ are increasing in t (in the sense of first-order stochastic dominance) making higher growth rates less likely for older patents. Thus, the property that $\widetilde{V}^K(t-1, r) \geq \widetilde{V}^K(t, r)$ and $\widetilde{V}^L(t-1, y) \geq \widetilde{V}^L(t, y)$ must hold for the general case:

Assume that $\widetilde{V}^L(t+1, y) \leq \widetilde{V}^L(t, y) \Rightarrow \widetilde{V_L}(t+1, y) \leq \widetilde{V_L}(t, y)$.

Thus,

$E\left[\widetilde{V_L}(t+1, g^l g^k_{t+1} r)\right] \leq E\left[\widetilde{V_L}(t, g^l g^k_t r)\right]$, since $F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1)$.

Then,

$$\widetilde{V}^L(t,y) = -\tfrac{f_t}{2} + y + \beta E\left[\widetilde{V_L}(t+1, g^l g^k_{t+1} r)\right] \leq$$
$$\leq -\tfrac{f_{t-1}}{2} + y + \beta E\left[\widetilde{V_L}(t, g^l g^k_t r)\right] = \widetilde{V}^L(t-1,y).$$

Now, assume that $\widetilde{V}^K(t+1,r) \leq \widetilde{V}^K(t,r)$.

We know that $\widetilde{V}^L(t+1,y) \leq \widetilde{V}^L(t,y)$ and thus it must be that

$\widetilde{V_K}(t+1,r,y) \leq \widetilde{V_K}(t,r,y)$.

Therefore,

$E\left[\widetilde{V_K}(t+1, g^k_{t+1} r, g^l_{t+1} g^k_{t+1} r)\right] \leq E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right]$,

since $F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1)$ and $F_{g^l}(u^l \mid t) \leq F_{g^l}(u^l \mid t+1)$.

With $f_{t-1} < f_t$, we can easily conclude that

$$\widetilde{V}^K(t,r) = -f_t + r + E\left[\widetilde{V_K}(t+1, g^k_{t+1} r, g^l_{t+1} g^k_{t+1} r)\right] \leq$$
$$\leq -f_{t-1} + r + E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right] = \widetilde{V}^K(t-1,y).$$

Proof of Proposition 2.1

(i)

In this case the patentee is indifferent between (L) and (X). We know that the value function $\widetilde{V}^L(t, g_t^l r)$ is weakly increasing in returns r. Thus, if the per period returns from full patent protection are increasing, $\hat{g}^{l-}$ must be decreasing with r to maintain the equality in $\widetilde{V}^L(t, \hat{g}_t^{l-} r) = 0$.

(ii)

The patent owner has to choose between (K) and (L).

Consider the last period T:

One can easily calculate that $\hat{g}_T^{l+} = 1 - \frac{f_T}{2r}$ and increasing in r.

The higher r, the smaller is the cost reduction relative to possible losses in patent returns due to the LOR declaration.

Now, consider period $t < T$:

$\hat{g}_t^{l+}$ is defined as

$$\widetilde{V}^K(t, r) - \widetilde{V}^L(t, \hat{g}_t^{l+} r) = -\tfrac{f_t}{2} + r - \hat{g}_t^{l+} r +$$
$$+\beta \left\{ E\left[\widetilde{V_K}(t+1, g_{t+1}^k r, g_{t+1}^l g_{t+1}^k r)\right] - E\left[\widetilde{V_L}(t+1, g_{t+1}^k r, \hat{g}_t^{l+} g_{t+1}^k r)\right]\right\} = 0.$$

After applying the implicit function theorem:

$$\frac{\partial \hat{g}_t^{l+}}{\partial r} = -\frac{\partial(\widetilde{V}_t^K(.) - \widetilde{V}_t^L(.))/\partial r}{\partial(\widetilde{V}_t^K(.) - \widetilde{V}_t^L(.))/\partial \hat{g}_t^{l+}} = \frac{1 - g_t^l + \beta \frac{\partial \left\{ E\left[\widetilde{V_K}(.)\right] - E\left[\widetilde{V_L}(.)\right]\right\}}{\partial r}}{r + \beta \frac{\partial E\left[\widetilde{V_L}(.)\right]}{\partial \hat{g}_t^{l+}}}$$

The expression will be positive if and only if

$$1+\beta\frac{\partial\left\{E\left[\widetilde{V_K}(.)\right]-E\left[\widetilde{V_L}(.)\right]\right\}}{\partial r} > \hat{g}_t^{l+}.$$

As long as this inequality holds, $\hat{g}_t^{l+}$ will be increasing in r. This will in turn depend on the exact stochastic specification of the model, especially on how we model the distributions of the growth rates.

Proof of Proposition 2.2

Take an arbitrary g^l. The cut-off value $\hat{r}_t$ is defined as $\widetilde{V}^K(t,\hat{r}_t)=0$ and $\hat{r}_{t+1}$ as $\widetilde{V}^K(t+1,\hat{r}_{t+1})=0$. From Lemma 2.1 we know that $\widetilde{V}^K(.)$ is increasing in r and non-increasing in t. Thus, to maintain equality in both equations it must be that $\hat{r}_{t+1}\geq\hat{r}_t$.

Proof of Proposition 2.3

(i)

In this case the patent owner is indifferent between (L) and (X). We know from Lemma 2.1 that $\widetilde{V}^L(t,y_t)$ is increasing in r_t and non-increasing in t. Thus, if we take the same returns $r_t=r_{t+1}=r$ in two consecutive periods, then $\hat{g}_t^{l-}(r)$, which is defined as the solution to

$$\widetilde{V}^L(t,y)=\hat{g}_t^{l-}r-\tfrac{1}{2}f_t+\beta E\left[\widetilde{V_L}(t+1,\hat{g}_t^{l-}g_{t+1}^k r)\right]=0,$$

must be at least as large as $\hat{g}_{t-1}^{l-}(r)$.

(ii)

The patent owner is indifferent between (L) and (K) if $g_t^l=\hat{g}_t^{l+}$. The cut-off function $\hat{g}_t^{l+}(r_t)$ is implicitly defined in

$$\widetilde{V}^L(t,\hat{g}_t^{l+}r_t)=\hat{g}_t^{l+}r_t-\tfrac{1}{2}f_t+\beta E\left[\widetilde{V_L}(t+1,\hat{g}_t^{l+}g_{t+1}^k r_t)\right]=$$

$$=r_t-f_t+\beta E\left[\widetilde{V_K}(t+1,g_{t+1}^k r_t,g_{t+1}^l g_{t+1}^k r_t)\right]=\widetilde{V}^K(t,r_t).$$

Let's look at the last two periods and assume that $r_{T-1} = r_T = r$ and $y_{T-1} = y_T = y$ ($g^l_{T-1} = g^l_T$).

The option values in the last period are always 0 and we can easily calculate:

$\hat{g}^{l+}_T(r_T) = 1 - \frac{f_T}{2r}$.

Let's look whether $\hat{g}^{l+}_T(r) \leq \hat{g}^{l+}_{T-1}(r)$.

Since $E\left[\widetilde{V_L}(T, g^l_{T-1} g^k_T r)\right]$ is increasing in g^l_{T-1} we have to show that

$\widetilde{V}^K(T-1, r) - \widetilde{V}^L(T-1, \hat{g}^{l+}_T r) \leq 0$ (with $\hat{g}^{l+}_T(r) = 1 - \frac{f_T}{2r}$).

We know that

$\widetilde{V}^K(T-1, r) - \widetilde{V}^L(T-1, \hat{g}^{l+}_T r) =$

$r - f_{T-1} + \beta E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - \hat{g}^{l+}_T r + \frac{f_{T-1}}{2} - \beta E\left[\widetilde{V_L}(T, \hat{g}^{l+}_T g^k_T r)\right] =$

(after inserting $\hat{g}^{l+}_T(r_T) = 1 - \frac{f_T}{2r}$)

$= \frac{f_T}{2} - \frac{f_{T-1}}{2} + \beta\left\{E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - E\left[\widetilde{V_L}(T, (1 - \frac{f_T}{2r}) g^k_T r)\right]\right\} =$

$= \frac{f_T}{2} - \frac{f_{T-1}}{2} + \beta\left\{E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - E\left[\widetilde{V_L}(T, g^k_T (r - \frac{f_T}{2}))\right]\right\}.$

Already for the last two periods we see that whether $\hat{g}^{l+}_T(r) \leq \hat{g}^{l+}_{T-1}(r)$ will depend on whether the term $E\left[\widetilde{V_K}(T, g_T^k r, g_T^l g_T^k r)\right] - E\left[\widetilde{V_L}(T, g_T^k(r - \frac{f_T}{2})\right]$ will exceed the cost difference $\frac{f_T}{2} - \frac{f_{T-1}}{2}$. This in turn will depend on the exact stochastic specification as well as the fee structure.

2.8.2 Renewal Fee Schedules for Cohorts 1983-1988

year	before January 01, 2002	after January 01, 2002
1	0	0
2	0	0
3	51.13	70
4	51.13	70
5	76.69	90
6	115.04	130
7	153.39	180
8	204.52	240
9	255.65	290
10	306.78	350
11	409.03	470
12	536.86	620
13	664.68	760
14	792.50	910
15	920.33	1060
16	1073.71	1230
17	1227.10	1410
18	1380.49	1590
19	1533.88	1760
20	1687.26	1940

Table 2.6: Renewal Fee Schedules in €

2.8.3 Parametric Bootstrap

Since we do not know the empirical distribution of the observed hazard rates we will apply a parametric bootstrap method to estimate the standard errors of the parameters ω. Instead of simulating bootstrap samples that are i.i.d. from the empirical distribution as it is done in non-parametric bootstrap methods, we simulate bootstrap samples that are i.i.d. from the estimated parametric model. Following Efron and Tibshirani (1993) we apply the following bootstrap algorithm:

1. Use the estimated parameters $\hat{\omega}^*$ and generate a random sample of N patents.
2. Simulate the decisions resulting from the model specification and obtain the sequence of pseudo hazard rates $\eta(\hat{\omega}^*)$.
3. Minimize the loss function in function 2.3 using $\eta(\hat{\omega}^*)$ instead of h_N and obtain $\hat{\omega}_b^*$.
4. Repeat steps 1.-3. B times.
5. Calculate the parametric bootstrap estimate of the standard errors:

$$\hat{se}_B = \left\{ \frac{\sum_{b=1}^{B} \left[\hat{\omega}_b^* - \hat{\omega}^*(.)\right]^2}{(B-1)} \right\}^{\frac{1}{2}}, \text{ where } \hat{\omega}^*(.) = \frac{\sum_{b=1}^{B} \hat{\omega}_b^*}{B}$$

2.8.4 Model with Learning

In our second approach, we allow for learning. The difference to the deterministic model is that the growth rate of returns from full patent protection g_t^k is not constant anymore. We assume that the patentee can discover a new use or another way how to exploit his invention and increase his returns. This dynamic approach follows closely the models in Pakes (1986), Lanjouw (1998), and Deng (2011). In this specification the growth rate g_t^k may exceed the minimum growth rate $\delta < 1$. Therefore, we model g_t^k as the maximum of either the constant growth rate δ, or an alternative growth rate u^k, such that $g_t^k = max(\delta, u^k)$. We assume that u^k is drawn randomly from an exponential distribution:

$$q^k(u^k \mid t) = \frac{1}{\sigma_t^k} exp(-\frac{u^k}{\sigma_t^k}) \tag{2.6}$$

Since the probability of getting higher returns is supposed to decrease with a patent's maturity, the standard deviation σ_t^k of the random growth rate u^k is set to $\sigma_t^k = (\phi^k)^t \sigma_0^k$, with $\phi^k \leq 1$ and $t \in 1, ..., T$.

The parameters ϕ^k and σ_0^k both determine how fast learning vanishes. Since renewal fees in the early periods are low, they also determine when hazard proportions of expiration start to exceed the obsolescence rate. Besides, if learning vanishes fast, the cost advantage of the LOR declaration will gain in importance throughout all years and this will shift the $HR^L(t)$-curve upwards. The parameter δ mainly determines the variation in hazard proportions for ages when learning has already vanished or when patents get closer to their expiration date. The variance of the distribution of initial returns, σ_{IR}, particularly affects the curvature of $HR^X_{NoLOR}(t)$ and $HR^X_{LOR}(t)$. Higher values of σ_{IR} imply a more skewed distribution of patent returns which cause higher dropout rates for intermediate ages and lower dropout rates for higher ages, when renewal fees are highest. Lower values of σ_{IR} have the opposite effect.

Together with the probability of not becoming obsolete, θ, the parameters that determine the distribution of initial returns, μ_{IR}, σ_{IR}, and the parameters that determine the LOR growth rates, ϕ^l, σ_0^l, the model with learning depends on eight structural parameters:

$$\mu_{IR}, \sigma_{IR},\ \theta,\ \phi^l, \sigma_0^l,\ \phi^k, \sigma_0^k, \delta$$

The estimation results are presented in Table 2.7.

Although the reported mean square error (MSE) is higher compared to the deterministic model the overall model fit is slightly improved. MSE was calculated without using

Parameter	Model with Learning (Stochastic)
β (fixed)	0.950
μ_{IR}	8.787
σ_{IR}	1.654
θ	0.920
θ_{1998}	0.978
θ_{2002}	0.832
δ	0.976
ϕ^k	0.202
σ_0^k	0.948
ϕ^l	0.461
σ_0^l	3.399
Age-Cohort Cells	282
Sample Size	211,869
Simulation Size	635,607
MSE_{All}	0.000973
$Var_{All}(h_N)$	0.0055
$1 - MSE_{All}/Var_{All}(h_N)$	0.8233

Table 2.7: Parameter Estimates

the weights we had put on the hazard proportions for estimation (matrix $A(\omega)$ in the objective function (2.3)). Graphically, the hazard proportions of expiration do not differ much between both models (see Figures 2.8-2.10). However, the stochastic model allows the hazard rates of declaration to rise more clearly for the years seven to twelve.

Compared to the deterministic model (see Table 2.3) we receive higher estimates for the parameters which determine the distribution of the initial returns, μ_{IR} and σ_{IR}. Therefore, the mean initial value (25,638€) and the median initial value (6,534€) are higher. Furthermore, we confirm the result from previous patent renewal studies that learning possibilities for patents, defined as $Pr(g_t^k \geq \delta)$, disappear after age five (see Table 2.8). Overall, we obtain value distributions with higher mean values for the stochastic model (see Table 2.9). The average value of patent protection is 300,415€. This is surprising, since in previous patent renewal studies the patent value estimates from the stochastic models (Pakes 1986; Lanjouw 1998) were lower than the ones from the deterministic models (Schankerman and Pakes 1986; Schankerman 1998).

A possible explanation for the discrepancy could be found in how we constructed the weighting matrix $A(\omega)$ in the objective function (2.3). Since the hazard proportions of declaration are at least ten times smaller than the hazard proportions of expiration we have increased the weights given to the distance between sample and simulated hazard proportions of declaration. Since our focus lies on the license of right system and the value of exclusivity, we thereby tried to improve the efficiency of estimating the distribution of the parameters associated with the LOR growth rates. This might have undermined the

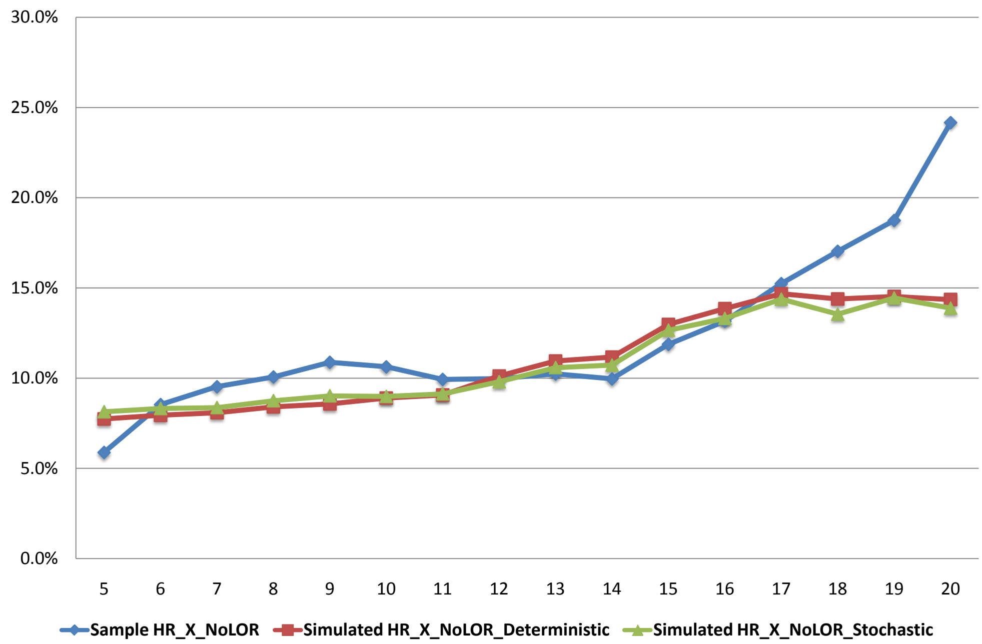

Figure 2.8: Hazard Proportions of Expiration for Patents Not Endorsed LOR

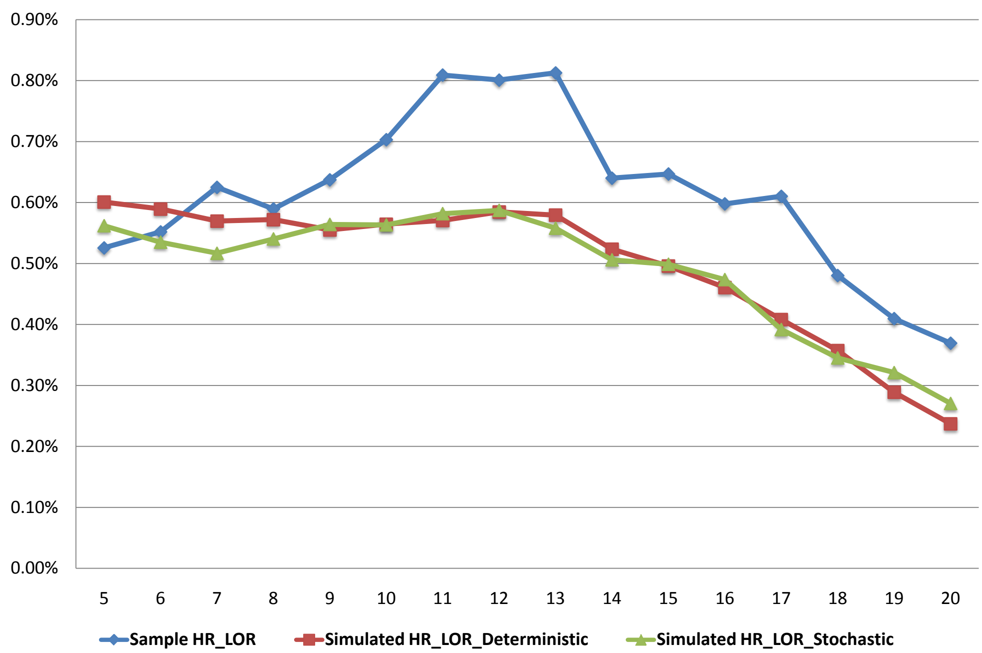

Figure 2.9: Hazard Proportions of LOR Declaration

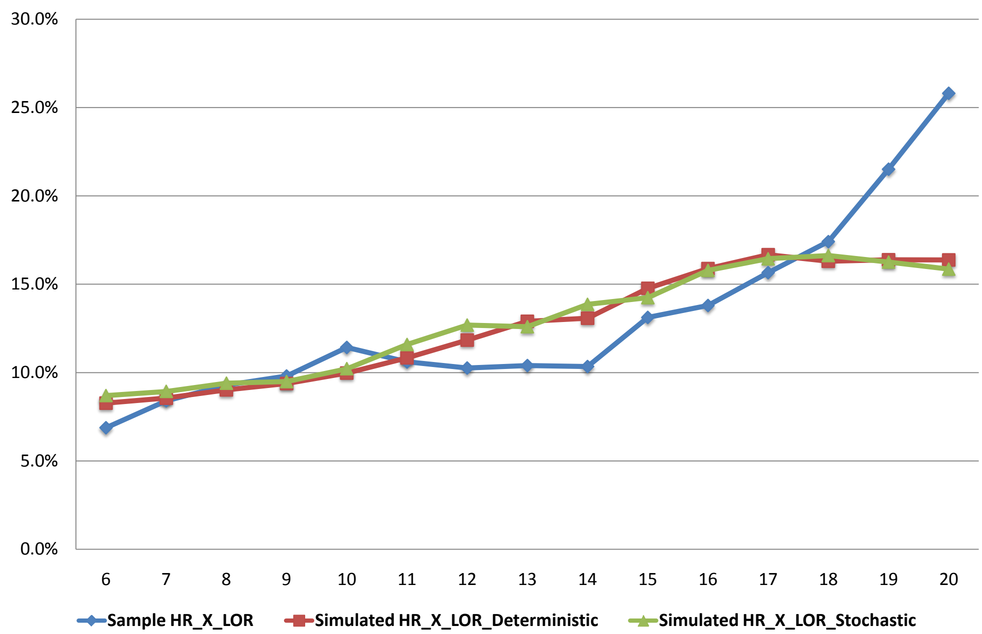

Figure 2.10: Hazard Proportions of Expiration for Patents Endorsed LOR

efficiency of estimating the parameters that determine the variation in returns from full patent protection, μ_{IR}, σ_{IR} and ϕ^k, σ_0^k. Besides, the stochastic model is computationally more costly, since double integrals have to be evaluated numerically. Therefore, it was not possible to run the global optimization algorithms, which rely on random search, enough times to ensure that the estimator did not get stuck in a local optimum. In the deterministic model, in turn, the variation in returns from full patent protection is completely determined by the parameters of the distribution of initial returns, μ_{IR} and σ_{IR}. Furthermore, since we do not have to evaluate double integrals, we have performed enough runs to believe that we have obtained robust results.

Age	2	3	4	5	6	7
$Pr(g_t^k \geq \delta)$	26.88%	5.77%	0.21%	<0.01%	0.00%	0.00%

Table 2.8: Learning and Patent Age

Nevertheless, the main results obtained from the deterministic model remain valid. Patents for which LOR has been declared are on average 21.74% less valuable than patents which have never been endorsed LOR. Furthermore, on average, 64.42% of the value of patents for which LOR had been declared was generated after the declaration. Since the estimated parameters which determine the LOR growth rates, ϕ^l and σ_0^l, do not differ much between both models, we obtain a similar distribution of the value of (non-) exclu-

Percentile	at Age 10	at Age 5	at Age 1		
	All		All	No LOR	Endorsed LOR
50	0	14,405	56,144	57,569	39,082
75	19,256	87,867	200,108	204,275	131,080
90	113,525	317,003	602,521	610,462	450,369
95	258,759	652,934	1,164,599	1,176,564	952,350
99	1,045,241	2,370,391	3,931,909	3,960,412	3,495,881
99.9	4,563,423	9,798,748	15,373,407	15,396,543	14,666,449
Mean	62,758	160,938	300,415	304,182	238,049

Table 2.9: Value Distributions for Cohort 1983 in 2002€ (Stochastic Model)

sivity (see Table 2.10). Almost 8% of patents could maintain at least 50% of the returns from full patent protection if they declared LOR in the first year and only less than 2% if they declared in the twentieth year. Some patents, 0.63%, could even increase their returns if they gave up exclusivity in the first year and less than 0.03% if they gave up exclusivity in the last year.

Age	$Pr(g_t^l \geq 1)$	$Pr(g_t^l \geq 0.75)$	$Pr(g_t^l \geq 0.5)$
1	0.63%	2.25%	7.96%
2	0.56%	2.04%	7.48%
3	0.49%	1.86%	7.01%
4	0.43%	1.68%	6.56%
5	0.38%	1.52%	6.14%
6	0.33%	1.37%	5.73%
...	...	...	...
18	0.05%	0.32%	2.16%
19	0.04%	0.28%	1.96%
20	0.03%	0.24%	1.78%

Table 2.10: Evolution of LOR Growth Rates (Stochastic Model)

The welfare implications also do not differ. Compared to the deterministic model the fraction of unambiguously welfare decreasing declarations (Cost-Saving Motive) is somewhat higher for early declarations and lower for declarations made for older patents (see Table 2.11). If we excluded the possibility to declare LOR from the patent system the aggregated private value of patent rights would fall by 0.47% but the patent office's revenues would rise by 2.31%. If we made the LOR declaration compulsory for all patents (Compulsory Licensing) the aggregated private value of patent rights would fall by 80.44%.

Age	1-5	6-10	11-15	16-20	1-20
Cost-Saving Motive	0.31%	4.44%	11.12%	16.57%	4.17%
Commitment Motive	99.69%	95.56	88.88	83.43	95.83%

Table 2.11: Motive for LOR Declaration (Stochastic Model)

Chapter 3

Deferred Patent Examination

3.1 Introduction

Traditionally, the literature on the economics of innovation (e.g., Pakes and Schankerman 1984; Pakes 1986; Schankerman and Pakes 1986; Lanjouw 1998) has exploited post-grant patent renewals to analyze the value of patents and its role in incentivizing R&D (Cornelli and Schankerman 1999; Scotchmer 1999). We refer to patent renewal as a patentee's decision to pay the required maintenance fees to maintain an already issued patent right. These fees are charged by the national patent offices and are due at several points in the life of a patent. However, the patent term does not start with the date a patent is granted but already with the filing date of the patent application.[95] Prior to the grant a patent application has to be examined. Additionally, most patent offices allow to defer the examination request for several years. Indeed, many patents exist longer as a pending application than as a granted patent. Nevertheless, the timing issues in the early stages of a patent's life have largely been neglected.

This paper addresses the research gap by providing a structural model of the application, examination, and renewal process in patent offices. By extending previous models with an option to defer patent examination and by modeling examination itself in detail, we provide a much richer foundation for patent valuation and for policy simulations than previous studies have done. Under deferred examination, applicants have the option of requesting examination at some point in time. Patent offices may differ with respect to the time period during which examination can be requested as well as to the fees associated with examination and the maintenance of patent filings. While a few patent offices, notably the USPTO (US Patent and Trademark Office), follow a policy of automatic and–

[95] Prior to 1995 the patent term in the US was 17 years following the grant date but was modified to 20 years following the patent application date.

if possible–immediate examination, other offices such as the German patent office offer applicants a time period of up to seven years during which they can request examination.[96] The timing of examination constitutes one of the most startling institutional differences between different patent systems, but it has not received much attention so far.[97]

The framework will further allow us to contribute to the academic debate on how to handle patent backlogs. In the last three decades the number of patent filings has risen substantially: partially due to the increased tactical and strategic importance (Hall and Ziedonis 2001; F.T.C. 2003; N.R.C. 2004) and partially due to the lower costs and availability of patent protection (Harhoff 2006; Guellec and van Pottelsberghe 2007; Bessen and Meurer 2008). As a consequence, the patent workload has increased substantially giving reason for concern about its impact on examination quality. Deferred patent examination may constitute a solution to the problem. This system was first introduced by the Dutch government on January 1, 1964 as a reaction to the vast amount of unexamined and pending patent applications. They observed that many patents lapsed already shortly after grant despite low renewal fees. The possibility to defer the examination request for up to seven years allowed the patentees to abandon applications with no commercial value without any examination. Indeed, Yamauchi and Nagaoka (2008), who try to explain the rapid increase in the number of requests for patent examination in Japan in the recent decade, conclude that one of the causes of the increase was the shortening of the period of examination requests. The workload of examiners in Japan has been increased with low quality patents.

Opting for fast examination entails a number of advantages. The main argument is that uncertainty for users of the system is reduced quickly. Both applicants and their rivals will learn soon after the filing date about the actual delineation of patent claims and possible infringement, and they may then adapt their investments accordingly. The argument that uncertainty over examination outcomes and long pendencies have negative consequences is intuitively appealing and has found some empirical support (Gans et al. 2008). Some practitioners have argued that applicants are intentionally increasing the volume and complexity of their filings, frequently delay the examination process, and thus create uncertainty for other users of the system.[98] They argue that such delay tactics should be sanctioned by patent offices.

However, delayed examination has advantages, too. Giving applicants additional time for

[96]The USPTO recently announced a move towards deferred examination and to let applicants choose from three examination tracks: the examination timing as previously offered, a fast-track option for applicants seeking fast examination (similar to the option of accelerated examination at the EPO), and finally a three-year deferment option. During this time period the USPTO would not undertake any substantive examination. (Cf. http://www.uspto.gov/news/pr/2011/11-24.jsp for details.)

[97]See Harhoff (2012) for a more detailed description of deferment systems in 35 countries.

[98]See McGinley (2008), Opperman (2009), and Harhoff and Wagner (2009).

assessing the value of their patents may lead them to drop out of the examination process voluntarily, and thus reduce examination workloads. While this effect has been discussed in the literature for some time, it has not been captured in structural models of patent examination. In comparison to the classical models of patent renewal, a model of deferred examination has to allow for three possible decisions: to request examination, to defer examination, and to let the application (respectively the granted patent) lapse altogether. We embed these three choices in a model of applicant decision-making, allowing the applicant to make optimal decisions in each period, given the information he has received so far, his knowledge of the overall distribution of patent value, and its expected evolution over time. Aside from adding an important feature to the choice set of applicants, we also employ a more detailed model of patent examination in which the applicant may drop the application after receiving a signal from the examiner. We allow unexamined patent applications to differ in terms of value from examined and granted applications. In the empirical part of our paper, we use data from the Canadian patent office (CIPO) to estimate the parameters of the value distribution of Canadian applications and of the learning process.

Our estimates of patent value match those of earlier studies. Furthermore, results reveal that the private value of having a pending application is substantial. The returns from just having an unexamined patent application exceed the costs for keeping it in force for the majority of the applicants, even if they will never get a patent granted. The model estimates also provide insights into the learning process during the application and examination stages. Learning possibilities are relatively high and deteriorate only slowly over time.

Additionally, we employ the parameter estimates to estimate the impact of deferment on patent office workload and on the value of unexamined as well as granted applications. The policy experiments indicate that each additional year of deferment would significantly reduce the number of examination requests, and hence the workload. Also, the additional time would diminish the uncertainty about the value of inventions for which patent protection is sought, allowing for the correct decision on whether to request examination. As a consequence, the option to defer the examination request for one additional year increases the value of unexamined and granted applications.

The analysis is presented in four sections. In Section 2, we develop a structural model of deferred examination and patent renewals. Our data are described in Section 3, the estimation approach is presented in Section 4. We conduct two simulation experiments that allow us to identify the impact of changes in the deferment period on patent value and on patent office workload. Section 5 concludes with a summary and a discussion.

3.2 Structural Model

In this section we first describe the general setup of the model, explain the structure of the patent system, how patent applicants derive profits, and their information structure. Subsequently we describe their optimization problem and how it can be solved.

3.2.1 General Setup

Patent system We construct a model of patent examination and renewal in which applicants have the option to defer examination. In this section we describe the general setup of this model. Before an agent can get patent protection for his invention he first needs to file an official application at the patent office and pay the corresponding application fees C_{PO}^{Appl}. Modern patent systems require a patent to fulfill certain patentability criteria, such as novelty and inventiveness. The application is subject to a substantive examination before the patent is granted.[99] We assume that examination has to be requested by the applicant within L years from the application day.[100] This means that we allow the agent to defer the examination and the associated fees for examination C_{PO}^{Exam} for up to L years (maximum deferment term). However, deferment is not free of charge and the agent has to pay fees c_t^A $(t \in 1, ..., L)$ to maintain the application pending for one more year. We assume that once examination had been requested it takes S years for the patent examiner to completely resolve the case and to provide the final decision on the patentability of the invention. If examination had been requested and the application has successfully passed the examination process the applicant can finally get the patent issued if he pays the final fee C_{PO}^{Grnt}. A patent gives the patentee the right to exclude others from using the patented invention. The patent right can be renewed for up to T years (maximum patent term) from the application date on as long as the patent owner pays the yearly renewal fees c_t^G $(t \in 1, ..., T)$ for the granted patent. We assume that the maintenance fees for an application and a patent are the same $c_t^A = c_t^G = c_t$ $(t \in 1, ..., T)$, and that they are non-decreasing in t. If any of the fees are not paid to the patent office the application or patent expires irrevocably.

Returns The right to exclude others allows the patentee to generate non-negative returns r_t in every year the invention is protected by the patent. Since the exclusivity right is not enforceable before the patent is finally granted, we assume that the owner of a pending application is only able to realize a part $0 < q < 1$ of the returns of an already

[99]Registration systems without ex ante examination still exist in some countries, in particular for utility models.
[100]We assume that all decisions are made at the beginning of a year.

granted application, qr_t. The parameter q must be positive, since a pending application can already create value for its owner, e.g., by creating uncertainty for competitors or forming the basis for negotiations.[101]

The returns from patent protection evolve in the following way over time. The potential returns from patent protection in the first period, r_1, are drawn i.i.d. from a continuous distribution F_{IR} on a positive domain. In the next period the value from patent protection might increase or decrease depending on the information the owner obtains about his invention. The new information is represented by a growth rate $g_t \in [0, B]$ which is drawn from a distribution with the cumulative density function $F(u \mid t) = Pr\,[g_t \leq u \mid t]$. Thus, the returns in the second period are $r_2 = g_2 r_1$, and $r_t = g_t r_{t-1}$ in the following ones. Since the probability to learn how to increase the returns from patent protection should be higher for younger patents, we assume that the probability of having a high growth rate g_t decreases with a patent's maturity in the sense of first-order stochastic dominance $(F(u \mid t) \leq F(u \mid t+1))$.[102]

Before a patent is granted it has to pass an examination at the patent office. During this procedure the examiner has to verify whether the application fulfills the patentability criteria. He may require the applicant to change the patent specification, or he may even reject the application. This means that the distributions of growth rates of examined or granted patents might be different from the ones of pending applications. In the following let $g_t^A \sim F^A(u^A \mid t)$ denote the growth rate in case of a pending and unexamined patent application, and $g_t^G \sim F^G(u^G \mid t)$ in case of an examined or granted patent application. To account for cases when a patent application becomes absolutely worthless economically due to obsolescence, we assume that in every period with some probability $1-\theta$ all future returns can become a zero sequence. We allow the obsolescence rate to be the same for pending as well as granted applications.

Agents We assume that every patent application belongs to exactly one profit maximizing agent. This means that in every period the agent always chooses the strategy with the highest expected payoff given his information structure.

At the beginning of a period the growth rate g_t^A, respectively g_t^G, is revealed to the agent, so that he knows the potential returns r_t from patent protection for this period. Furthermore, we assume that he also knows the distributions of all future growth rates, and thus is able to build expectations on how the returns will evolve in the future. Since

[101] Patent owners are entitled to licensing fees from the day of publication. With the grant of the patent, they can also seek injunctions against potential infringers.

[102] Usually, the use of an invention should be determined early in a patent's life. The probability to discover new uses in later periods should accordingly be lower.

the distributions of growth rates from patent protection are exposed to an unexpected shock during patent examination, the patent applicant has to readjust his expectations about future growth rates. We assume that this change in expectations is not anticipated by the applicant. Practically, this means that if the applicant has not yet requested application in period x, his growth rate is drawn from $F^A(u^A \mid x)$, and he expects the growth rates of patent returns to be distributed according to $F^A(u^A \mid t > x)$ in the future periods. Once he requests examination and receives a response on the patentability of the application from the patent office, he has to adjust his expectations on the evolution of returns from patent protection according to what was considered patentable by the examiner. Therefore the growth rates for subsequent periods are drawn from $F^G(u^G \mid t)$. Usually, the value of a patent application is very uncertain. It is not only uncertain whether the patented invention will have any commercial value but also whether the application can fulfill the patentability requirements. Whereas the economic uncertainty may remain throughout the life of the patent, the latter, technical uncertainty can be resolved through examination. Hence, F^A and F^G should differ.

The fees which have to be paid to the patent office are only a part of the costs which are necessary to obtain a patent. Usually, an applicant has to invest resources in addition to the statutory fees. To properly model the choices of a representative agent during the life of a patent application we have to account for the cost of filing a patent application C_{self}^{Appl} (search, draft, translation) as well as the cost incurred during the examination proceeding C_{self}^{Exam} (negotiations with the examiner are usually conducted with the aid of a patent attorney).

3.2.2 Value Functions and the Maximization Problems

As described above, the life of a patent application comprises three parts:

- the application stage, in which the agent has to decide whether to apply for patent protection and, if he does, whether and when to request examination;
- the examination stage, in which the agent has to decide whether his application will be fully examined and granted, or withdrawn during the examination process;
- the patent stage, in which the agent has to decide whether to renew patent protection or to let it lapse before the expiration of its full term.

Since the model has a final horizon, the statutory patent term T, and returns are conditional only on returns in the previous age, we will see that the model can be solved recursively starting from the final age. Therefore, we continue in reverse chronological order by first analyzing the patent stage, then the examination stage, and lastly the application stage.

Patent stage If a patent is already granted at the beginning of period t the owner has to decide whether he wants to keep patent protection (K) until next period or to let it irrevocably expire (X). His choice will depend on his expected value from both strategies $\widetilde{V}^K(t, r_t)$ and $\widetilde{V}^X(t, r_t)$. The value of an expired patent is always zero, $\widetilde{V}^X(t, r_t) = 0$. The expected revenue from renewing a granted patent is the sum of current returns from patent protection r_t, less the maintenance fees c_t plus the option value of being able to renew patent protection in the next period $E\left[\widetilde{V_K}(t+1, r_{t+1}) \mid r_t\right]$.[103] With β as the discount factor between periods the value function is:

$$\widetilde{V}^K(t, r_t) = r_t - c_t + \beta\theta E\left[\widetilde{V_K}(t+1, r_{t+1}) \mid r_t\right] \tag{3.1}$$

with

$$\widetilde{V_K}(t+1, r_{t+1}) = max\left[\widetilde{V}^K(t+1, r_{t+1}), \widetilde{V}^X(t, r_t)\right]$$

and

$$E\left[\widetilde{V_K}(t+1, r_{t+1}) \mid r_t\right] = \int \widetilde{V_K}(t+1, u^G r_t) dF^G(u^G \mid t)$$

Since the agent's choice in every period is discrete, there exists a threshold return $\hat{r}_t$ for each period t that determines the patent owner's optimal decision (see Figure 3.1):

- $\left\{\hat{r}_t^K\right\}_{t=S+1}^{T}$: minimum patent returns needed for an agent to decide to keep (K) patent protection in period t and not to let it expire (X). This is the solution to $\widetilde{V}^K(t, r_t) = \widetilde{V}^X(t, r_t) = 0$.[104]

In period $t = T$ the option value is zero since the patent cannot be renewed anymore. Thus, the cut-off value in the last period is $\hat{r}_T^K = c_T$.

Examination stage There are two ways to model the examination stage. Assume that a complete examination of a patent application takes S years. During this time period

[103] $\widetilde{V}^K(t, r_t)$ denotes the value function if strategy K is chosen in year t. In contrast, $\widetilde{V_K}(t, r_t)$ denotes the value function if strategy K was chosen in the previous year $t-1$ and the value maximizing strategy is chosen subsequently in year t. The optimal subsequent strategy doesn't have to be K.

[104] The proof that $\widetilde{V}^K(t, r_t)$ is continuous and increasing in r_t, and decreasing in t can be found in Pakes (1986). These properties ensure that the sequence $\left\{\hat{r}_t^K\right\}_{t=1}^{T}$ exists and is increasing in t.

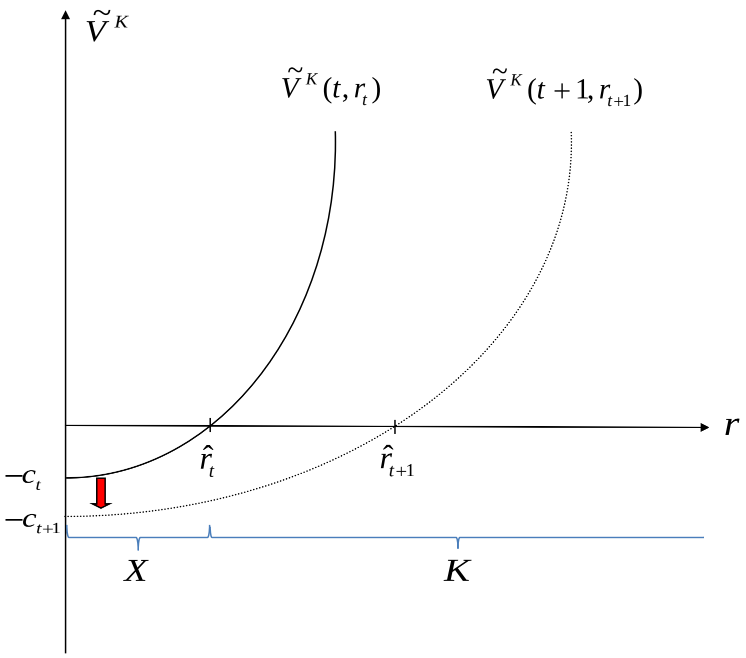

Figure 3.1: Value Functions and Cut-off Values - Patent Stage

the examiner searches for prior art and studies the claims in the patent application. He either approves but more often objects to some or all claims. The examiner's objection will be outlined in a report or letter called a patent office action. The applicant has to respond to the examiner's objections and requirements whereupon the examiner further reconsiders and either approves or calls for further amendments. Only if the applicant has met all requirements and overcome all objections raised by the examiner the patent application will be allowed. Once the application has been allowed the applicant usually has to pay an additional granting fee for the patent to issue.

One way to model the examination stage is to look at it as a process where the applicant has the choice at the beginning of each period to continue the examination (CE) and incur the respective costs, or to withdraw his application (W) during an ongoing examination. Moreover, if the application has finally been approved as patentable, the applicant has to confirm the grant (G) by paying the granting fees C_{PO}^{Grnt} or he can still let it expire. As already explained above, during the examination process the expectation of how the future returns from patent protection evolve might change. We assume that the applicants adjust their distributions of future growth rates right upon the receipt of the first substantive action from the examiner. This action provides new information on what is actually allowed to be granted from the examiner's perspective and is issued s ($s < S$) periods after the examination has been requested. The first action is followed by a (costly) dispute between the applicant (or representative patent attorney) and the examiner for $S - s$ remaining periods. We assume that these costs C_{self}^{Exam} are incurred in equal parts during these periods.

Assume that examination was requested in period $t = a$. We consider the grant decision in period $a + S$ first. If the applicant withdraws the examined application, then $\widetilde{V}^W(a + S, r_{a+S}) = 0$. If instead he wants the patent to be granted he will have to incur costs $c_{a+S} + C_{PO}^{Grnt}$:

$$\widetilde{V}^G(a + S, r_{a+S}) = r_{a+S} - (c_{a+S} + C_{PO}^{Grnt}) + \beta\theta E\left[\widetilde{V_K}(a + S + 1, r_{a+S+1}) \mid r_{a+S}\right] \tag{3.2}$$

with

$$E\left[\widetilde{V_K}(a + S + 1, r_{a+S+1}) \mid r_{a+S}\right] = \int \widetilde{V_K}(a + S + 1, u^G r_{a+S}) dF^G(u^G \mid a + S)$$

- $\left\{\hat{r}_{a+S}^G\right\}_{a=1}^L$: minimum patent returns needed for the agent to allow the examined application to be granted at age $t = a + S$. This is the solution to $\widetilde{V}^G(a+S, r_{a+S}) = \widetilde{V}^W(a + S, r_{a+S}) = 0$.[105]

Consider the time periods after the first substantive action has been issued, $t = a + s, ..., a + S - 1$. In these periods, the patentee knows what can actually be protected by the patent. These are also the periods when the correspondence with the examiner occurs and C_{self}^{Exam} has to be paid. The applicant's options are either to withdraw the application, $\widetilde{V}^W(t, r_t) = 0$, or to continue the correspondence with the examiner:

$$\widetilde{V}^{CE}(t, r_t) = qr_t - [c_t + \frac{C_{self}^{Exam}}{S - (s + 1)}] + \beta\theta E\left[\widetilde{V_{CE}}(t + 1, r_{t+1}) \mid r_t\right] \tag{3.3}$$

with

$$\widetilde{V_{CE}}(t + 1, r_{t+1}) = \begin{cases} max\left[\widetilde{V}^G(t + 1, r_{t+1}), \widetilde{V}^W(t + 1, r_{t+1})\right] & \text{if } t = a + S - 1 \\ max\left[\widetilde{V}^{CE}(t + 1, r_{t+1}), \widetilde{V}^W(t + 1, r_{t+1})\right] & \text{if } t = a + s, ..., a + S - 2 \end{cases}$$

and

$$E\left[\widetilde{V_{CE}}(t + 1, r_{t+1}) \mid r_t\right] = \int \widetilde{V_{CE}}(t + 1, u^G r_t) dF^G(u^G \mid t)$$

[105] Similar to Pakes (1986) one can show that $\widetilde{V}^G(a+S, r_{a+S})$ is continuous and increasing in r_{a+S}, and decreasing in a. Therefore, the sequence $\left\{\hat{r}_{a+S}^G\right\}_{a=1}^L$ exists and $\hat{r}_{a+S}^G$ is increasing in a.

- $\left\{\hat{r}_t^{CE}\right\}_{t=a+s}^{a+S-1}$: minimum patent returns needed for the agent to continue the examination process at age $t = a+s, ..., a+S-1$. This is the solution to $\widetilde{V}^{CE}(t, r_t) = \widetilde{V}^{W}(t, r_t) = 0$.[106]

The remaining periods in the examination stage are the ones right after the examination request and before the first substantive action is issued, $t = a+1, ..., a+s-1$. Here, the applicant hasn't yet learned the examiner's objections and assumes that the future growth rates are drawn from $F^A(u^A \mid t)$:

$$\widetilde{V}^{CE}(t, r_t) = qr_t - c_t + \beta\theta E\left[\widetilde{V_{CE}}(t+1, r_{t+1}) \mid r_t\right] \tag{3.4}$$

with

$$\widetilde{V_{CE}}(t+1, r_{t+1}) = max\left[\widetilde{V}^{CE}(t+1, r_{t+1}), \widetilde{V}^{X}(t+1, r_{t+1})\right]$$

and

$$E\left[\widetilde{V_{CE}}(t+1, r_{t+1}) \mid r_t\right] = \int \widetilde{V_{CE}}(t+1, u^A r_t) dF^A(u^A \mid t)$$

- $\left\{\hat{r}_t^{CE}\right\}_{t=a+1}^{a+s-1}$: minimum patent returns needed for the agent to continue the examination process at age $t = a+1, ..., a+s-1$. This is the solution to $\widetilde{V}^{CE}(t, r_t) = \widetilde{V}^{W}(t, r_t) = 0$.[107]

Therefore, the expected revenue from requesting examination in period $t = a$, $\widetilde{V}^{E}(a, r_a)$, is:

$$\widetilde{V}^{E}(a, r_a) = \begin{cases} qr_a - (c_a + C_{PO}^{Exam} + C_{PO}^{Appl} + C_{self}^{Appl}) + \\ +\beta\theta E\left[\widetilde{V_{CE}}(a+1, r_{a+1}) \mid r_a\right] & \text{if } a = 1 \\ qr_a - (c_a + C_{PO}^{Exam}) + \\ +\beta\theta E\left[\widetilde{V_{CE}}(a+1, r_{a+1}) \mid r_a\right] & \text{if } a = 2, ..., L+1 \end{cases} \tag{3.5}$$

The traditional way of modeling the examination stage (Deng 2007; Serrano 2011) is to assume that a patent examination takes S years and at the end of these periods the application will be approved for grant with probability π_{Grnt} or rejected with probability

[106] Similar to Pakes (1986) one can show that $\widetilde{V}^{CE}(t, r_t)$ is continuous and increasing in r_t, and decreasing in t as well as a. Therefore, $\left\{\hat{r}_t^{CE}\right\}_{t=a+S}^{a+S-1}$ must exist and $\hat{r}_t^{CE}$ is increasing in a as well as t.

[107] Similar to Pakes (1986) one can show that $\widetilde{V}^{CE}(t, r_t)$ is continuous and increasing in r_t, and decreasing in t as well as a. Therefore, $\left\{\hat{r}_t^{CE}\right\}_{t=a+S}^{a+S-1}$ must exist and $\hat{r}_t^{CE}$ is increasing in a as well as t.

$1 - \pi_{Grnt}$. This means that once the applicant requests examination he has to continue the examination process until the final decision of the examiner on the patentability, and if the examination was successful, he always wants his patent to be granted. The agent might only withdraw his application during the examination if the invention becomes obsolete, or its protection commercially worthless. According to this view the expected value of requesting examination in year $t = a$, $\widetilde{V}^E(a, r_a)$ comprises the expected returns from having a pending application minus all expected examination costs $K = C_{PO}^{Exam} + C_{self}^{Exam} + C_{PO}^{Grnt}$ and maintenance fees, plus the expected returns from a pending application and the expected returns from full patent protection in the future:

$$\widetilde{V}^E(a, r_a) = \begin{cases} qr_a + \\ +\beta\theta q E(r_{a+1}|r_a) + ... + (\beta\theta)^{S-1} q E(r_{a+S-1}|r_a) - \\ -(c_a + C_{PO}^{Exam} + C_{PO}^{Appl} + C_{self}^{Appl}) - \\ -\beta\theta c_{a+1} - ... - (\beta\theta)^{S-1}(c_{a+S-1} + \frac{C_{self}^{Exam}}{S-(s+1)}) + \\ +(\beta\theta)^S \pi_{Grnt} \left(E\left[\widetilde{V_K}(a+S, r_{a+S}) \mid r_a\right] - C_{PO}^{Grnt} \right) & \text{if } a = 1 \\ \\ qr_a + \\ +\beta\theta q E(r_{a+1}|r_a) + ... + (\beta\theta)^{S-1} q E(r_{a+S-1}|r_a) - \\ -(c_a + C_{PO}^{Exam}) - \\ -\beta\theta c_{a+1} - ... - (\beta\theta)^{S-1}(c_{a+S-1} + C_{self}^{Exam}) + \\ +(\beta\theta)^S \pi_{Grnt} \left(E\left[\widetilde{V_K}(a+S, r_{a+S}) \mid r_a\right] - C_{PO}^{Grnt} \right) & \text{if } a = 2, ..., L+1 \end{cases} \tag{3.6}$$

with

$$E(r_{a+S-1}|r_a) = \int \cdots \int (u_{a+1}^A \cdot ... \cdot u_{a+S-1}^A \cdot r_a) dF^A(u_{a+1}^A \mid a) ... dF^A(u_{a+S-1}^A \mid a+S-2)$$

and

$$E\left[\widetilde{V_K}(a+S, r_{a+S}) \mid r_a\right] =$$
$$= \int \cdots \int \widetilde{V_K}(a+S, u_{a+1}^A \cdot ... \cdot u_{a+S}^A \cdot r_a) dF^A(u_{a+1}^A \mid a) ... dF^A(u_{a+S}^A \mid a+S-1)$$

Application stage During the application stage the potential applicant has to decide first whether he wants to file a patent application and, once he has decided to file an application, whether and when to request examination. The decision to request examination can be deferred for at most L periods. This means that an agent who still holds a pending application in the beginning of period $t = L+1$ has to decide whether he finally wants to request examination (E) or to withdraw (W) it completely. Given the expected revenues from requesting examination $\widetilde{V}^E(a, r_a)$ from equations (3.5) or (3.6) and with $\widetilde{V}^W(t, \hat{r}_t) = 0$ we define:

- $\hat{r}^E_{L+1}$: minimum patent returns needed for the agent to request an examination (E) and not to withdraw (W) the application in period $t = L+1$. This is the solution to $\widetilde{V}^E(L+1, r_{L+1}) = \widetilde{V}^W(L+1, r_{L+1}) = 0$.[108]

In earlier periods, $t = 1, ..., L$, the owner of a pending application has three options. Besides the possibilities to withdraw (W) the application and to request examination (E) he can also choose to defer (D) the decision to the next period. The expected value of the third option $\widetilde{V}^D(t, r_t)$ consists of the returns from having a pending application in this period, minus the deferment fees and the expected returns from the option of having the same choices in the next period:

$$\widetilde{V}^D(t, r_t) = \begin{cases} qr_t - (c_t + C^{Appl}_{PO} + C^{Appl}_{self}) + & \\ +\beta\theta E\left[\widetilde{V_D}(t+1, r_{t+1}) \mid r_t\right] & \text{if } t = 1 \\ qr_t - c_t + \beta\theta E\left[\widetilde{V_D}(t+1, r_{t+1}) \mid r_t\right] & \text{if } t = 2, ..., L \end{cases} \tag{3.7}$$

with

$$\widetilde{V_D}(t+1, r_{t+1}) = \begin{cases} max\left[\widetilde{V}^E(t+1, r_{t+1}), \widetilde{V}^W(t+1, r_{t+1})\right] & \text{if } t = L \\ max\left[\widetilde{V}^E(t+1, r_{t+1}), \widetilde{V}^D(t+1, r_{t+1}), \widetilde{V}^W(t+1, r_{t+1})\right] & \text{if } t = 1, ..., L-1 \end{cases}$$

and

$$E\left[\widetilde{V_D}(t+1, r_{t+1}) \mid r_t\right] = \int \widetilde{V_D}(t+1, u^A r_t \mid r_t) dF^A(u^A \mid t)$$

Since at this stage the applicant has three options, in every period $t = 1, ..., L$ there exist two threshold values that determine the optimal choices (see Figure 3.2):

- $\left\{\hat{r}^D_t\right\}^L_{t=1}$: minimum patent returns needed for the agent to defer the decision (D) at age t and not let it expire (W). This is the solution to $\widetilde{V}^D(t, r_t) = \widetilde{V}^W(t, r_t) = 0$.[109]

[108] One can easily show that $\widetilde{V}^E(L+1, r_{L+1})$ is continuous and increasing in r_{L+1}, such that $\hat{r}^E_{L+1}$ exists.

[109] Similar to Pakes (1986) one can show that $\widetilde{V}^D(t, r_t)$ is continuous and increasing in r_t so that $\left\{\hat{r}^D_t\right\}^L_{t=1}$ must exist. For $t = 2, ..., L$, $\widetilde{V}^D(t, r_t)$ is decreasing in t. Therefore, the sequence of cut-off values $\left\{\hat{r}^D_t\right\}^L_{t=2}$ is increasing in t. In $t = 1$, $\hat{r}^D_1$ might be higher than in the subsequent periods, since the applicant has to incur additional costs for the application ($C^{Appl}_{PO} + C^{Appl}_{self}$).

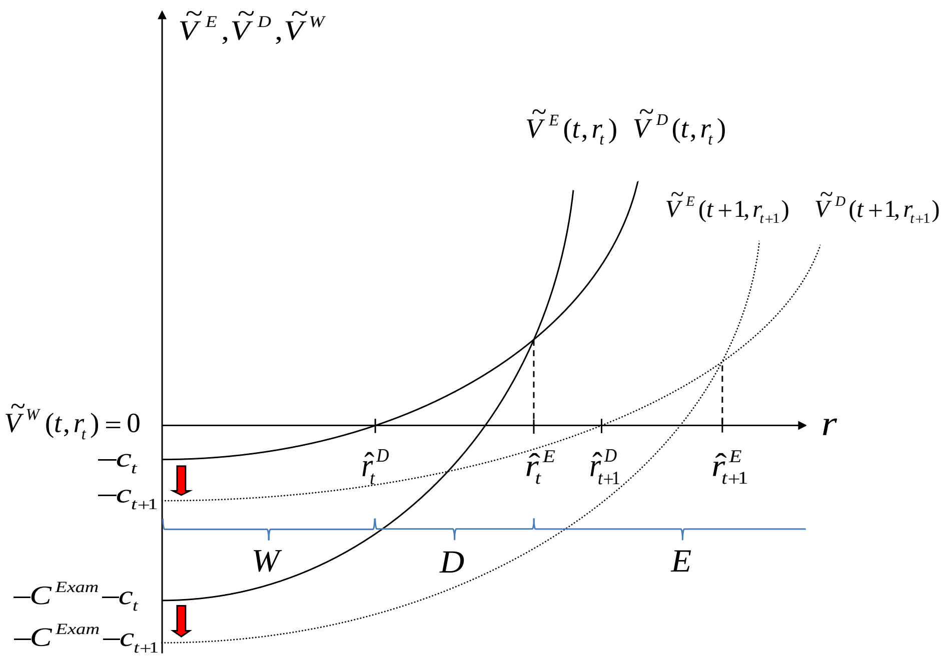

Figure 3.2: Value Functions and Cut-off Values - Application Stage prior to Examination Request

- $\left\{\hat{r}_t^E\right\}_{t=1}^L$: minimum patent returns needed for the agent to request an examination (E) instead of deferring the decision (D) at age t. This is the solution to $\widetilde{V}^E(t, r_t) = \widetilde{V}^D(t, r_t)$.[110]

According to the study by Henkel and Jell (2010), the two main motives behind the decision to defer examination are to create uncertainty for competitors and to gain time for evaluation of the commercial value. Both motives are incorporated in our model. The value of creating uncertainty in the marketplace is incorporated in the returns from patent protection that can be already realized through a pending application, qr_t. Given that the potential returns from patent protection are not high enough to request examination the applicant will choose to defer examination either if qr_t is high or the option value of future returns is high enough ($\triangleq$ gain time for evaluation).

Since the problem described above is finite and returns in one period depend only on returns realized in the previous period, the model can be solved for the sequences of the cut-off values by backward recursion.[111]

[110] Since $\widetilde{V}^E(t, r_t)$ and $\widetilde{V}^D(t, r_t)$ are continuous in r_t, so must be $\widetilde{V}^E(t, r_t) - \widetilde{V}^D(t, r_t)$. The proof that $\widetilde{V}^E(t, r_t) - \widetilde{V}^D(t, r_t)$ is increasing in r_t can be found in Appendix 3.7.1. Thus, the sequence $\left\{\hat{r}_t^E\right\}_{t=1}^L$ must exist.

[111] See Appendix 3.7.2 for a sketch how the model is solved recursively.

3.3 Data

For our estimations we are using data on Canadian patent applications.[112] In particular, we analyze 211,550 patent applications filed between October 1, 1989 and September 30, 1996 with information from years 1989-2008. Patent protection could be renewed for up to 20 years from the application, $T = 20$. On October 1, 1989 renewal fees had been introduced for the first time, and until September 30, 1996 the examination request had to be made within 7 years from the filing date of the application, $L = 7$. Since Canada is a PCT (Patent Cooperation Treaty) member, applications which had gone through the PCT route only entered the national stage at the CIPO (Canadian Intellectual Property Office) 30 months after their priority date (which is typically 18 months from the application at the Canadian patent office). In turn, information on applications which had directly been submitted at the CIPO is available from the first day on. Furthermore, a different fee schedule applies for international applications to get examined. Therefore, we exclude all PCT applications from the data and use only 137,397 CIPO patent applications. Besides the date of the application, for each application we observe the date when examination was requested or the application withdrawn. In case examination had been requested, the data include information about the grant date or the date of withdrawal during examination. For granted patents we also observe when the patent owner stopped paying the renewal fees and the patent lapsed.

As one can see in Figure 3.3, on average, about 30,000 applications were submitted each year at the Canadian IP Office.[113] In 1990 almost 69% of all Canadian patent applications took the national application route through the CIPO, of which 74% have requested examination within the deferment period. In 1995 the portion of applications taking the national route decreased to 38% with almost 90% requesting examination. The average grant rate, defined as the percentage of applications that have successfully gone through a patent examination out of those that had actually requested examination was 68.71%. It remained almost stable over all cohorts.[114] According to the CIPO Annual Reports, 80% percent of applications with a request for examination were waiting less than 2 years for

[112] In a companion paper Harhoff (2012) studies the policy reforms at the Canadian Intellectual Property Office (CIPO) in more detail. Canada switched in 1989 from a US-style system with publication at grant to a seven-year deferment system with publication of the unexamined application after 18 months. In 1996, CIPO reduced the deferment period to five years.

[113] For cohorts 1989 and 1996 only patents filed between October and December 1989, respectively January and September 1996, were affected by the change to the patent system.

[114] There was some variation within cohorts. The grant rate lied slightly above 70% and remained stable for applications for which examination has been requested within the deferment period. If application had been requested at the end of the deferment period the grant rate dropped to 64%. Nevertheless we maintain the assumption that there is no selection into grant rates throughout the paper. Grant rates may also vary across technologies and applicant types (see Schankerman 1998). However, in this paper we aggregate over all non-PCT applications and maintain a common grant rate.

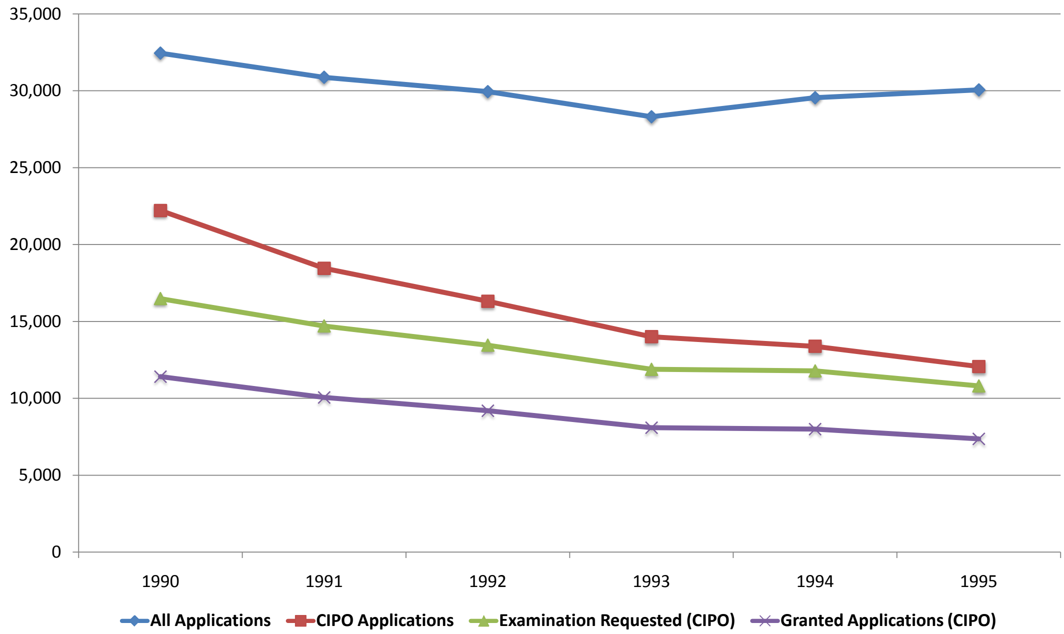

Figure 3.3: Canadian Patent Applications by Filing Year (1989-1995)

a first substantive examination action (including all known objections to patentability). On average, a patent was granted about 4 years after examination had been requested. Hence, we set $s = 2$ and $S = 4$.

Cost structure The maintenance fees at the CIPO for pending applications, as well as patents, were zero in the first two years, 100 CAD$ for years 3-5, 150 CAD$ for years 6-10, 200 CAD$ for years 11-15, and 400 CAD$ for years 16-20.[115] There was one change in the nominal fee schedule which was applied to renewals starting from January 1, 2004. The maintenance fees were increased by 50 CAD$ for the years 6-20. To ease the computational burden, we have used the weighted average of the maintenance fees before and after the change in the fee structure for estimation. The fee for filing an application amounted to 200 CAD$ and 400 CAD$ for requesting examination for the cohorts under consideration. A final fee of 300 CAD$ was due for the publication of the grant.[116]

[115] Indeed, the fee structure is different for small and large applicants. By CIPO's definition, a small applicant is an entity that employs 50 or fewer employees or that is a university. Small applicants are offered a 50% reduction on application and maintenance fees. Unfortunately, we are not able to distinguish between small and large entities. Nevertheless, small applications consist of less than 15% of total applications.

[116] To make the cost structure more realistic we have added 50 CAD$ to each payment due to the patent office. Usually patent attorneys charge their clients for these money transfer services or the applicant has at least to invest time for the completion of the respective forms. Since these costs can vary a lot we

As already mentioned above, it would be incorrect to assume that the decisions made during the application and examination stage depend solely on the statutory patent fees. To have a rough estimate we use the information on the costs of filing a patent application in Canada provided by Canadian law firms.[117] According to this information the costs of examination range from 750 CAD$ to 7,500 CAD$ depending on the complexity and the number of arguments put forward by the examiner. The filing costs may have even a higher variation depending on its length, whether it requires translation from other languages, and whether the applicant does a search to find out whether anyone else has already thought of the idea to be patented. We decided to set C_{self}^{Exam} to 3,000 CAD$ such that $C_{PO}^{Exam} + C_{self}^{Exam} + C_{PO}^{Grnt} = 250 + 3000 + 450 = 3700$ CAD$.

3.4 Estimation

3.4.1 Estimation Strategy

We use a simulated minimum distance estimator developed by McFadden (1989) and Pakes and Polland (1989) for the estimation.[118] In the first step we assign a stochastic specification to our structural model by making functional form assumptions which in turn will depend on a vector of parameters ω. In order to determine the vector ω_0 of the true parameters we fit the hazard probabilities derived from the theoretical model to the true hazard proportions as proposed in Lanjouw (1998). Each parameter has a different effect on the structure of the sequences of the cut-off values derived from the model, $\left\{\hat{r}_t^j\right\}$ with $j = E, D, CE, G, K$ and the distribution of returns in each age, r_t, which in turn determine the hazard probabilities. This allows the identification of the model parameters. Although in theory a solution to the structural model, i.e., the sequences $\left\{\hat{r}_t^j\right\}$ can be found analytically, this is hardly possible in practice due to the complexity of the model. Thus, we use a weighted simulated minimum distance estimator (SGMM) $\hat{\omega}_N$. The estimator is the argument that minimizes the norm of the distance between the vector of true and simulated hazard proportions. We use a weighting matrix $A(\omega)$ to improve the efficiency of the estimator:

regard 50 CAD$ as a lower bound.

[117] See for example http://www.valuetechconsulting.com/cost.php, last accessed December 2012.

[118] McFadden (1989) and Pakes and Polland (1989) provide conditions required to ensure the consistency and asymptotic normality of the estimator. Pakes (1986) and Lanjouw (1998) show that the required conditions hold for our type of model.

$$A(\omega)\,\|h_N - \eta_N(\omega)\| \;\text{ with } \hat{\omega}_N^* = arg\,\underset{\omega}{min}\,A(\omega)\,\|h_N - \eta_N(\omega)\| \tag{3.8}$$

- h_N is the vector of sample or true hazard proportions.
- $\eta_N(\omega)$ is the vector of simulated hazard proportions (predicted by the model).
- $A(\omega) = diag\sqrt{\underline{n}/N}$ is the weighting matrix. $\underline{n}$ is the vector of the number of patents in the sample for the relevant age-cohort. N is the sample size.

In order to calculate the simulated hazard rates for a parameter set ω we first have to calculate the sequences of the cut-off values $\left\{\hat{r}_t^j\right\}$ with $j = E, D, CE, G, K$. To do so we proceed recursively by first determining the value functions in the last period and calculating the corresponding cut-off values. Subsequently, with these cut-off values, we calculate the value functions in the second last period and proceed recursively in the same manner until the first period. Once we have calculated the cut-off functions for all periods we perform five simulations. In each simulation we take $3 \cdot N$ pseudo random draws from the initial distribution and exactly the same amount of draws from each distribution of the growth rates g_t^A and g_t^G. Afterwards we pass the initial draws through the stochastic process, compare them with the corresponding cut-off values, and calculate the hazard proportions for all years. The vector of hazard rates from each simulation is then averaged over the five simulation draws and inserted in the objective function (3.8). The objective function is then minimized using a two step approach. We use global optimization algorithms in the first step and a Nelder-Mead-type local optimization search algorithm to find the local minimum in the second step.[119]

We will fit three types of hazard proportions: (1) HR_E, the percentage of applications for which examination was requested, (2) HR_D, the percentage of applications which were deferred to the next period in a given year out of those that had been deferred in the previous period, and (3) HR_X, the hazard proportion of expired patents. There are two possible ways to calculate HR_X depending on the way we model the examination stage. According to the traditional view (Version 1 assuming $\pi_{Grnt} < 1$), HR_X^1 is the percentage of granted patents that expire in a given year out of those granted and renewed in the previous period. But if we explicitly model the examination stage, then HR_X^2 (Version 2 with $\pi_{Grnt} = 1$) is the percentage of all granted patents and applications

[119]MATLAB (matrix laboratory) is a numerical computing environment developed by MathWorks. Since the objective function is supposed to be non-smooth we apply the Simulated Annealing algorithm and the Genetic algorithm in the first step. Both are probabilistic search algorithms (see description of the Global Optimization Toolbox for MATLAB). The Nelder-Mead-type search algorithm implemented in MATLAB is called *fminsearch.*

under examination that expire in a given year out of those applications that have already requested examination and patents which are still alive.

We decided to use only the traditional way of modeling the examination stage for the estimation. The reason is that estimation requires us to assume the same duration of patent examination for all applications. If we used this way of modeling the examination stage where we do not distinguish between patents under examination and already granted patents we could get biased results. In reality examination patents can be examined within 2 years or examination can even take more than 10 years. Assuming a constant duration of examination of four years for all patents thus leads to simulated hazard rates $HR_X^2(t)$ whose composition of patents still under examination and already granted patents would mismatch the composition of the real hazard rates. Assume that examination was requested in the third period and the patent has already been granted after 2 years. This will reduce the hazard rate in the fifth year $HR_X^2(5)$. Since by assumption such a low duration of examination is not possible, the model trying to fit this hazard rate will be adjusted by allowing more applications which requested examination in the first year to be granted or more patents to be renewed. A similar reasoning applies to patents which were examined longer than 4 years and not granted.[120] This kind of bias is avoided if we use the traditional way of modeling the examination stage, such that the hazard rates only includes patents which are already granted $HR_X = HR_X^1$.

Since for the applications in our data the maximum deferment period was 7 years, we calculate HR_D for 7 periods and HR_E for 8 periods for each of the seven cohorts. The decision to request examination can be made anytime within the 7 years period. Therefore we assign all requests which were made within the first 6 months past the filing date of the application to the first period and all requests which were made in the following 12 months to the second period, and so forth.[121] The maximum patent term in Canada was 20 years but since we only observe events before the end of 2008 the vector $HR_X^1(t)$ consists of 15 entries for cohort 1989 and 8 for cohort 1996 (beginning with period 5).

Furthermore, we do not consider the application decision for our final estimation. The reason is that the estimation results, especially the parameters of the initial distribution, will highly depend on the costs of filing an application. Since we do not observe these costs and they tend to vary considerably across patents, incorporating this decision might

[120]To avoid this kind of bias one could restrict the sample to applications which had never requested examination and applications which had requested examination but were either granted only after 4 years or were dropped less than 4 years after the request. But we refrained from sub-sampling the data in this way, since this approach could introduce an even stronger bias and considerably restrict the validity of our results.

[121]A few recording dates for the examination request exceeded 7.5 years. We assigned these decisions to the 8th period.

bias the estimation results.[122]

3.4.2 Stochastic Specification

Initial returns As in previous patent renewal studies we assume that the initial returns r_1 of all applications are lognormally distributed where $F_{IR}(\mu_{IR}, \sigma_{IR})$ is a normal distribution with mean μ_{IR} and variance σ_{IR}:[123]

$$log(r_1) \sim Normal(\mu_{IR}, \sigma_{IR}) \tag{3.9}$$

Distributions of the growth rates For the growth rates during the years before the patent has been examined we follow a similar stochastic specification as in Pakes (1986). We assume that the realized growth of returns is the maximum between the minimum growth rate δ^A, and a growth rate which is drawn from an exponential distribution v^A with variance $\sigma_t^i = (\phi^i)^{t-1}\sigma_0^i$: $g_t^A = max(\delta^A, v^A)$. The second growth rate, v^A , represents the cases when the applicant is able to "learn" about how to increase the returns above the minimum growth rates. We also assume that $\phi^A < 1$ such that the probability of getting higher returns will decrease with age t. The overall distribution of g_t^A can be represented as follows:

$$g_t^A \sim F^A(u^A \mid t) = \begin{cases} 1-\theta & \text{if } 0 \leq u^A < \delta^A \\ 1-\theta+\theta(1-exp(-\frac{u^A}{\sigma_t^A})) & \text{if } \delta^A \leq u^A \end{cases} \tag{3.10}$$

We model the evolution of the growth rates during the patent stage, $F^G(u^G \mid t)$, in a more static way. We assume that learning possibilities disappear once the patent has been examined.[124] This means that uncertainty about future returns from patent protection

[122]To our knowledge Deng (2011) is the only one who has estimated a dynamic stochastic patent renewal model incorporating the application decision for European patent filings. She has only considered the statutory application and granting fees at the European Patent Office (EPO) for estimation and disregarded the costs of drafting and translating EPO patent applications. These costs usually exceed the statutory fees and vary considerably across technology areas as well as applicant types.

[123]Lanjouw (1998) was the only one who deviated from this assumption. She assumed that the initial returns of patents applications is zero and its value only evolves over time.

[124]We have also estimated a competing model where we explicitly allowed for learning opportunities during the patent stage. This dynamic model provided a somewhat better fit to the data since the evolution of returns during the patent stage was now determined by three parameters $\phi^G, \sigma_0^G, \delta^G$ instead of a single one δ^G. The increased fit could be fully attributed to adjustments in the simulated $HR_X(t)$. All other parameters remained in a narrow range of the presented model. Apart from the value distributions, which have become more skewed due to the additional learning opportunities, all results presented below, in particular the qualitative ones, continue to hold. The reason why we have chosen the more static model for the following analysis is that the identification of $\phi^G, \sigma_0^G, \delta^G$ relies solely on the variation in

completely disappears after the grant. The evolution of returns is then fully deterministic and they depreciate at a constant rate δ^G.

To ease the computational burden we fix the discount rate $\beta = 0.95$. Furthermore, since the first weighted hazard rate of expiration (HR_X for period 5) is 0.0465, we set $\theta = 0.9535$. Year 5 is when the first patent applications are granted. Therefore, we find it plausible to assume that patents from a cohort which are granted first expire in the first year after grant because of obsolescence and not because of too high renewal fees. The maintenance fees for the fifth year amount to only 100 CAD$. Since the fraction of applications which were granted out of those that had requested examination was 68.71%, the probability that an application which has not become obsolete during the examination process will be successfully granted is: $\pi_{Grnt} = \frac{0.6871}{\theta^{S-1}} = \frac{0.6871}{0.9535^3} = 79.26\%$.

With q as the fraction of returns an application can generate already before grant we are left with seven structural parameters to be estimated:

$$q, \;\mu_{IR}, \sigma_{IR}, \;\phi^A, \sigma_0^A, \delta^A, \;\delta^G$$

These parameters altogether determine the structure of the sequences of the cut-off values derived above, $\hat{r}_t^j$ with $j = E, D, K$, and the distribution of returns in each period, r_t.

3.4.3 Identification

Like in other patent renewal models the parameters are identified by the cost structure and the non-linearity of the model. Different parameter values imply different cut-off value functions which in turn imply different hazard rates.

In particular, the parameters μ_{IR} and σ_{IR} determine the mean and variance of the initial distribution of returns. Both have an effect on all three sequences of hazard rates. Variation in σ_{IR} results in changes in $HR_E(t)$ in the first and last year, and changes in $HR_D(t)$ in the first and third year, but leaves the hazard rates in the other years rather unchanged. In contrast, variation in μ_{IR} changes $HR_E(t)$ and $HR_D(t)$ in all years. Interestingly, whereas higher values of μ_{IR} result in a higher hazard rate of deferment in the third period $HR_D(3)$, the period when the first maintenance fees are due, higher variance σ_{IR} has the opposite effect.

The parameter q, which represents the fraction of the returns from patent protection which can be realized with an unexamined patent application, is mainly identified by the

$HR_X(t)$ and the variation in the patent renewal fees. We cannot fully exclude offsetting effects between these three parameters.

variation in $HR_D(t)$, and especially in $HR_E(t)$. A higher q raises the hazard rates of deferment for all years almost constantly whereas it increases the hazard proportion of requesting examination only in the last, eighth year and decreases them for years 1 to 7. A lower q would have the opposite effect.

The distributions of growth rates of returns from pending applications $F^A(u^A \mid t)$ are fully determined by ϕ^A, σ_0^A, and δ^A. The parameters ϕ^A and σ_0^A have similar impact on all three hazard rates. Higher values of parameters go along with higher hazards of examination request in all years and lower hazard of deferment except for the third year, $HR_D(3)$, where it leads to an increase. Different values of ϕ^A and σ_0^A have also an impact on the curve of the hazards of expiration. Higher values produce a concave curve such that the hazard proportions decline or remain constant for older patents. Lower values produce a convex curve with increasing hazard proportions for older patents. This is the consequence of constant maintenance fees for the years 16-20. Nevertheless, there is a difference between variation in ϕ^A and variation in σ_0^A. Higher values of the first parameter imply increasing hazard proportions of examination request for the years 2-7 whereas higher values of the latter imply decreasing hazards for the same years and vice versa. δ^A, together with the other two parameters determine from what year on the hazard proportions of expiration, $HR_X(t)$, start to exceed the rate of obsolescence. Furthermore, a higher depreciation rate, i.e., lower δ^A, decreases $HR_E(t)$ in all years. It also decreases $HR_D(t)$, but only for periods 3 to 7, when maintenance fees are due, but increases $HR_D(t)$ in the first two periods.

δ^G determines the evolution of returns of already examined patent applications, $F^G(u^G \mid t)$. Therefore δ^G does neither impact $HR_D(t)$ nor $HR_E(t)$, and is identified by the variation in $HR_X(t)$ only.

As with other renewal models, the main caveat of our estimates is the sensitivity to the functional forms assumed for the distribution of returns. As Lanjouw (1998) notes: "Unlike the patents which are dropped, and which thereby indicate that they have expected returns at that point bounded above by the renewal fee, there is no information in the data which directly identifies an upper bound on the returns generated by patents which renew until the statutory term. The value of the patents in this group is identified indirectly by the functional form assumptions, together with the fact that the potential for high returns in the future influences renewal decisions in the early years."

Parameter	Estimates	(s.e.)
β (fixed)	0.9500	-
θ (fixed)	0.9535	-
μ_{IR}	5.9015	(0.0491)
σ_{IR}	1.8865	(0.0222)
q	0.7307	(0.0032)
ϕ^A	0.9659	(0.0011)
σ_0^A	1.4090	(0.0238)
δ^A	0.8400	(0.0101)
δ^G	0.9363	(0.0026)
Age-Cohort Cells	212	
Size of Sample	137,427	
Size of Simulation	412,281	
$Var_{All}(h_N)$	0.117316	
$MSE_{All}{}^{\dagger}$	0.000855	
$1 - MSE_{All}/Var_{All}(h_N)$	99.27%	
$Var_E(h_N)$	0.050834	
MSE_E	0.000115	
$Var_D(h_N)$	0.002848	
MSE_D	0.000154	
$Var_X(h_N)$	0.000586	
MSE_X	0.000619	

†MSE is the sum of squared residuals divided by the number of age-cohort cells.

Table 3.1: Parameter Estimates

3.4.4 Estimation Results

The estimation results are presented in Table 3.1.[125]

Fit of the model To get an indication of how well the estimated model fits the data, we compare the simulated with the sample hazard proportions. Furthermore, we also report how much of the variability in the sample hazard proportions can be explained by the model. Figures 3.4-3.6 show the simulated and sample hazard rates from the pooled data. By looking at the hazard proportions of examination requests and declarations, $HR_E(t)$ and $HR_D(t)$, one can see that there are no major deviations between the empirical and simulated moments. The model seems to capture all sharp increases as well as decreases. The mean square errors (MSE_E and MSE_D) are low compared to the variance in the actual hazard proportions ($Var_E(h_N)$ and $Var_D(h_N)$). Only 5.41%, respectively 0.23% of the variance in the actual hazard proportions is not accounted for by the model. For

[125] A sketch of how the value functions and the cut-off values have been calculated can be found in Appendix 3.7.2. We are using a parametric bootstrap method to obtain the standard errors as described in Appendix 3.7.3.

the hazards of expiration, however, the model overpredicts the hazard proportions for the years 12 and 16, and underpredicts them in all others. Consequently, the mean square error, MSE_X, is high compared to the variance. Why the model performs poorly in explaining the variation in $HR_X(t)$ may lie in the assumptions we have made regarding the cost structure and the duration of examination. The kink in year 16 coincides with the year when the official renewal fees almost double and then stay the same for the following years. However, the real costs associated with patent renewal might be much higher such that the official renewal fees represent only a fraction of them. This might explain why we do not observe a kink in the actual hazard proportions.[126] The jump in year 12 is due to our assumption that examination takes exactly 4 years for all applications and applicants always proceed the examination unless the application becomes completely worthless. According to our model, owners of patents of lower economic value defer examination until the last deferment period, and then decide whether to request it. If they request examination the patent will be granted exactly 4 years later. However, for many of these patents the value will have depreciated such that the renewal fees in year 12 will exceed the expected returns. In reality, the duration of examination is heterogeneous and the decision whether to continue examination might be endogenous as well. Therefore, the patent lapses the model predicts for year 12 are allocated around this year in the actual data. Furthermore, we have assumed that the examination costs are the same for all applicants. However, the actual examination costs should differ across applicants. Applicants with patents of lesser economic value should have requested examination earlier than predicted by the model if their examination costs were low enough. Applicants with higher examination costs should have postponed the examination request or even dropped the application although their applications were relatively valuable. Therefore, we observe higher hazard proportions of expiration especially for younger patents in the sample compared to the ones predicted by the model.[127] Nevertheless, the overall MSE_{All} is very low, suggesting that our estimated model fits the data well and is able to explain 99.27% of the overall variation.

Estimated parameters We now turn to the discussion of the estimated model parameters.[128] The initial distribution of returns is determined by μ_{IR} and σ_{IR}, and implies a

[126] Another possible explanation is that the assumption of a constant rate of obsolescence for all granted patent applications might be unrealistic. An increasing rate of obsolescence for older patents might provide a better fit for the progression of the hazard proportions of expiration but would make calculations and identification more difficult.

[127] One possible way to alleviate this bias is to assume that the costs of examination are proportional to the duration of examination. The examination costs would then simply be a function of the duration of examination making them heterogeneous across applicants. However, the problem arises how to assign a duration to applications for which examination has never been requested, or which have never been granted.

[128] All monetary values are in units of 2002 CAD$. Standard errors are reported in parenthesis.

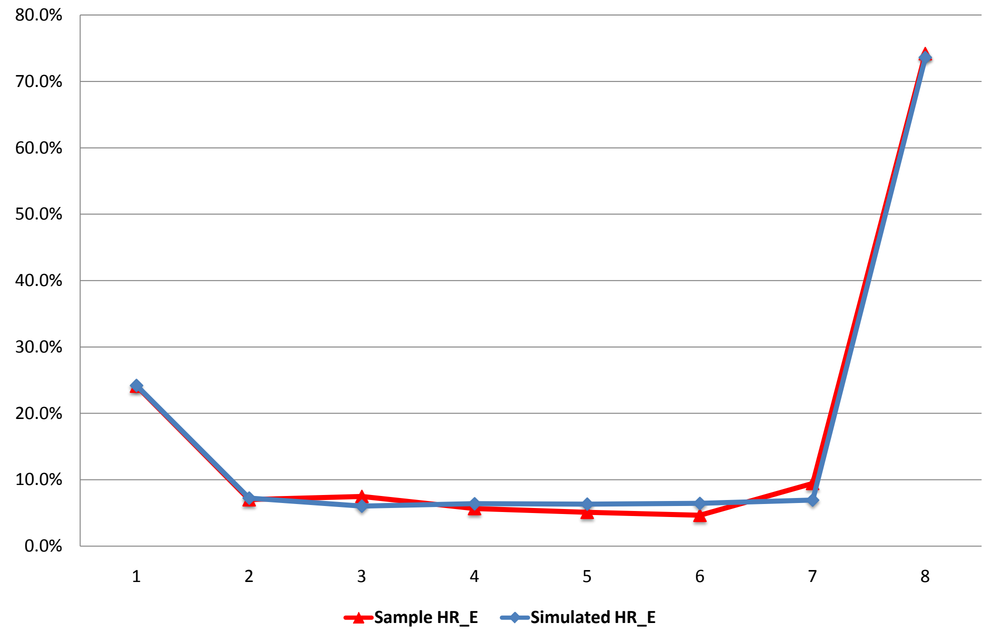

Figure 3.4: Simulation vs. Sample Hazard Proportions $HR_E(t)$

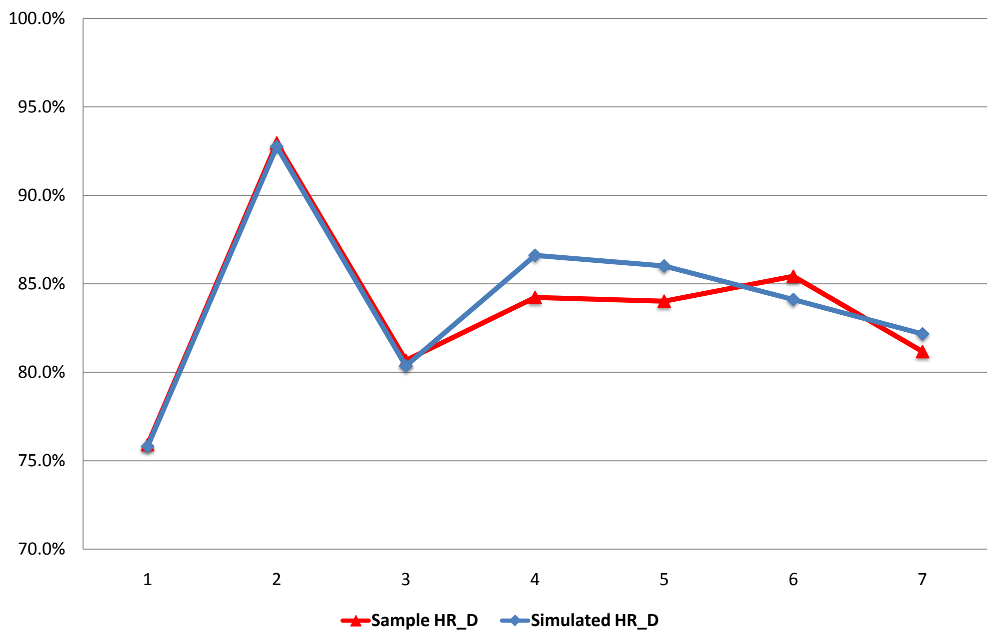

Figure 3.5: Simulation vs. Sample Hazard Proportions $HR_D(t)$

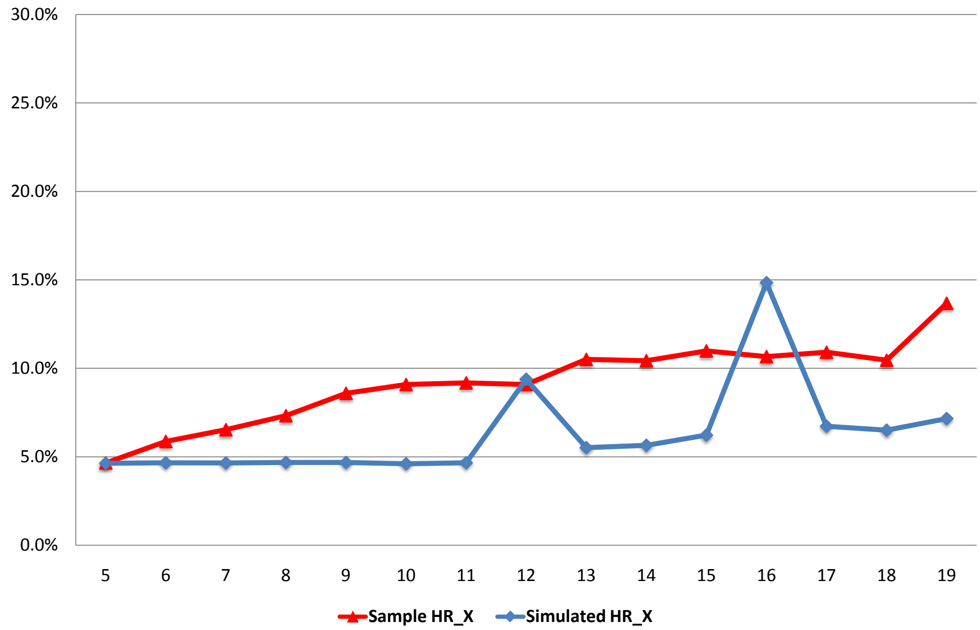

Figure 3.6: Simulation vs. Sample Hazard Proportions $HR_X(t)$

mean initial potential return from patent protection for all applications of 2,155 CAD$ (122 CAD$) and a median value of 365 CAD$ (17 CAD$). The parameters ϕ^A, σ_0^A, and δ^A determine the evolution of returns during the application stage. The implication of these parameters, especially of ϕ^A being close to 1, is that before an application is examined the applicants expect high and slowly decreasing learning opportunities. If an applicant is not able to learn how to increase the returns from his patent application the next years returns depreciate by 16%. In Table 3.2 we see that 53.9% of pending patent applications in the second year and still 46.8% in the eighth year are able to increase the potential returns from patent protection and defy depreciation. Interestingly, although learning opportunities for Canadian patent applications diminish with age, they do it at a much slower pace as estimated for granted patent applications by previous patent renewal studies. For example, Pakes (1986) reports that learning is over by age 5 for German patents. Lanjouw (1998) estimates a similar speed of learning.

The parameter q, which was defined as the fraction of potential returns from patent protection that can already be realized before the patent is finally granted, is estimated to be 73.1%. Although the applicant practically has not yet gained the right to enforce his right to exclude others, he is able to profit from having a pending application. This means that even though he might never receive a patent on his invention, the realized value might

Age	2	3	4	5	6	7	8
$Pr(g_t^A \geq \delta^A)$	53.95%	52.78%	51.61%	50.41%	49.21%	47.99%	46.76%
(s.e.)	(0.81%)	(0.79%)	(0.77%)	(0.75%)	(0.73%)	(0.71%)	(0.69%)

Table 3.2: Learning Possibilities During the Application Stage

still exceed the expenses. Since we assumed that there are no learning possibilities for already examined patent applications, the returns from full patent protection depreciate at $1 - \delta^G = 6.3\%$ per year.

3.5 Implications

Value of Canadian patent applications In this section we use the estimated parameters to calculate the value distributions of Canadian patent applications for the 1989 cohort. We simulate the patent system by taking 250,000 pseudo-random draws from the initial distributions and passing them through the model using the estimated parameter values. Then, the net value of protection defined as the discounted present values of the streams of returns less the discounted maintenance fees was calculated for each simulated application. In case the application was still pending we multiplied the return in the respective period by q and in case examination had been requested we subtracted the discounted costs incurred for examination.

Table 3.3 presents the simulated value distributions for all patent applications, for applications which have been granted, and for applications which have not been granted. All monetary values are in 2002 CAD$. Similar to previous renewal studies, we find that the value distributions are highly skewed. The median simulated application value is 2,132 CAD$, whereas the mean value is 25,743 CAD$. Less than 10% of all applications are worth more than 50,870 CAD$ and less than 0.1% are worth more than 1,705,073 CAD$.

Unsurprisingly, there is a huge difference between patents and not granted applications. The average value of a patent is 50,954 CAD$. 50% are worth more than 15,361 CAD$ and 1% even more than 615,681 CAD$. These numbers confirm the results of previous patent renewal studies for other countries (Serrano 2006 for the USA; Deng 2007 for EPO patent applications). Patent applications which have never been granted were worth 4,547 CAD$ on average. Interestingly, the median value is positive with 184 CAD$.

Additionally, we are able to report what part of the value is generated before and what part after a patent has been granted. It seems that on average a patent owner is able to realize 50.38% of the overall value already during the application and examination stages. Only less than 50% of all patents have realized more than 67.85% of the overall value

Percentile	All Applications	Patents Overall Value	Patents Before Grant†	Not Granted Applications
50	2,132	15,361	42.15%	184
(s.e.)	(213)	(794)	(0.54%)	(36)
75	16,299	40,096	66.06%	2,093
(s.e.)	(894)	(1,915)	(0.36%)	(203)
90	50,870	99,029	88.97%	8,457
(s.e.)	(2,535)	(4,721)	(0.51%)	(701)
95	97,697	178,425	100.00%	17,445
(s.e.)	(4,844)	(9,284)	(-)	(1,281)
99	362,397	615,681	100.00%	70,463
(s.e.)	(21,352)	(40,859)	(-)	(5,076)
99.9	1,705,073	2,654,362	100.00%	400,452
(s.e.)	(125,165)	(225,414)	(-)	(30,818)
Mean Value	25,743	50,954	50.38%	4,547
(s.e.)	(1,536)	(2,961)	(0.43%)	(393)

†Calculated as the fraction of returns which accrued before the patent had been granted.
We did not subtract any costs to avoid negative numbers.

Table 3.3: Value Distributions for Cohort 1989 in 2002 CAD$

during the patent stage. These are mostly patents which have requested examination very early. Owners of more than 5% of granted patent applications had only been able to accrue value during the application and examination stages. These patents became worthless shortly before or after they had been granted.

Withdrawn or not granted patent applications account for 54.33% of all patent applications. According to the simulation results, the owners of these applications do not make losses on average. Since applicants can profit from a pending application as well, even the 50th percentile is positive. The other reason why we observe positive values for not granted patent applications is that some of them have become obsolete or failed examination in spite of having high potential returns in the past.

Value of deferment Now, we use the estimated parameters to shed light on the role of the possibility to defer the examination request. We calculate the vectors of cut-off values for two additional patent systems: one which allows deferment for up to six years, and one for up to five. Using the same simulated cohort of applications as in the previous section with a patent system which allows deferment for up to seven years, we calculate and compare the value distributions across the patent systems. This allows us to calculate the option value of the possibility to defer the examination request for one additional year. Furthermore, we also compare the number of total examination requests and assess the implications of different lengths of deferment for the patent office's workload.

Age	$L = 5$	$L = 6$	$L = 7$
1	58,914 (262)[†]	58,091 (250)	57,460 (240)
2	14,226 (199)	14,007 (201)	13,846 (202)
3	11,383 (116)	11,142 (128)	10,986 (128)
4	9,464 (89)	9,095 (99)	8,872 (115)
5	8,361 (88)	7,835 (94)	7,562 (108)
6	76,998 (292)	7,096 (96)	6,715 (102)
7		64,959 (276)	6,055 (97)
8			54,267 (270)
$\sum$	179,346 (352)	172,225 (338)	165,763 (340)

[†]Standard errors in parenthesis.

Table 3.4: Examination Requests

Table 3.4 presents the simulated numbers of patent examination requests for the years examination can be requested. The table shows that the overall number of requests increases if we shorten the deferment period. It will increase by 4.13% (0.083%) if we reduce the period of request for examination by one year and by 8.19% (0.150%) if we reduce it by two years. This is consistent with the analysis by Yamauchi and Nagaoka (2008) who observed a significant increase in the number of requests for patent examinations in Japan, while the number of patent applications remained rather stable. They show empirically that one of the major causes of the increase was the shortening of the deferral period from 7 to only 3 years. The difference is highest in the last period in which examination can be requested.

In the patent system with a maximum deferment period of five years 46.93% of all examinations were requested in the last year, whereas in the patent system with a maximum deferment period of seven years only 32.74%. The explanation is that applicants are given additional time to evaluate their invention and unveil the uncertainty surrounding it. The additional deferment period permits two types of corrections. First, it allows those applications that become obsolete or are exposed to value depreciation in the following year not to request costly examination. Second, applicants may learn that their inventions are capable of generating higher returns and still request examination.

The effect on the value distributions of the simulated patent cohort is consistent with the effect on the number of examination requests. Since examination is requested early for patents which are known to be valuable as early as at the application date, patents in the top percentiles of the distribution are not affected by the extended deferment period. However, a shorter deferment period reduces the effect of both correction mechanisms. Many owners of applications with initially low returns are deprived of additional time to reevaluate the value of their inventions and to request examination in case they would

change in the	$5 \leftarrow 7$ years	$6 \leftarrow 7$ years
value/ all applications	-5.49%	-2.56%
(s.e.)	(0.168%)	(0.080%)
value/ patents	-4.81%	-2.25%
(s.e.)	(0.152%)	(0.081%)
mean value/ patents	-11.99%	-5.93%
(s.e.)	(0.398%)	(0.178%)
value/ not granted applications	-11.86%	-5.56%
(s.e.)	(0.561%)	(0.283%)
mean value/ not granted applications	-5.37%	-2.34%
(s.e.)	(0.660%)	(0.321%)

Table 3.5: Option Value of Deferment

have discovered a way to increase them. Besides, applications which devaluate in the sixth or the seventh year nevertheless request examination since they have to decide before this information is revealed to them. As presented in Table 3.5 the value of all patents decreases by 2.25% if we shorten the deferment period by one year and by 4.81% if we shorten it by two years. Since the number of examination requests increases if we reduce the maximum deferment period, the decrease in the average patent value is even higher.

The value of applications which have been withdrawn or have failed examination decreases by 2.34%, respectively 5.37%, on average. More applicants request examination and incur costs for the examination if the deferment period is shortened. Consequently, the value of all patent applications in the cohort falls by even 5.56%, respectively 11.86%.

3.6 Conclusion

The model developed in this paper is the first to embed the option of deferred patent examination in the context of stochastic optimization. We utilize the rich information from deferment and renewal actions to estimate parameters of the value distribution of Canadian patent applications and granted patents, as well as of the associated learning process. Knowledge of these parameters allows us to perform two simulation experiments and to study the impact of the timing of examination on the patent office's capacity problem as well as on the value of unexamined and granted patents.

Our first main finding is that a substantial part of the value from patent protection is generated in the time before a patent gets actually granted. We estimate that already during the application and examination stages an owner of a pending patent application is able to realize 73.09% of the returns he would generate if he had full patent protection.

As a consequence, the majority of Canadian patent applications which have never been granted have a positive discounted value. Furthermore, the learning process of the value of applications which are still pending is much slower compared to the one of granted patents studied in previous literature.

In addition, our model allows us to simulate a change in the patent system from a seven years to a five years deferment period. This experiment is particularly interesting considering that the maximum deferment period in the Canadian patent system was indeed shortened from seven to five years for applications filed on or after October 1, 1996. The simulation experiment resulted in an increase in the number of examination requests which have to be dealt with at the Canadian patent office by 8.19%.[129] The applicants were deprived of time necessary to reduce the uncertainty associated with the value of their inventions. Therefore, many applications which would have turned out to be valuable in the future were withdrawn. Even more applicants decided to request examination and incur the corresponding costs although they would have become worthless shortly after. We estimate a considerable negative impact on the value of unexamined as well as granted patents, as a consequence.

Although we have used data on Canadian patent applications the results ought to be valid for other patent systems as well. A possibility to defer the examination request does not only reduce the patent office's workload but also acts as a quality control mechanism. Applicants seeking patent protection for inventions with highly uncertain value have the possibility to defer the examination request after the uncertainty has been resolved. Nevertheless, delayed examination may create additional possibilities for applicants to act strategically and increase uncertainty in the marketplace. However, to constrain strategic behavior by applicants most countries allow third parties to request examination and impose a fee on this activation right to prevent abuses. Concern has also been expressed that deferred patent examination could potentially increase patent filing rates. Indeed, our estimates show that for many patent applications returns realized during the application stage have been high enough to cover even the application costs. Nevertheless, an increase in the number of high-quality filings should not give cause for concern. To avoid an increase in poor-quality filings one could either try to raise the quality threshold for initial filings, involve third parties, or use the deferment fee structure as an additional policy instrument weeding out such applications.

The literature on the optimal renewal fees starting with Cornelli and Schankerman (1999)

[129] In reality the number of patent examination requests for Canadian applications has increased by about 6.9% after the reform. The deviation from the estimated percentage number may arise out of three reasons: 1) The simulated results apply to 1989 applications. 2) We do not take potential consequences of the policy intervention for the application filing decision into account. 3) We have used data on applications which were filed directly with the Canadian patent office for estimation and excluded all PCT applications.

and Scotchmer (1999) has identified the renewal structure as a direct revelation mechanism. Assuming heterogeneity in R&D productivity across firms and information asymmetry on the part of the government, optimal patent renewal fees should be low in early years and rise sharply with patent length. Baudry and Dumont (2009) arrive at the same conclusion for the welfare optimizing "one profile fits all" renewal fees. Nevertheless, both studies disregard the fact that in many patent systems the patent renewal fees constitute only a part of the total statutory fees. Our framework incorporates application fees, deferment fees, as well as patent renewal fees. Assuming a particular welfare function which relates the deadweight loss to the private value from patent protection, one could try to determine the welfare optimizing cost structure taking into account the interplay between the different types of fees. For example Cornelli and Schankerman (1999) report that the optimal patent renewal schedule should be more sharply graduated if there is post-patent learning, compared to the case when there is no uncertainty about the value of the invention. If we assume that applicants defer examination because they are highly uncertain about the value of their invention, then welfare could be increased by applying different schemes to deferment fees and patent renewal fees. Thus, the model developed in this paper provides the suitable framework for tackling these research questions in a more comprehensive manner.

3.7 Appendix

3.7.1 Proof that $\widetilde{V}^E(t,r_t) - \widetilde{V}^D(t,r_t)$ is increasing in r_t

The proof is done by induction for the traditional way of modeling the examination stage. The proof for the alternative way of modeling the examination stage is identical to setting $\pi_{Grnt} = 1$.

We know that $\widetilde{V}^E(t,r_t)$, $\widetilde{V}^D(t,r_t)$, $\widetilde{V}^K(t,r_t)$ are continuous and increasing in r_t. Assume that $q < \pi_{Grnt}$ and without loss of generality that the examination period takes only one year ($S = 1$).

Consider period $t = a = L$ first:

$$\widetilde{V}^E(L,r_L) = qr_L - (c_L + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) + \beta\theta\pi_{Grnt}E\left[\widetilde{V_K}(L+1,r_{L+1}) \mid r_L\right];$$

$$\widetilde{V}^D(L,r_L) = qr_L - c_L + \beta\theta E\left[\widetilde{V_D}(L+1,r_{L+1}) \mid r_L\right];$$

$$\widetilde{V}^K(L+1,r_{L+1}) = r_{L+1} - c_{L+1} + \beta\theta E\left[\widetilde{V_K}(L+2,r_{L+2}) \mid r_{L+1}\right].$$

We show that $\widetilde{V}^E(L,r_L) - \widetilde{V}^D(L,r_L) + (C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt})$ is increasing in r_L:

$$\widetilde{V}^E(L,r_L) - \widetilde{V}^D(L,r_L) + (C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) =$$

$$= \beta\theta\left\{\pi_{Grnt}E\left[\widetilde{V_K}(L+1,r_{L+1}) \mid r_L\right] - E\left[\widetilde{V_D}(L+1,r_{L+1}) \mid r_L\right]\right\} =$$

$$= \beta\theta\{\pi_{Grnt}E\left[max\left(\widetilde{V}^K(L+1,r_{L+1}), \widetilde{V}^X(L+1,r_{L+1})\right) \mid r_L\right] -$$

$$-E\left[max\left[\widetilde{V}^E(L+1,r_{L+1}), \widetilde{V}^W(L+1,r_{L+1})\right] \mid r_L\right]\} =,$$

and since deferring examination is not possible in $t = L+1$,

$$= \beta\theta\{E\left[max\left(\pi_{Grnt}\widetilde{V}^K(L+1,r_{L+1}), 0\right) \mid r_L\right] - E\left[max\left(\widetilde{V}^E(L+1,r_{L+1}), 0\right) \mid r_L\right]\}.$$

Since $r_{L+1} = g_{L+1}r_L$ it suffices to show that $\pi_{Grnt}\widetilde{V}^K(L+1, r_{L+1}) - \widetilde{V}^E(L+1, r_{L+1})$ is increasing in $r_{L+1} \geq 0$:

$$\pi_{Grnt}\widetilde{V}^K(L+1, r_{L+1}) - \widetilde{V}^E(L+1, r_{L+1}) =$$

$$= \pi_{Grnt}r_{L+1} - \pi_{Grnt}c_{L+1} + \pi_{Grnt}\beta\theta E\left[\widetilde{V_K}(L+2, r_{L+2}) \mid r_{L+1}\right] - qr_{L+1}+$$

$$+(c_{L+1} + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) - \beta\theta\pi_{Grnt}E\left[\widetilde{V_K}(L+2, r_{L+2}) \mid r_{L+1}\right] =$$

$$= \pi_{Grnt}r_{L+1} - qr_{L+1} + \pi_{Grnt}\beta\theta E\left[\widetilde{V_K}(L+2, r_{L+2}) \mid r_{L+1}\right] -$$

$$-\beta\theta\pi_{Grnt}E\left[\widetilde{V_K}(L+2, r_{L+2}) \mid r_{L+1}\right] + (c_L + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) - \pi_{Grnt}c_{L+1} =$$

$$= (\pi_{Grnt} - q)r_{L+1} + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) + (1 - \pi_{Grnt})c_{L+1}\ ,$$

and increasing in $r_{L+1} \geq 0$.

Now, consider periods $t = 1, ..., L-1$:

$$\widetilde{V}^E(t, r_t) = qr_t - (c_t + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) + \beta\theta\pi_{Grnt}E\left[\widetilde{V_K}(t+1, r_{t+1}) \mid r_t\right];$$

$$\widetilde{V}^D(t, r_t) = qr_t - c_t + \beta\theta E\left[\widetilde{V_D}(t+1, r_{t+1}) \mid r_t\right];$$

$$\widetilde{V}^K(t+1, r_{t+1}) = r_{t+1} - c_{t+1} + \beta\theta E\left[\widetilde{V_K}(t+2, r_{t+2}) \mid r_{t+1}\right].$$

Assume that $\widetilde{V}^E(t+1, r_{t+1}) - \widetilde{V}^D(t+1, r_{t+1})$ is increasing in r_{t+1}.

We have to show that with this assumption,

$\widetilde{V}^E(t, r_t) - \widetilde{V}^D(t, r_t) + (C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt})$ is increasing in r_t.

$$\widetilde{V}^E(t, r_t) - \widetilde{V}^D(t, r_t) + (C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) =$$

$$= \beta\theta\{\pi_{Grnt}E\left[\widetilde{V_K}(t+1, r_{t+1}) \mid r_t\right] - E\left[\widetilde{V_D}(t+1, r_{t+1}) \mid r_t\right]\} =$$

$$= \beta\theta\{E\left[max\left(\pi_{Grnt}\widetilde{V}^K(t+1, r_{t+1}), 0\right) \mid r_t\right] -$$

$$-E\left[max\left(\widetilde{V}^E(t+1, r_{t+1}), \widetilde{V}^D(t+1, r_{t+1}), 0\right) \mid r_t\right]\}.$$

Since $\pi_{Grnt}\widetilde{V}^K(t+1, r_{t+1}) - \widetilde{V}^E(t+1, r_{t+1}) =$

$= (\pi_{Grnt} - q)r_{t+1} + C_{PO}^{Exam} + C_{self}^{Exam} + \beta\theta\pi_{Grnt}C_{PO}^{Grnt}) + (1 - \pi_{Grnt})c_{t+1}$ is increasing in r_{t+1},

and by assumption $\widetilde{V}^E(t+1, r_{t+1}) - \widetilde{V}^D(t+1, r_{t+1})$ is increasing in r_{t+1},

then $\pi_{Grnt}\widetilde{V}^K(t+1, r_{t+1}) - \widetilde{V}^D(t+1, r_{t+1})$ must also be increasing in r_{t+1}.

Given that r_{t+1} is increasing in r_t, $\widetilde{V}^E(t, r_t) - \widetilde{V}^D(t, r_t)$ must also be increasing in r_t and the proof is complete.

3.7.2 Value Functions and Cut-off Values

Here, we present a sketch of how the value functions and the cut-off values can be calculated assuming $L = 7$, $S = 1$ and K expected examination costs. The presentation is general and not restricted to a specific type of stochastic specification or assumptions concerning the examination stage.

Periods 2-20 if patent is already granted: $(g_t = g_t^G \sim F_t^G(u_T^G))$

Period 20:

$\widetilde{V}^K(20, r_{20}) = r_{20} - c_{20} = g_{20}^G r_{19} - c_{20};$

Cut-off value:

$\widetilde{V}^K(20, r_{20}) = 0 \Rightarrow \hat{r}_{20}^K = c_{20}$ (respectively $\hat{g}_{20}^K = \frac{c_{20}}{r_{19}^G}$).

Period 19:

$$\widetilde{V}^K(19, r_{19}) = r_{19} - c_{19} + \theta\beta \int_{\hat{g}_{20}^K}^{B} \widetilde{V}^K(20, r_{20}) dF_{20}^G(u_{20}^G) =$$

$$= r_{19} - c_{19} + \theta\beta \int_{\frac{c_{20}}{r_{19}^G}}^{B} (u_{20}^G r_{19} - c_{20}) dF_{20}^G(u_{20}^G);$$

Cut-off value:

$\widetilde{V}^K(19, r_{19}) = 0 \Rightarrow \hat{r}_{19}^K$ (respectively $\hat{g}_{19}^K = \frac{\hat{r}_{19}^K}{r_{18}}$).

Period 18:

$$\widetilde{V}^K(18, r_{18}) = r_{18} - c_{18} + \theta\beta \int_{\hat{g}_{19}^K}^{B} \widetilde{V}^K(19, r_{19}) dF_{19}^G(u_{19}^G) =$$

$$= r_{18} - c_{18} + \theta\beta \int_{\hat{g}_{19}^K}^{B} \left[u_{19}^G r_{18} - c_{19} + \theta\beta \{ \int_{\hat{g}_{20}^K}^{B} (u_{20}^G r_{19} - c_{20}) dF_{20}^G(u_{20}^G) \} \right] dF_{19}^G(u_{19}^G) =$$

$$= r_{18} - c_{18} + \theta\beta \int_{\frac{\hat{r}_{19}^K}{r_{18}^G}}^{B} \left[u_{19}^G r_{18} - c_{19} + \theta\beta \{ \int_{\frac{c_{20}}{u_{19}^G r_{18}^G}}^{B} (u_{20}^G u_{19}^G r_{18} - c_{20}) dF_{20}^G(u_{20}^G) \right] dF_{19}^G(u_{19}^G);$$

Cut-off value:

$\widetilde{V}^K(18, r_{18}) = 0 \Rightarrow \hat{r}_{18}^K$ (respectively $\hat{g}_{18}^K = \frac{\hat{r}_{18}^K}{r_{17}}$).

Period 17:

...

Periods 1-8 in case of a pending application: $(g_t = g_t^A \sim F_t^A(u_t^A))$

Since the shock on the growth rate during the examination is unexpected one also has to calculate $\widetilde{V}_t^K(t, r_t)$ and $\hat{r}_t^K$ (respectively $\hat{g}_t^K$), $t \in 2, ..., 20$ assuming $g_t = g_t^A \sim F_t^A(u_t^A)$ since these are the returns the applicants expect to receive in future periods. These value functions and cut-off values are then used for the calculation of value functions of the applicant.

Period 8

if examination is requested:

$$\widetilde{V}^E(8, r_8) = qr_8 - K - c_8 + \theta\beta\pi_{Grnt} \int_{\hat{g}_9^K}^{B} \widetilde{V}^K(9, r_9) dF_9^A(u_9^A) =$$

$$= qr_8 - K - c_8 + \theta\beta\pi_{Grnt} \int_{\frac{\hat{r}_9^K}{r_8}}^{B} \widetilde{V}_9^K(9, g_9^A r_8) dF_9^A(u_9^A);$$

cut-off value:[130]

$\widetilde{V}_8^E(8, r_8) = 0 \Rightarrow \hat{r}_8^E$ (respectively $\hat{g}_8^E = \frac{\hat{r}_8^E}{r_7}$).

Period 7

if examination is requested:

$$\widetilde{V}_7^E(7, r_7) = qr_7 - K - c_7 + \theta\beta\pi_{Grnt} \int_{\frac{\hat{r}_8^K}{r_7}}^{B} \widetilde{V}_8^K(8, g_8^A r_7) dF_8^A(u_8^A);$$

if examination is deferred:

$$\widetilde{V}_7^D(7, r_7) = qr_7 - c_7 + \theta\beta\pi_{Grnt} \int_{\frac{\hat{r}_8^E}{r_7}}^{B} \widetilde{V}_8^E(8, g_8^A r_7) dF_8^A(u_8^A);$$

cut-off values:

$\widetilde{V}_7^D(7, r_7) = 0 \Rightarrow \hat{r}_7^D$ (respectively $\hat{g}_7^D = \frac{\hat{r}_7^D}{r_6}$);

[130] Deferment is not possible anymore.

$\widetilde{V}_7^E(7, r_7) = \widetilde{V}_7^D(7, r_7) \Rightarrow \hat{r}_7^E$ (respectively $\hat{g}_7^E = \frac{\hat{r}_7^E}{r_6}$).

Period 6

if examination is requested:

$$\widetilde{V}_6^E(6, r_6) = qr_6 - K - c_6 + \theta\beta\pi_{Grnt} \int\limits_{\frac{\hat{r}_7^K}{r_6}}^{B} \widetilde{V}_7^K(7, g_7^A r_6) dF_6^A(u_6^A);$$

if examination is deferred:

$$\widetilde{V}_6^D(6, r_6) = qr_6 - c_6 + \theta\beta\pi_{Grnt} \int\limits_{\frac{\hat{r}_7^E}{r_6}}^{B} \widetilde{V}_7^E(7, g_7^A r_6) dF_7^A(u_7^A) + \int\limits_{\frac{\hat{r}_7^D}{r_6}}^{\frac{\hat{r}_7^E}{r_6}} \widetilde{V}_7^D(7, g_7^A r_6) dF_7^A(u_7^A);$$

Cut-off value:

$\widetilde{V}_6^D(6, r_6) = 0 \Rightarrow \hat{r}_6^D$;

$\widetilde{V}_6^E(6, r_6) = \widetilde{V}_6^D(6, r_6) \Rightarrow \hat{r}_6^E$.

Period 5

...

3.7.3 Parametric Bootstrap

Since we do not know the empirical distribution of the observed hazard rates we will apply a parametric bootstrap method to estimate the standard errors of the parameters ω. Instead of simulating bootstrap samples that are i.i.d. from the empirical distribution as it is done in non-parametric bootstrap methods we simulate bootstrap samples that are i.i.d. from the estimated parametric model. Following Efron and Tibshirani (1993) we apply the following bootstrap algorithm:

1. Use the estimated parameters $\hat{\omega}^*$ and generate a random sample of N patent applications.
2. Simulate the decisions resulting from the model specification and obtain the sequence of pseudo hazard rates $\eta(\hat{\omega}^*)$.
3. Minimize the loss function in 3.8 using $\eta(\hat{\omega}^*)$ instead of h_N and obtain $\hat{\omega}_b^*$.
4. Repeat the steps 1.-3. B times.
5. Calculate the parametric bootstrap estimate of standard error:

$$\hat{se}_B = \left\{ \frac{\sum_{b=1}^{B} \left[\hat{\omega}_b^* - \hat{\omega}^*(.)\right]^2}{(B-1)} \right\}^{\frac{1}{2}}, \text{ where } \hat{\omega}^*(.) = \frac{\sum_{b=1}^{B} \hat{\omega}_b^*}{B}$$

Chapter 4

Summary of the Results and Outlook

This thesis has analyzed two institutional choices for patent system design, the license of right and the option to defer patent examination. By declaring the license of right a patentee voluntarily forgoes his right to exclude others. In return the legislator grants him a reduction on the costs of maintaining patent protection. Furthermore, the patentee maintains the right to reasonable compensation through licensing. In Chapter 1 we have shown that LOR is used by many patentees in Germany but the usage rates depend significantly on the type of technology, the value and age of the patent as well as applicant and market characteristics. Deferred examination exists in many patent systems and allows the applicant to postpone the patent examination request for several years after the filing date. Using data on Canadian patent applications we observe that most applicants defer the decision to request examination for at least one year. Some applicants even let the examination option lapse and never request examination.

We have exploited patent applicants' decisions to either declare LOR (Chapter 2) or to defer patent examination (Chapter 3). Using structural estimation techniques we estimated the distributions of different types of patent protection. In Chapter 2 we have shown that a major part of the private value from patent protection is derived from the right to exclude others but some patentees can maintain or even increase their returns if they commit to license non-exclusively. In Chapter 3 we have estimated that a significant part of the returns from patent protection can already be realized before the patent is even granted and the application is still pending. Using counterfactual policy experiments we were further able to calculate the option value of the two patent system design choices. Both increase the private returns provided by the patent system. Furthermore, LOR is likely to decrease social costs by helping to remove exclusivity earlier. Deferred patent examination is able to reduce the patent offices' workload and improve the quality of granted patent applications. These results highlight that the institutional design significantly impacts the incentive structure to undertake R&D investments as well as the market imperfections, which are both created by the patent system.

The results in the last two chapters relied on structural estimation techniques using aggregated data. The next logical step is to look at different technology areas and applicant types separately. Differences between as well as within discrete and complex technology areas can be significant. In Chapter 1 we have seen that LOR has been declared for 11.4% of all patents in electrical engineering while only for 1.3% of all patents in chemicals and pharmaceuticals. Large corporations declare LOR for 12.2% of their patents but small corporations only for 1.6%. Besides, the timing of declaration as well as the expiration decision may depend on the technology the patent belongs to and the type of the proprietor. These differences indicate that the distribution of the value of exclusivity should vary across the aforementioned groups. Thus, the welfare implications and the effectiveness of the license of right system could differ, too. Henkel and Jell (2010) identified that the technology field is also a major driver of the decision to defer the examination request for German patent applications. They observe that in complex technology areas patent applications are more likely to be pending for seven years, the maximum deferment period in Germany, than in discrete technology areas. The nature of the invention and the associated uncertainty usually differ across technologies and with it the role of patent protection. Thus, the value of patent applications and the value of the option to defer examination should vary, too.

Another avenue for future research could be the development of an integrated model which incorporates all major facets of patent systems. The classical models developed in Pakes and Schankerman (1984) and Pakes (1986) relied solely on the patentees' decisions whether to renew an already granted patent application, or not. Lanjouw (1998) recognized that patent rights are often infringed and patent prosecution is an important part of patent protection. Therefore, she has introduced litigation into the renewal model. Putnam (1996) and Deng (2011) have further extended the model and allowed applicants to apply in several countries. Thus, they were able to use additional information on the size of the patent family for their estimations. Serrano (2011) recognized that patents are often reassigned during their lives. He incorporated the decision to transfer the patent right into the patent renewal model and used US reassignment data for estimation. In Chapter 1 of the thesis we accounted for the possibility to declare LOR in the German patent system.

The model developed in Chapter 2 already incorporates the application, the examination, and the renewal stage, but still does not include all options that exist in patent systems. Different institutional choices have different effects on the applicants' or patentees' behaviour. Although it is important to analyze them in isolation, a model which incorporates all options may have certain advantages. First, it will allow to use additional information for estimation. Nowadays, data on legal events is recorded electronically by almost all patent offices and may be easily accessed. Additional information and the cost structure associated with different institutional choices may considerably improve identification and precision of estimation. Second, it may allow for more elaborate counterfactual analysis. Policy changes often have secondary effects. Using a complete model one could also analyze the effects on other choices made by the applicants. For example a change in the incentive structure for the LOR declaration may as well affect application or examination decisions.

Although all patent renewal models rely on the importance of patent fees for patentees to derive information about the value of patent protection, they disregard that patent offices charge many other fees besides post-grant renewal fees. Application, examination and patent validation are usually never free of charge and are due before the patent is issued. Post-grant fees are more likely to effect the lifetime of already granted patents whereas pre-grant fees ought to have an impact on the decision where and whether to get a granted patent. Many patent applications are often withdrawn before or even during the examination process. A complete model would significantly contribute to the discussion on how patent fees should optimally be designed. So far the economic literature is unclear about the optimal integrated fee structure (see de Rassenfosse and van Pottelsberghe 2012) and important differences exist between patent systems worldwide. Previous studies have either looked at the role of pre-grant fees or post-grant fees in isolation but rarely in combination. The optimal fee structure should create the right balance between providing incentives to invest in R&D and the social costs of having exclusion rights and will surely depend on the underlying technology, too.

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