EKONOMI OCH SAMHÄLLE
ECONOMICS AND SOCIETY

KU LEUVEN
FACULTY OF ECONOMICS
AND BUSINESS

HANKEN

Essays on the Economics of Patent Rights

Measuring the value of patents using renewal information

ALEXIS STEVENSON

Ekonomi och Samhälle
Economics and Society

Skrifter utgivna vid Svenska handelshögskolan
Publications of the Hanken School of Economics

Nr 362

(KU Leuven nr. 788)

Alexis Stevenson

Essays on the Economics of Patent Rights

Measuring the value of patents using renewal information

Helsinki 2022

Essays on the Economics of Patent Rights: Measuring the value of patents using renewal information

Keywords: patents, innovation, intellectual property, dynamic models, industrial organization

Supervised by
Otto Toivanen
Professor
Aalto University School of Business, Finland

Mattia Nardotto
Associate Professor
KU Leuven, Belgium

Tuomas Takalo
Senior Research Advisor
Bank of Finland

Opponent
Carlos Serrano
Associate Professor
Pompeu Fabra University, Spain

Alexis Stevenson
Hanken School of Economics
Department of Finance and Economics
Subject: Economics
P.O.Box 479, 00101 Helsinki, Finland

Hanken School of Economics
ISBN 978-952-232-466-5 (printed)
ISBN 978-952-232-467-2 (pdf)
ISSN-L 0424-7256
ISSN 0424-7256(printed)
ISSN 2242-699X (pdf)

Hansaprint Oy, Turenki 2022

Dissertation presented to obtain a Double Doctoral Degree between Hanken School of Economics and KU Leuven

Doctor of Science in Economics and Business Administration,
Hanken School of Economics, Finland

Doctor of Business Economics,
KU Leuven, Faculty of Business and Economics, Belgium

Supervisors

Prof. Dr. Mattia Nardotto
KU Leuven

Dr. Tuomas Takalo
Bank of Finland, Helsinki GSE

Prof. Dr. Otto Toivanen
Aalto University School of Business, Helsinki GSE, CEPR

ACKNOWLEDGMENTS

While only my name is written on the cover of this dissertation, I do not consider myself as its sole author. I would not have been able to achieve this work without the constant help and support of my supervisors and co-authors, colleagues, friends and family.

I am deeply grateful to my supervisors Otto Toivanen and Tuomas Takalo from whom I have learnt so much. I could not have asked for a better team of advisors. Despite the obstacles presented by the pandemic and remote working, they were always present and supportive in all of the steps of my PhD track. They guided me and contributed significantly to the content of all of the essays including as co-authors of the last chapter.

In addition, I wish to thank my Committee Mattia Nardotto, Ari Hyytinen, Carlos Serrano and Jo Seldelsacht. Each of them provided valuable comments and suggestions during meetings and presentations, which improved considerably the content of this thesis. Furthermore, I am grateful to Ari and Tuomas for allowing me the opportunity to contribute to a policy report on Intellectual Property Rights in Finland which piqued my interest in working at the intersection of research and policy.

I was very grateful to initially spend a year as a visiting PhD student in the Department of Economics in KU Leuven in autumn 2018. This year turned out to be 18 months and then was followed by a double doctoral degree between KU Leuven and Hanken School of Economics thanks to the support and supervision of Mattia Nardotto. I want to thank the IO group in Helsinki, in KU Leuven as well as the MSI department for welcoming me and giving me the opportunity to present and receive insightful remarks and questions. A special thanks to Topi Miettinen for accepting to be my degree supervisor in the first years, Rune Stenbacka for giving me the opportunity to teach and act as the chairman, Jiekai Zhang with whom I share this exotic Toulouse-Helsinki-Leuven connection and Jo van Biesebroeck for inviting me to KU Leuven.

I was also extremely fortunate to have met other PhD students and postdocs who were very supportive and with whom I shared both moment of despair as well as excitement. I want to thank specifically Min, Olena, Elyas, Katia, Hugo and Marcelina. I also wish to thank all of the other students I met along the way at Hanken and KU Leuven, who made my experience of PhD studies much more enjoyable.

I am sincerely thankful to the Hanken Foundation, OP-Pohjola Foundation, Yrjö Jahnsson Foundation, KAUTE Foundation and the IPR University Center for providing academic and financial support on my doctoral journey.

I also have a debt to all of those who helped me to navigate the maze of administrative procedures in order to make this doctoral degree happen: Anu Helkkula, Anja Hayes, Elfriede Lecossois, Ari Hyytinen and Rune Stenbacka. I am also grateful to Marlene Günsberg and Johanna Tenström for the great work on the layout of this thesis.

Last but not least, I would like to extend my sincere thanks to my family outside of academia: My mother Francine for proofreading this thesis, to her and Jean-Pierre for always pushing me to achieve my goals. I am grateful to my siblings Marc and Chloé for all the cherished moments spent together despite living relatively far from each other. I want to thank also my friends Marion and Tanguy who visited Finland and with whom trips to Lapland distracted me from my PhD and gave me a much-needed break. Finally, I want to thank my love Caoimh for your unconditional support and encouragement to finish this thesis. I couldn’t have done it without you.

Aix-en-Provence, July 2022

CONTENTS

> *Before […], any man might instantly use what another had invented; so that the inventor had no special advantage from his own invention. The patent system changed this; secured to the inventor, for a limited time, the exclusive use of his invention; and thereby added the fuel of interest to the fire of genius, in the discovery and production of new and useful things.*
>
> – Abraham Lincoln - Lecture on “Discoveries and Inventions”, 1858

1 BACKGROUND ON THE ECONOMICS OF PATENTS

1.1 A short introduction on innovation

Innovation is key to address global challenges of our time and to foster sustainable development. Innovation is largely accountable for rising standards of living that benefit consumers, businesses and the economy as a whole. Studies in growth theory have confirmed the essential role of innovation and diffusion of knowledge in long term economic development (e.g. Aghion, Akcigit and Howitt, 2014). Nevertheless, the mechanisms by which higher rates of innovation could lead to higher inequality and therefore be an impediment to economic development are currently debated (Blundell, Jaravel and Toivanen, 2021).

The Oslo Manual (OECD and Eurostat, 2018) defines an innovation as “a new or improved product or process (or combination) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)”. Innovations are often protected by intellectual property rights (IPRs). The term IPRs refers to patents, trademarks, copyrights, industrial designs and other types of intangible property. Most developed countries have research and innovation (R&I) policies to encourage innovation and promote the use and diffusion of new inventions. Patents are an important instrument of innovation policy and they are widely used by companies and individuals as a method of legal protection. Patent systems are designed to provide incentives to engage in R&D with a limited period of exclusivity and without preventing the diffusion of knowledge. This thesis provides an in-depth study into the incentives and rents created by patent systems.

2.2 The patenting process

A patent is a temporary right granted to a patentee to prevent others from using, selling, making or importing an invention without the consent of the patent owner in a region where a patent is in force. Therefore, a patent is a territorial right and it extends only within the borders of the jurisdiction that has granted it. It could be a country or a region such as in the case of EPO patents which are granted in several European countries.

The patenting process follows some usual steps with some specificities for EPO patents or patents under the Patent Cooperation Treaty (PCT) for instance. First, patent applicants (individuals, companies, universities, NGOs, etc...) file an application describing the invention to a patent office. The patent office is in charge of the examination which usually lasts two to six years. The invention is then disclosed 18 months after the filing date of the patent, without possibility for others to exploit the invention. At the end of the examination stage, the office decides to grant a patent or reject the application. To be granted a patent, an invention requires three features: i) Be new or novel; ii) be nonobvious (US patent law) or involve an inventive step (European patent law); and iii) be useful (US patent law) or capable of industrial application (European patent law). Additionally, the invention should be a patent-eligible subject matter[1] Most patent offices charge renewal fees, also called maintenance fees, to keep the patent in force and patents are usually granted for a maximum period of 20 years from the filing date. Renewal fee schemes have a role in screening less valuable patents with short renewal decisions from more valuable patents that are renewed longer. The role of renewal fee schemes is the focus of this thesis.

1.3 A brief history of patent systems in Europe and in the US

The first modern patents were granted by the Republic of Florence in the fifteenth century (see Guellec and van Pottelsberghe de la Potterie, 2007, for description of the history of patent systems). An oft-cited example is the architect Brunelleschi who received what is considered to be the first ever industrial patent in 1421. The patent protected a system of transport for marble on the Arno river by giving the right to exclude any new means of transport on the river for three years (Prager, 1946). In 1474, the Venitian Senate adopted the first patent law that was in force

---

[1] Patents can protect all fields of technology but aesthetic creations, theories and abstract ideas are excluded from patentability

up to 1650. The initial goal was to attract foreign craftsmen to settle and work in Venice and train local workers with a 10-year patent exclusivity. England granted the first concession to an inventor

in 1561 but the system was mostly used by the Crown to reward servants. In 1623, the grant of monopolies was codified in line with the Venitian law and, progressively, the Crown lost the right to grant concessions for the benefit of the Courts.

Modern patent laws started in Great Britain in 1718 with Courts requesting a detailed description of the invention to be published at the time of the grant. The United States introduced its own system in 1790. Initially, the US system included a prior review process of patent applications to ensure the novelty of patented inventions. In 1793, the examination procedure was abolished and replaced by a simple registration system due to the difficulty of handling the high number of patent applications submitted. In 1836, the US Patents and Trademark Office (USPTO) was created to examine and grant patents. The duration was 14 years and then extended to 17 years in 1861. In France, “patentes royales” were issued in the sixteenth century to attract foreign craftsmen. The term was on average 20 years and the invention was disclosed after its expiration. The patent system was reformed in 1791 after the French Revolution. It became mainly a registration system with a patent term of 5, 10 or 15 years. During the nineteenth century, many European countries introduced patent laws inspired by the French system: Austria in 1810, Prussia in 1815, Spain in 1820, Sweden in 1834, Portugal in 1837, etc...

Between 1850 and 1875 a strong European movement against patents emerged (Machlup and Penrose, 1950). The main critiques pointed to the negative effects of patents on competition and came from movements against monopoly and in favor of free trade. The anti-patent movement led to the abolition of the Dutch patent system in 1869 (which was reinstated in 1911), as well as to the delay in the adoption of patent systems in the German Zollverein and in Switzerland. Since the end of the nineteenth century and the early twentieth century, there has been an increasing harmonisation of patent systems and a strengthening of patent protection. One important example is the Paris Convention signed in 1883 which established the principle of national treatment: Foreigners are treated the same as nationals. It also established the principle of priority application which is the possibility for an applicant to file an application in a country other than their own within a specified time limit (currently 12 months).

1.4 Patent from an economic point of view

The traditional view in the economic literature considers patents as a policy instrument to address the failure of the market to provide sufficient incentives to innovate. In fact, property rights are created to protect knowledge. Knowledge is a public good which is both non-rivalrous and non-excludable. Non-rival means that once the knowledge is disclosed, different persons can use it without reducing the total quantity of knowledge available. Non-excludable refers to the fact that it is not possible to exclude others from having access to knowledge. The argument for patents is that in perfect competition, without exclusive rights to legally protect inventions, markets tend to generate an under-optimal rate of inventions. Public intervention is then needed to restore private incentives to innovate. In other words, patents work as incentive mechanisms for further innovation.

The standard trade-off of patents is well-known at least since Nordhaus (1969). The trade-off is between static inefficiency - created by the patent holder's monopoly power - and dynamic efficiency by promoting innovation and diffusion. On the one hand, patents create incentives to innovate by giving extra-rewards beyond competitive profits to recoup R&D investments. Patents can also encourage diffusion with early publication of inventions which might otherwise not have been disclosed. On the other hand, patents create an economic inefficiency called deadweight loss. With a patent, an inventor can exert some market power and charge a price above the marginal cost by excluding others from using an invention during the patent life.

In reality, the trade-off is more complex (Hall and Harhoff, 2012) and takes into account multiple dimensions. Measuring costs and benefits of patent systems should also include the cumulative dimension of inventions. Patent systems have an important role in simultaneously increasing innovation and the diffusion of information (Kultti, Takalo and Toikka, 2007). Empirical work shows that the disclosure of inventions through the opening of patent library can be beneficial for follow-on innovation (Furman, Nagler and Watzinger, 2018).

Patents, by preventing imitation, can also increase social costs. Indeed, although imitation reduces the profit for an inventor, it increases the probability of follow-on innovations which can improve the future profits of the inventor (Bessen and Maskin, 2009). Stronger patent protection can also be detrimental to innovation by slowing down market introduction. Under some circumstances, patents increase the threshold value for market introduction and enhance the ability of the innovators to wait for the introduction of the innovation (Takalo and Kanniainen, 2000). In more recent years, some patent holders have used property rights strategically in a way that could harm innovation as is the case with patent trolls (Bessen, Ford and Meurer, 2011). Another strong limitation is that patent enforcement requires significant amounts of financial resources that are not used in the innovation process.

In fact, it has been hard to find any positive effects of stronger patent protection on innovation. Examining the impact of 177 shifts in patent policy in 60 countries over a period of 150 years, Lerner (2009) finds the puzzling result that strengthening patent protection does not have a clear and significant positive effect on innovation. Similarly, reviewing a large body of studies including surveys, natural and quasi-experiments, Sampat (2018) does not find any conclusively positive effects. He highlights that the effects of patents are sector-specific with stronger effects in pharmaceuticals and chemicals industries. Additionally, strengthening patent protection would not necessarily increase innovation even if it leads to changes in patent propensity, as a large number of innovations occur outside the patent system. Some economists even claim that the society would be better off without patents (Boldrin and Levine, 2013).

1.5 Patent data in economic research

Patent data are valuable and widely used information to study trends in science and innovation. They are very rich and include information on technologies, inventors, applicants and types of invention on a wide geographical and time scale. Patent data have been increasingly used in economic research because of the widening availability, relative standardisation across countries and increasing computing power. The pioneers using patent data in economics are Scherer (1965), Schmookler (1966) and Griliches (1979). More particularly, Griliches is the first to use computerised USPTO data as well as one of the first to develop the idea that patent data can be used as a measure of innovation output and R&D spillovers. Today, researchers increasingly exploit full-text patents as it becomes more readily available.

2 MOTIVATION FOR THE THESIS

2.1 Surge of intangible assets

In developed economies based on knowledge, the importance of intangible assets (patent portfolio, design, data, brand image, ...) relative to tangible assets like machinery or buildings (Haskel and Westlake, 2017) is growing. This trend is confirmed by different metrics including the number of patent applications and patents granted in major patent offices.

According to WIPO IP Statistics Data Center, there were more than 600,000 patent applications (direct and PCT) in the US in 2020 and around 350,000 patents granted by the USPTO. This demonstrates a significant rise since 2000 when less than 300,000 patent applications were received by USPTO and 150,000 patents were granted. Similarly, in Europe, there were 180,000 patent applications received by the EPO (direct and PCT) in 2020, marking an 80% increase since 2000. Even more striking is the number of patent applications and patents granted in China. There were approximately 1.5 million applications and 450,000 patents granted in 2019 in comparison to only 51,000 applications and 13,000 patents granted in 2000.

There is a debate which attempts to explain the patent explosion at the end of the twentieth century and early twenty-first century. Researchers have highlighted a number of factors to explain the rise in patent filings (Fink, Khan and Zhou, 2016). In pioneering work, Kortum and Lerner (1999) tested different hypotheses and concluded that changes in the management of innovation and research productivity can explain the patenting surge in the US between 1980 and the late 1990’s. Hall and Ziedonis (2001) underline the importance of patent portfolio races induced by institutional changes in explaining the surge of patenting in the semiconductor industry in the US. Several other researchers have associated the increase in patenting behaviour with the shift in the use of patents for strategic and tactical reasons. This strategic patenting behaviour includes patenting to increase bargaining power for cross-licensing (Shapiro, 2000; Kultti, Takalo and Toikka, 2006), to block other firms and prevent litigation, to prevent other firms patenting their similar discoveries (Kultti, Takalo and Toikka, 2007), to signal to secure capital (Hsu and Ziedonis, 2008; Hochberg, Serrano and Ziedonis, 2018), and patenting by nonpracticing entities or patent trolls (Bessen, Ford and Meurer, 2011). Additionally, globalisation and deregulation have opened new markets to companies. Danguy, De Rassenfosse and van Pottelsberghe de la Potterie (2014) look at 18 industries in 19 countries between 1987 and 2005 and show that the higher demand for patents can be attributed to globalisation rather than a surge in research productivity. This result has been particularly apparent for China (Zhang, 2010). Another argument supported by patent surveys is that the development of the Internet and other new means of communication make it more difficult to keep an invention secret. Therefore, legal means of protection are increasingly used for that reason. Moreover, patent subject matters have expanded notably to genomics material, software and business methods which can explain an increase in patenting.

The explosion of patent applications has outpaced other measures such as R&D and GDP. This trend begs the question of the quality and economic significance of the numerous patent applications and patents granted. There is a strong need to develop tools to accurately measure the value of the patented inventions. The overwhelming number of patents and consequently forward citations (Kuhn, Younge and Marco, 2020) is also a concern as patent counts and forward citations are widely used to measure technological progress.

The first essay of this thesis contributes to this debate by measuring the private value of patents granted in Finland using a dynamic renewal model with aggregate patent data. The second essay develops a dynamic model whereby inventors can “learn” the true value of their invention using information provided by citations received across time. The model is then applied to measure the private value of patents as well as citations received for patents granted in Germany in the semiconductor industry. Moreover, measuring the private value of patents and comparing them with previous works can give insights into the effectiveness of patent systems. In fact, it is informative to measure the extend to which the renewal fee scheme plays a role in encouraging more valuable inventions and discouraging those less valuable.

2.2 Strengthening patent protection

Over the past 50 years, patent systems have evolved with increasing integration and strengthening of patent protection. The strengthening takes multiple forms. It can be a change in the duration and coverage. As an example, the TRIPS Agreement in 1994 created some legal and quality standards for patent systems worldwide including a maximum patent term of 20 years from the patent application. Today, 164 parties are signatories to this agreement. The creation of the European patent in 1973 is an example of a change in geographical coverage with a single harmonised application and granting procedure for patents in the European Union. The strengthening can expand the protection to new subject matters. Multiple patent reforms in the US in the 1980's and 1990's extended the patentability to: Genetically engineered organisms in 1980, software in 1981 and business methods and financial services in 1998. Strong patent protection can also give more power to patentees in lawsuits and make it easier to enforce a patent. This has been the case with the creation of the Central Court of Appeal for the Federal Circuit (CAFC) in the US in 1982. The creation of the Unitary patent and the Unified Patent Court in Europe is also expected to contribute to the strengthening of patent protection and enforcement.

The series of "pro-patent" reforms raise multiple questions on the welfare effect of a broader patent protection. There is a need for more IP policy evaluation to ensure that the design of patent systems and patent policies fulfill the missions of maximising social welfare. There is a large body of empirical work using changes in patent policy as a natural experiment to provide insights into the effects of patent protection on patenting activities or on innovation (e.g. Lerner, 2002; Moser, 2005; Hall and Helmers, 2019; Izhak, Saxell and Takalo, 2021). Nevertheless, only few articles in industrial organization study the welfare effect of IP policy changes (e.g. Schuett and Schankerman, 2021). Adopting a theoretical approach, Stenbacka and Tombak (2020) analyse the welfare effect of changes of funding policy for universities including the Bayh-Dole Act of 1980 in the USA which allows the universities to licence the results from funded research. In the trade literature, some articles look specifically at the implication of strengthening patent protection for the less innovative South versus the more innovative North (e.g. Bilir, Moser and Talis, 2011). Nonetheless, most of the works are ex-post policy evaluations and very few works provide an ex-ante evaluation of IP policy (e.g. Danguy and van Pottelsberghe de la Potterie, 2011).

In the third essay, we develop a counterfactual analysis to quantify certain dimensions of private and social gains of a major institutional change in the patent system in Europe, the creation of the Unitary patent (UP). The new UP system allows a single harmonised post-grant procedure which will significantly reduce the cost of patenting in Europe. To evaluate the expected effects of the UP system, we link a renewal decision model to a patent production function and a demand model. We then use the estimates of the model to simulate the counterfactual effects of introducing the UP option on the private value and the quality of existing patented inventions as well as on the surplus for European consumers.

3 A LITERATURE REVIEW OF PATENT VALUATION METHODS[2]

3.1 The private value of patent rights

The private value of patents can be defined as the economic benefits received by a patent holder from patent protection. These economic rewards can be either direct or indirect (Murphy, Orcutt and Remus, 2012). Direct economic rewards refer to the discounted sum of returns for the patent owner. They are the above-average profits resulting from owning the patent. Patent protection can also create indirect economic rewards in the sense of competitive advantages. For instance, patents can provide positive signals to help firms acquire financial capital, even in the absence of patent revenues (Hsu and Ziedonis, 2008; Hochberg, Serrano and Ziedonis, 2018). Patents could also give a signal on the value of a firm to potential buyers. In this regard, Ali-Yrkkö, Hyytinen and Pajarinen (2005) find that the number of patents owned by a firm is positively associated with the probability of the firm being acquired. Patent rights can also have a value unrelated to economic benefits for some patent owners. This is notably the case for some individual inventors for whom a patent is a symbol of achievement or accomplishment even without a real economic value for the invention. The role of higher education and particularly engineering education in driving invention has been acknowledged (Toivanen and Väänänen, 2016).

In this literature review, we will adopt a definition of patent value consistent with direct and indirect economic rewards. To summarise, the private value of a patent will be defined here as the incremental value, above the profits that are captured in the absence of patent protection. It is noticeable that the patent valuation methods reviewed here do not usually consider the social value of patents that include externalities not appropriated by patent holders, such as knowledge spillovers. Additionally, other actors (e.g colleagues in a firm, company owner) can benefit from the returns of an invention. In an empirical study using data from Finland, Aghion et al. (2018) show important income spillover effects of inventions within firms where inventors collect less than 10% of the total private return, entrepreneurs collect 44.6% whereas blue-collar and white-collar share almost equally the remaining part.

---

[2] See also Takalo, Hyytinen and Stevenson (2021)

The literature does not always make a distinction between the value of patent rights, patent quality and the value of the patented invention. Nevertheless, these three concepts are different. An invention might have a private value even without patent protection. This is the case where other means of appropriability, such as e.g. trade secrecy, are used. Moreover, the private value of patent rights is sometimes used as a synonym of patent quality. In theory, the patent quality for a given invention is defined by the distance in the technology space between the invention and other existing inventions (De Rassenfosse and Jaffe, 2018). An invention can have a large inventive step and therefore a high patent quality, but generate small revenues and consequently have a low private value. This would be the case for an innovative treatment for a rare disease for which the market is small. To summarise, patent quality, the value of patent rights and the value of the patented invention are correlated but distinct.

Decision-makers rely on patent valuation to make informed decisions. These decisions could be: Acquiring an asset for a company by comparing the value of the asset to the cost; estimating damages in an infringement lawsuit; deciding on obtaining a patent and in which countries to obtain it; using a patent for securitisation (e.g. Hochberg, Serrano and Ziedonis, 2018), etc... The value of patents is also important information for public authorities when they take into account intangible assets in merger control or when they measure the reward given by a patent system. Patent rights are rarely traded (e.g. Figueroa and Serrano, 2019) so it is difficult to get a direct estimation of the market value of a patent. Therefore, indirect measures are often used to estimate the value of patents. Different methods have been developed in the literature based on indicators, surveys, market valuation and renewal decision models. We are reviewing the different approaches because they will be used in the subsequent essays.

3.2 Patent metrics to proxy for the value of patents

A first approach consists of isolating some patent metrics that are correlated with patent values. The most most common patent characteristics used in the literature are citations, claims, family size, opposition/litigation and renewal decisions (see Van Zeebroeck, 2011, for a review). A number of studies use these variables to estimate a regression function and approximate the value of patents. In other words, patents without known market value can be valued by comparing their patent metrics with the ones from patents whose market values are established (Falk and Train, 2017). Most of the time, this approach is used to construct patent counts taking into account the patent quality, to measure the inventive output.

Forward citations Forward citations are the citations received by a patent from subsequent patent filings. The early literature finds a positive association between the number of forward citations and some measures of private (Carpenter, Narin and Woolf, 1981) and social values of inventions (Trajtenberg, 1990). Forward citations are now extensively used in the literature as a measure of scientific and economic value. For an overview see Jaffe and De Rassenfosse (2019). The positive association has been confirmed by many empirical studies using different approaches. Harhoff et al. (1999) and Harhoff, Scherer and Vopel (2003a) find a positive correlation between the level of citations and values reported in surveys for US and German patents. The most highly cited patents are very valuable and a single citation implies an average value of about $1 million. Hall, Jaffe and Trajtenberg (2000, 2005) find that patents held by companies with relatively high stock market values are more frequently cited, all other things being equal. An extra citation per patent increases the market value by 3% (Hall, Jaffe and Trajtenberg, 2005). Lanjouw and Schankerman (2004) construct a composite indicator of patent quality and find that forward citations are a good predictor for renewal decisions and litigation. Recent studies highlighting this positive association include Kogan et al. (2017) and Moser, Ohmstedt and Rhode (2018).

If patent citations as a proxy for patent value are widely used in the economics of innovation, it is commonly acknowledged that the relationship is noisy and might even be ambiguous. Bessen (2008) finds that patent citations explain little variance in patent values which suggests some limitation in the use of this metric. Recent studies have started to question the interpretation of patent citations. Kuhn, Younge and Marco (2020) underline the possibly biased results from citation-based measures. They observe a change in the data generating process of patent citations in the US with a strong increase in the number of citations across years. It is mainly due to a small proportion of patents with an overwhelming number of references. Abrams, Akcigit and Grennan (2013) find that the relation between private values based on licensing fees and patent citations is non-monotonic with an inverse-U relationship. The positive correlation between citations and value holds only for low-value inventions. On the other hand, the high-value inventions are protected through aggressive strategies that reduce downstream innovation and explain a negative relationship between citations and value above a certain threshold.

The number of forward citations is primarily a measure of the scientific value of an invention rather than the private value. For instance, a patent could be of minor scientific advance and as a result has only received a small number of citations but may have a huge effect on blocking follow-on innovation. A main limitation in the use of forward citations is that the procedure is not easily applicable to recently issued patents because they do not have time to accumulate enough citations to make comparisons with other patents. The standard method in the literature is to count the number of citations received in a given period of time, e.g. 5 years from the publication. The number of forward citations needs to be analysed cautiously because citations can vary a lot across technologies, industries and regions and reflect different strategies in drafting, filing and managing patent applications by applicants and examiners (Alcácer, Gittelman and Sampat, 2009).

Backward citations Backward citations are all of the references to the existing prior art made in a patent application during the search and examination process. These references can be to other patents but also to the non-patent literature which is mostly scientific. Harhoff, Scherer and Vopel (2003a) find that the number of backward citations to patents and non-patent literature are positively correlated with patent value from surveys. The examiners tend to insert more references when patents are broader in scope. Similarly to forward citations, backward citations vary by patent offices, technologies and industries. Nikulainen, Hermans and Kulvik (2008) investigate the patenting behavior of Finnish biotechnology firms. They relate the present value of current and anticipated future sales revenues to backward and forward citations. They estimate different regression models with instrumental variables using various firm characteristics as controls. In all their specifications, they find a positive and statistically significant association between the number of backward citations and the present value of current and anticipated future sales. However, their results do not suggest any significant association with forward citations.

The number of claims and IPC codes The number and length of independent claims[3], and the number of IPC codes are often used as a measure of patent scope (called also breadth) in the literature (Marco, Sarnoff and Charles, 2019). Lanjouw and Schankerman (2001, 2004) find a positive association between the number of claims and forward/backward citation counts. It suggests that patents with high claim counts have a larger scope of protection and thereby a higher expected value. Nevertheless, they mention that it is difficult to say if patent claims are a good measure of the patent scope, the degree of patent protection and the patent value. Bessen (2008) finds that an additional claim increases the private value of patents measured by renewal data by around 2%. The length of patent claims has been recently used to measure radical versus incremental innovation (Akcigit and Ates, 2019). A patent with longer claims is likely to be narrower in scope and be associated with an incremental innovation. Claims are also influenced by the specificities of each patent office and legal system. It is the reason why Van Zeebroeck and Van Pottelsberghe de la Potterie (2011) suggest using a count of claims deflated by the mean or median number of claims in application from the same technological area and year of application, instead of using a raw count of claims. The number of IPC (International Patent Classifications) codes is also a measure of the scope of a patent or an indicator of patent complexity. Lerner (1994) for instance relates the market value of biotech firms to the number of four-digit IPC classes and finds a positive association.

Family size Family size is the number of jurisdictions in which a given invention is protected. Formally, the OECD defines a patent family as “the set of patents (or applications) filed in several countries which are related to each other by one or several common priority filings” (OECD, 2009). The idea of using the size of patent families was popularised by Putnam (1996) and Lanjouw, Pakes and Putnam (1998). Inventions protected in many countries are of a higher value because the owner of the patent decides to incur higher costs associated with multiple filings if the patent is of sufficient value to recoup them. Numerous studies find a positive correlation between patent or firm value and patent family size (Putnam, 1996; Harhoff, Scherer and Vopel, 2003a; Lanjouw and Schankerman, 2004; Van Pottelsberghe de la Potterie and Van Zeebroeck, 2008).

---

[3] The claims define in technical terms and concisely the matter for which protection is sought. Independent claims state the essential features which stand on their own whereas dependent claims express particular embodiments of the invention.

The triadic patent family which is a family including patent applications filed in the three largest patent offices: European Patent Office, US Patent and Trademark Office and the Japan Patent Office is a common measure of family size. The OECD uses the triadic patent family as an indicator of a high economic value patent. Dechezleprêtre, Ménière and Mohnen (2017) find also that the time duration between the first and the last filings within a family provide an indication of the value of patented inventions. It should be noted that the size of a family can change over time when some patents are abandoned in some countries and not in others.

Opposition and Litigation Opposition filed against EPO patents and opposition outcomes are also used as an indicator of patent value (Harhoff, Scherer and Vopel, 2003a; Van Zeebroeck, 2011). An opposition can be filed up to nine months after the grant of a patent by a third party. When an opposition is filed, it suggests that a patent is worth enough to justify the costs associated with a dispute. On average 6% of EPO patents filed between 1980 and 2002 have been opposed (Van Zeebroeck, 2011). Galasso and Schankerman (2010) find that an increase in the patent value measured by the total number of citations received increases the likelihood of patent litigation suggesting a positive association between these two variables.

Patent transfer Few papers explore the characteristics of traded patents, for which data on transfers are available from the patent office (USPTO) (Figueroa and Serrano, 2019), from data on patent auctions (Odasso, Scellato and Ughetto, 2015) or from data based on technological M&A (De Marco et al., 2017). In a pioneering analysis, Serrano (2010) uses re-assignment information at the USPTO to study the dynamics of patent transfers. He relates patent characteristics with rates of transfer and renewal. His findings suggest that more valuable patents that are younger, highly cited, more original and recently traded are more likely to be traded and renewed. Around 13.5% of all US patents are sold during the period 1985 to 2001. Serrano (2018) extends the work with a structural model of transfer and renewal to estimate the gains from trade (See Section 3.5).

Renewal data The number of renewal years is used as an indicator of patent value. Once a patent is granted, the patent is enforced as long as the renewal fees are paid in each country where patent protection is sought. If renewal fees are not paid, the patent lapses. The statutory limit of the patent is 20 years from the filing date. Only a small fraction of patents are renewed to the maximum length which suggests that the expected returns are not sufficient to cover the renewal costs. The number of renewal years as a measure of patent value has been popularised by models of patent renewal developed by Pakes and Schankerman (1984); Schankerman and Pakes (1985); Pakes (1986). Hall and Harhoff (2012) defend the fact that patent renewals are a good measure for the value distribution of patents as it is a revealed preference approach. We review in more depth the patent renewal models in Section 3.5.

3.3 Inventor surveys

The information available in patent documents can be used as a proxy for the value of patents. Nevertheless, patent data tells us little about how patents are used, licensed, transferred and whether they result in the creation of new products. Another approach to collect this type of information and measure the value of patents would be to rely on inventor surveys.

The first surveys of patent holders looked at a small sample of firms in the US (Sanders, Rossman and Harris, 1958; Scherer, 1965). Later, Harhoff et al. (1999); Scherer and Harhoff (2000); Harhoff, Scherer and Vopel (2003*a,b*) survey multiple German and US patent owners and provide estimates for the value of patents. The value is defined as the minimum price for which the initial inventor would be willing to sell the patent. More precisely, the question asked in the survey is: “What is the minimum price for which you would have sold the patent, assuming that you had a good-faith offer to purchase?”. Inventors of 772 German patents for which the full term expiration was 1995 were asked to locate their patent’s value in one of the five broad value class intervals ranging from less than €70,000 to more than €55 million. The median value is between €70,000 and €280,000. A larger scale survey, PatVal I (Giuri et al., 2007; Gambardella, Harhoff and Verspagen, 2008, 2017) collected inventors’ willingness to sell 9,017 patents granted by the European Patent Office with priority years between 1993 and 1997. This large-scale survey intends to be representative of the universe of EPO patents covering six main countries: France, Germany, Italy, the Netherlands, Spain and the United Kingdom. In this survey, patent holders were asked to locate the value of their patents in one of the ten value classes ranging from less than €30,000 to more than €350 million. The median value lies between €345,000 and €1.15 million. The results in the PatVal I survey are significantly higher than in Harhoff et al. (1999). The contrasting results can be explained by the difference in coverage, with only German patents surveyed in Harhoff et al. (1999) and EPO patents up to six countries in the PatVal I. The results of the surveys are reported in Table 1.

As noted by Gambardella, Harhoff and Verspagen (2008), the private value measured in surveys is the incremental value relative to a situation in which another firm owns the patent. Therefore, it also includes a strategic aspect which is the possibility for the buyer to block related patents of the previous owner. The value inferred from inventor surveys is called “asset value” in the literature. The asset value is different from the private value estimated in renewal decision models. On the one hand, the asset value is estimated relative to a situation where the patent protection and a leadership on a specific technology is transferred to a buyer. On the other hand, the private value from renewal decisions is estimated relative to a situation where the patent becomes part of the public domain and can therefore be used by anyone, including the firm that previously owned the patent. The transfer to a competitor of a patent that has a broad coverage can significantly affect the stream of returns for a product or a process protected by multiple patents. For this reason, inventor survey results are not directly comparable with the results from renewal decisions models. As shown in Table 1, median values obtained using surveys tend to be higher than the median private values obtained using patent renewal data.

The main limitation of inventor surveys is that the values are subjective because they are self-reported. Some inventors tend to overestimate or underestimate the value of their patents. As underlined by Giuri et al. (2007), on the lower tail of the distribution, inventors may be tempted to over-estimate the value of their patents. This behaviour is derived from the fact that it is difficult for a respondent to acknowledge that their invention is worth very little. Moreover, the size of the sample is limited which makes it difficult to generalize the approach at a larger scale. Nevertheless, surveys provide interesting pieces of information because they do not rely on indirect measures of patent value and they can be used to approximate the most valuable patents (Harhoff, Scherer and Vopel, 2003*b*).

3.4 Firm market valuation

Tobin’q studies A substantial number of papers relate the market value of firms - usually the Tobin’s q[4] - to tangible and intangible assets. The intangible assets, also called “knowledge stock”, are measured by different metrics such as R&D expenditure, patents and/or citation-weighted patents (Griliches, 1981; Pakes, 1985; Cockburn and Griliches,

---

[4] Market value divided by the replacement value of firm assets

1988; Megna and Klock, 1993; Toivanen, Stoneman and Bosworth, 2002; Nicholas, 2008; Hall, Jaffe and Trajtenberg, 2005; Bessen, 2009; Kogan et al., 2017). The goal of these papers is usually more to estimate the contribution of intangible assets to the firm value, than to directly measure the rents of patents. See Hall (1999); Czarnitzki, Hall and Oriani (2006) for a review. A byproduct of this literature is an estimate of the private value of patents. This stream of literature started with Griliches (1981) and Pakes (1985) who find that a successful patent is worth approximately \$200,000 and \$810,000 respectively, based on a small sample of 157 US publicly listed firms for the years 1968-1974. Nevertheless, these results are more observations than rigorous inference about the value of patent rents (Bessen, 2009). Hall, Jaffe and Trajtenberg (2005) look at all patents granted in the US between 1965 and 1996. They estimate a market-value equation using three different measures of knowledge stock that depend on patent, R&D and citations. They find that all of these ratios significantly affect the market value and that the mean value of a patent is approximately €140,000 in EUR 2010. Bessen (2009) estimates some upper-bounds for the patent rents in the US using regression on Tobin's q and finds a mean value of approximately €410,000. Focusing on the largest Finnish companies, Rahko (2014) considers the relationship between the stock market valuation and the intangible assets measured by R&D, patents and organizational capital. Organizational capital is defined here by management and marketing investments. She uses Finnish employer-employee data which let her observe the composition, wages and characteristics of workforce in Finnish companies during the years 1995-2008. She finds that R&D stock, the number of patents and the number of forward patent citations are positively and significantly associated with firms' market value.

Event studies There is an important stream of literature using event study to measure innovations (See Chaney, Devinney and Winer (1991) and Austin (1993) for seminal papers). Using daily stock market data, (Korkeamäki and Takalo, 2013) estimate the private value of the Apple's iPhone as well as the related IP, based on stock market reactions to news such as patent grant and patent application events. They find a private value of the product to be 10-13% of the company market's cap (20 to 24.4bn USD). The contribution of the proprietary technologies is about 25% of the private value. Finally, the work by Kogan et al. (2017) looks at the impact of a patent arrival on the stock market valuation of publicly-listed companies. They compare the private value across different industries and time. The empirical analysis is based on 2 million patents granted over the period from 1926 to 2010 in the US. The median value of a patent is €5.6m (See Table 1).

Limitations of firm market valuation methods A major limitation of this approach is that it only applies to publicly traded firms, so the values tend to be higher than in renewal or survey methods. In fact, some works suggest that public firms use different strategies than private firms when pursuing innovation (Bernstein, 2015).

These results are difficult to generalize on a larger scale. Moreover, the private values reflect more the expectations than the realised value. They are based on the assumption that capital markets are efficient, meaning that the market value perfectly reflects the discounted sum of future profits. Works based on market-value regressions do not always have a formal theoretical foundation to measure the value of patents (Bessen, 2009). Therefore, it is difficult to make rigorous inferences about the contribution of patent rents to market value. It should also be noted that the values computed are based on the behaviour of the investor rather than the patent owner as it is the case in renewal decision models.

3.5 Renewal decision models

The last approach covered here relies on the patent renewal decisions together with a model to infer a patent value distribution. Most countries require patent holders to pay renewal fees or maintenance fees to keep the patent protection in force. If the patent fee is not paid, the patent lapses which means that it is cancelled and the invention becomes part of the public domain. The maximum legal length of a patent is usually 20 years from the filing date. In the US patent system, there are three renewal events at 4, 8 and 12 years following the patent's grant date. In Europe, most of the time renewal events are yearly starting from the third year following the patent application filing. The first work exploiting renewal data was produced by Dernburg and Gharrity (1961), but more refined econometric techniques started with Pakes and Schankerman (1984); Schankerman and Pakes (1986); Pakes (1986).

Studies in the patent renewal literature are based on the fact that it is costly for a patent owner to renew the patent protection. Therefore, the owner decides optimally to renew the patent as long as the expected returns from the patent exceed the renewal costs. The owner of the patent expects that the stream of returns will cover the maintenance fees through the use of technology, licensing or commercialization. The optimal solution for the patent holder has the form of a stopping rule which indicates whether to pay the renewal fee in each period. Pakes and Schankerman (1984) and Schankerman and Pakes (1986) find a highly right-skewed distribution for the value of patents. They assume that the patent returns decay deterministically over time. Their results suggest a log-normal or Paretian distribution of individual patent values. Pakes (1986) extends the model - called a stochastic model - to include learning shocks. In other words, the patent owner is uncertain about the sequence of returns if the patent is kept in force. The estimates suggest that most of this uncertainty related to the returns to patent protection occurs before the fifth year of the patent's life. Moreover, he finds a median value for patents of around €1,000 in France, €3,000 in the UK and €13,000 in Germany, measured in EUR 2010. Lanjouw (1998) refines the model to include the costs of litigation and the possibility of infringement. She also introduces a more flexible model of returns taking into account obsolescence, which happens when an invention becomes worthless. She estimates the distribution of the private value of patents for different technologies in West Germany. She finds a median value for patents between approximately €10,000 and €40,000 in EUR 2010. Some subsequent works suggest differences in private values by owners and patent characteristics in Europe (Schankerman, 1998) and the US (Bessen, 2008). Putnam (1996) and Deng (2011) look at the patenting decisions in an international context, respectively PCT patents and EPO patents. They also examine the joint decision of application and renewal. Serrano (2018) allows for the possibility of trading patents measured by their re-assignment. He finds that the median private value of traded patents is about five times higher than the mean value of untraded patents. The market for patent rights generates important private gains for companies but the distribution of the gains from trade is highly skewed.

Grönqvist (2009*b*) uses a deterministic model to estimate the private value of patents granted between 1971 and 1989 in Finland. She finds a mean value of €8,149 for patents granted to firms and €5,513 to patents granted to private persons. In another essay of her PhD thesis, Grönqvist (2009*a*) estimates the value of patents in Finland with a stochastic version of the model and using a different cohort. She finds that patents owned by firms are worth €4,575 whereas patents owned by private persons are worth €2,874 on average. She explains the differences in the results between the stochastic and deterministic models by the different assumptions on how the returns evolve across time. Renewal decision models have been applied in different countries and context including patents granted in France using a binomial tree approach (Baudry and Dumont, 2006), in Australia (Wang, 2012) and in Great Britain and Ireland between 1852 and 1876 (Sullivan, 1994). The main results of the renewal decision model literature including the results in this dissertation are summarised in Table 1.

Complementary to the dynamic renewal decision models, Pakes et al. (1989) develop a non-parametric analysis of the renewal decisions. They want to test for differences in the distribution of the value of patent protection by industry, cohort (date of application) and nationality of the patent holder. They present results using data on Norwegian patents between 1962 and 1979 and Finnish patents between 1969 and 1979. Their results suggest differences in the renewal behavior of foreign and domestic patents in Finland as well as inter-industry differences. Among the patents granted to foreign residents and controlling for industry and cohort, they don't find support to the hypothesis of differences associated with the nationality of the patent owner. Finally, they find that patents in pharmaceutical and chemical industries as well as machinery tend to be more valuable whereas patents in heavy industry grouping (farming, motor, construction) and low-tech grouping are of lower value.

Limitations Because renewal fees are usually quite low (from a few hundred EUR up to a thousand), this method is not able to provide reliable values for the upper tail of the distribution that corresponds to the most valuable patents (Hall and Harhoff, 2012). Therefore, the distribution for the most valuable patents is heavily based on assumptions and extrapolations of patents that previously expired. Moreover, because the distribution is skewed, a significant part of the aggregate value of patents comes from a small number of very high value patents. Another issue of these models is that the full renewal decision is available only after some time. It is therefore difficult to estimate the value of recent patents because of the data is truncated.

3.6 Conclusion of the literature review

The different approaches reviewed here arrive at contrasted results in the estimation of the private value of patents. In Finland, the median value of patents is between approximately €1,000 and €7,000 depending on the industry considered and the specifications of the renewal decision model used (Grönqvist, 2009*b*,*a*). In countries where the market is larger such as France, Germany or in the US, the median private values tend to be much higher; between four and five digits (Pakes, 1986; Schankerman, 1998; Harhoff, Scherer and Vopel, 2003a; Bessen, 2008; Serrano, 2018).

When considering only publicly listed firms, the mean value tends to be even higher; between six and seven digits (Bessen, 2009; Kogan et al., 2017). Even if this literature does not give a consensus in the valuation of patents, it still provides some general results. First of all, this body of literature discovers great heterogeneity in value across technologies, where notably pharmaceutical and chemical patents tend to be of high-value. Second, this research stream based on different methods draws the conclusion that the distribution of patent values is right-skewed (Scherer, 1965; Pakes, 1986; Harhoff, Scherer and Vopel, 2003*b*; Giuri et al., 2007). In other words, there is a large proportion of low-value patents and a small number of highly valuable patents. The latter accounts for a significant share of the total economic value of innovation.

Table 1: Estimation private value of patents, in EUR 2010

Studies	Methods	Patent value distribution 25%	Median	75%	90%	95%	99%	Mean	Region / Country	Patent year	Group
Harhoff et al. (1999)	Survey	< 70k	70k-280k	680k-3.4m	680k-3.4m	6.9m-13.8m	13.8m-27.6m	-	Germany	1995 (expiration)	All
Gambardella, Harhoff and Verspagen (2008)	Survey	115-345k	345k-1.15m	1.15-3.45m	3.45m-11.5m	11.5-35m	115-350m	3.5m	EPO [1]	1993-1997 (priority)	All
Cockburn and Griliches (1988)	Market value	-	-	-	-	-	-	251k	US	1980 (issued)	Manufacturing
Megna and Klock (1993)	Market value	-	-	-	-	-	-	404k	US	1972-1990 (issued)	Semiconductor
Hall, Jaffe and Trajtenberg (2005)	Market value	-	-	-	-	-	-	140k	US	1979-1988 (granted)	Manufacturing, public
Bessen (2009)	Market value	-	-	-	-	-	-	413k	US	1979-1997 (issued)	All, public firms
Bessen (2009)	Market value	-	-	-	-	-	-	2.7m	US	1979-1997 (issued)	Large pharma firms
Bessen (2009)	Market value	-	-	-	-	-	-	552k	US	1979-1997 (issued)	Chemical excl. pharma
Bessen (2009)	Market value	-	-	-	-	-	-	98k	US	1979-1997 (issued)	Other industries
Kogan et al. (2017)	Market value	1,2m	5.6m	15.7m	38.2m	66.0m	210.0m	17.9m	US	1926-2010 (issued)	All, public firms
Pakes (1986)	Renewal stochastic	159	1,130	7,899	36,883	66,915	140,808	11,920	France	1951-1979 (application)	All
Pakes (1986)	Renewal stochastic	753	3,211	16,824	47,009	73,542	137,759	15,574	UK	1950-1974 (application)	All
Pakes (1986)	Renewal stochastic	4233	13,237	41,441	93,656	139,195	250,547	34,229	Germany	1952-1972 (application)	All
Putnam (1996)	Renewal stochastic	-	-	-	-	-	-	92,783	US	1996 (issued)	All
Lanjouw (1998)	Renewal stochastic	-	15,194	37,218	69,513	97,014	167,414	27,354	Germany	1975 (application)	Computers
Lanjouw (1998)	Renewal stochastic	-	9,913	27,090	53,856	76,916	138,951	20,358	Germany	1975 (application)	Textiles
Lanjouw (1998)	Renewal stochastic	-	38,617	77,309	133,836	178,983	289,874	57,896	Germany	1975 (application)	Engines
Schankerman (1998)	Renewal deterministic	1,090	3,453	11,489	24,952	42,169	110,374	9,130	France	1970 (application)	Pharmaceuticals
Schankerman (1998)	Renewal deterministic	946	3,374	12,293	29,076	51,574	147,985	10,518	France	1970 (application)	Chemicals
Schankerman (1998)	Renewal deterministic	1,351	6,203	29,148	86,455	177,518	681,575	32,007	France	1970 (application)	Mechanical
Schankerman (1998)	Renewal deterministic	1,327	6,687	34,552	112,455	240,065	1,019,145	41,993	France	1970 (application)	Electronics
Barney (2002)	Renewal deterministic	2,391	10,362	44,665	167,495	368,490	1,622,843	109,192	US	1986 (issued)	All
Baudry and Dumont (2006)	Renewal stochastic	-	-	-	-	-	-	2,451	France	2002 (application)	All
Deng (2007)	Renewal stochastic	6,704	38,885	215,880	985k	2,5m	13.8m	930k	EPO in Germany	1978-1996 (application)	All
Deng (2007)	Renewal stochastic	13,409	103,247	608,755	2,805,099	6.8m	35.6m	2.4m	EPO [2]	1978-1996 (application)	All
Bessen (2008)	Renewal deterministic	-	8,447	-	-	-	-	92,037	US	1991 (issued)	All
Bessen (2008)	Renewal deterministic	-	21,206	-	-	-	-	133,130	US	1985-1991 (issued)	Manufacturing, public
Grönqvist (2009*b*)	Renewal deterministic	402	1,878	7,224	20,527	38,105	113,199	9,314	Finland	1971-1989 (issued)	All
Grönqvist (2009*b*)	Renewal deterministic	616	1,954	6,998	16,836	33,081	97,183	8,149	Finland	1971-1989 (issued)	Firms
Grönqvist (2009*b*)	Renewal deterministic	307	1,369	4,599	12,552	23,163	62,705	5,513	Finland	1971-1989 (issued)	Individuals
Grönqvist (2009*b*)	Renewal deterministic	1,129	6,611	30,872	114,356	260,528	1,204,095	75,816	Finland	1971-1989 (issued)	Chemicals and pharma
Grönqvist (2009*b*)	Renewal deterministic	575	1,873	6,874	19,041	34,240	90,848	8,095	Finland	1971-1989 (issued)	Consumer goods
Grönqvist (2009*b*)	Renewal deterministic	1,257	6,980	31,868	116,142	253,157	1,017,055	72,906	Finland	1971-1989 (issued)	Electrical
Grönqvist (2009*b*)	Renewal deterministic	275	828	2,568	6,236	10,035	25,484	3,684	Finland	1971-1989 (issued)	Instruments
Grönqvist (2009*b*)	Renewal deterministic	312	1,250	3,795	9,470	15,762	41,064	3,918	Finland	1971-1989 (issued)	Mechanical engineering
Grönqvist (2009*b*)	Renewal deterministic	354	1,579	5,853	15,696	28,596	83,686	6,943	Finland	1971-1989 (issued)	Process engineering
Grönqvist (2009*a*)	Renewal stochastic	-	1,442	7,737	17,184	23,533	43,646	4,575	Finland	1970-1983 (applied)	Firms
Grönqvist (2009*a*)	Renewal stochastic	-	0	5,334	14,439	19,537	33,866	2,874	Finland	1970-1983 (applied)	Individuals
Deng (2011)	Renewal stochastic	-	161k	764k	3.3m	7.6m	35.1m	2.4m	EPO [3]	1980-1985 (application)	Pharmaceutical
Deng (2011)	Renewal stochastic	-	67k	295k	1.2m	2.6m	12.6m	939k	EPO [3]	1980-1985 (application)	Electronics
Wang (2012)	Renewal deterministic	168	805	3,685	-	26,075	97,567	6,917	Australia	1991 (application)	Electrical Machinery
Wang (2012)	Renewal deterministic	265	1,177	4,628	-	28,818	94,961	6,937	Australia	1991 (application)	Electronics
Wang (2012)	Renewal deterministic	173	874	4,200	-	31,717	120,095	8,883	Australia	1991 (application)	Chemical
Wang (2012)	Renewal deterministic	177	970	4,773	-	39,367	161,090	10,505	Australia	1991 (application)	Pharmaceutical
Serrano (2018)	Renewal stochastic	4,091	12,666	39,383	111,780	213,776	-	56,001	US	1988-1997 (issued)	Untraded patents
Serrano (2018)	Renewal stochastic	25,638	63,881	162,244	386,986	655,376	-	176,956	US	1988-1997 (issued)	Traded patents
Author's result (2022) - Essay 1	Renewal stochastic	832	4,130	9,672	23,445	32,434	54,276	8,658	Finland	1990-2000 (issued)	Chemistry, firms
Author's result (2022) - Essay 1	Renewal stochastic	830	2,189	4,508	11,041	15,766	27,590	4,327	Finland	1990-2000 (issued)	Electrical, firms
Author's result (2022) - Essay 1	Renewal stochastic	555	3,203	7,857	19,697	27,536	46,379	7,145	Finland	1990-2000 (issued)	Instruments, firms
Author's result (2022) - Essay 1	Renewal stochastic	861	4,328	10,121	24,439	33,937	56,848	9,047	Finland	1990-2000 (issued)	Mechanical, firms
Author's result (2022) - Essay 1	Renewal stochastic	2,729	6,827	10,990	19,217	24,6087	37,639	8,791	Finland	1990-2000 (issued)	Other fields, firms
Author's result (2022) - Essay 2	Renewal stochastic	14,094	33,698	73,013	130,798	176,712	288,600	54,696	Germany	1995-2000 (filed)	Semiconductor
Authors' result (2022) - Essay 3	Renewal deterministic	30,518	76,900	185k	408k	663k	1.8m	230k	EPO	2000 (issued)	Chemical, excl. pharma

[1] EPO patents granted in up to 6 countries: France, Germany, Italy, Netherlands, Spain and U.K.

[2] EPO patents granted in up to 16 countries: Austria, Belgium, Switzerland, Germany, Denmark, Spain, France, U.K, Greece, Ireland, Italy, Luxembourg, Monaco, Netherlands, Portugal and Sweden.

[3] EPO patents granted in up to 10 countries: Austria, Belgium, Switzerland, Germany, France, U.K, Italy, Luxembourg, Netherlands and Sweden.

4 SUMMARY AND MAIN RESULTS

This thesis contributes to the literature on patent valuation methods reviewed in the previous section. This thesis consists of three empirical essays on the economics of patent rights. The essays quantify the incentives to innovate created by patent systems in different countries (Finland, Germany and Europe with European patents) and different sectors. The essays address distinct research questions using different empirical models and data as summarised in Table 2.

4.1 Essay 1: Private value of patent protection in Finland

Finland is one of the leading innovative economies in the world with an average share of R&D in GDP above 3% in the past decades (See Takalo and Toivanen (2018) on the Finnish innovation policy). Therefore, patents play an important role in the protection of Intellectual Property for Finnish companies.

The first essay estimates the private value of patents granted to companies in Finland between 1990 and 2000. The model is a dynamic stochastic model of patent renewal following Lanjouw (1998). The structural parameters are estimated using a simulated method of moments (SMM) where the moments are the hazard rates of granted patents. The patent data come from the Finnish Patent and Registration Office (PRH). This essay contributes to the existing literature by extending the work of Grönqvist (2009a) in three ways: i) By estimating the private value of Finnish patents using more recent data; ii) by decomposing the private value of patents by field of technology; iii) by computing a ratio of patent stock value on R&D expenditure in Finland. Patent returns and patent value distributions are simulated for five distinct technology areas: Chemistry, Electrical Engineering, Instruments, Mechanical Engineering and Other Fields. I find a right-skewed distribution in all technology areas which is in line with results in this literature. The average private value of patents is higher in Mechanical Engineering (€9,047) followed by Chemistry (€8,658), Instruments (€7,145) and Electrical Engineering (€4,327). The average value in the group “Other fields” is €8,791.

At the national level, the ratio of aggregate patent value to Business Enterprise R&D Expenditure (BERD) is around 0.7% in 2000. This ratio is in the bottom bracket of previous estimations (Schankerman, 1998; Lanjouw, 1998; Bessen, 2008). As an example, Bessen (2008) finds a ratio of 3% for US patents. A possible explanation of the low ratio is that firms willing to protect inventions in Finland have an alternative to national patents. Indeed, they can apply for European patents granted by the EPO because Finland has joined the European Patent Convention in 1996. In this essay, I only measure the value of national patents and do not consider European patents, which is the focus of the third essay.

Parts of the results in this essay are also published in Takalo, Hyytinen and Stevenson (2021) and Salminen et al. (2021).

4.2 Essay 2: How much are patent citations worth? A simulation estimation based on patent renewal decisions

The second essay estimates the private value of patents granted in Germany in the field of semiconductors. A dynamic stochastic model of patent renewal decisions is estimated at the patent-level using a simulated maximum likelihood (SML) estimator. The patent data come from the European Patent Office Database PATSTAT and include all the German national patents filed between 1995 and 2000 in the semiconductor industry.

This essay contributes both to the literature on renewal decision models and on the link between patent value and citations. The model includes the possibility for patent holders to learn about the value of their inventions across time with patent-level heterogeneity in the learning shocks, parameterised by the citations received across time. In other words, the minimum threshold returns to renew a patent are patent-specific and depend on the number of forward citations received up to a given period. This theoretical framework provides more accurate estimates of patent value and allows me to investigate the dynamic link between forward patent citations and patent value in a counterfactual exercise. Few papers estimate the value of an additional citation. Bessen (2008) develops a deterministic model of patent renewal and finds that at the sample median of citations, an additional patent citation increases the private value of a US patent by approximately 1 to 7% depending on the specification (three to five thousands dollars). Using market value approach, Hall, Jaffe and Trajtenberg (2005) find that an additional citation for a single patent increases the firm market value of the company by 3% which corresponds to $327,000 dollars on average.

Additionally, the theoretical framework includes patent-level predicted grant probabilities in order to model the pre-grant renewal decisions. Indeed, the payment of renewal fees starts three years after the application whereas the grant decision is not always taken at that time.

The predicted probabilities are computed off-line applying machine learning algorithms on the text of patent abstract as well as an other patent characteristics. In the counterfactual analysis, the effect of an additional citation in the first year on the private value of patents is quantified. The results of this essay suggest that an incremental citation is associated with an average increase in value of 17.8% which is €9,759. The mean value of a patent in the semiconductor industry in Germany is €54,696 which is in line with other works including Lanjouw (1998) (See Table 1 for comparison).

4.3 Essay 3: An analysis of the incentive and welfare effects of the European unitary patent

The third essay estimates the private value of European patents in the field of chemical (excluding pharmaceutical) and analyses the incentive and welfare effects of introducing the Unitary patent. Over the past 50 years the European patent system has evolved with increased integration and harmonisation, but the implementation of a real European patent with a centralised post-grant procedure has remained elusive until recently. The introduction of the Unitary patent (UP henceforth) is the first major overhaul and a big step towards the original objective and, at the same time, one of the most significant changes in the global intellectual property regime this millennium. Its major benefit is the “streamlining” of the application process and the reduction in costs by allowing inventors to apply for a single patent instead of multiple national patents, as is the case with European patents (EP). This change means that inventors save on legal and translation costs, and face a single schedule of renewal fees instead of multiple national renewal fee schedules.

To evaluate the expected effects of the UP option, we build a three-part model. The first part is a single-agent dynamic model of renewal decisions for the existing EPs, i.e., patents we observe in our data. The second part is a patent production function linking the level of R&D to the quality and thereby private value of patents. The second part allows us to evaluate how the introduction of UP will affect patent quality at the intensive margin, i.e., regarding existing patents. The last part is a mapping between private value and consumer surplus. We estimate the model using renewal data for EPs applied for in 2000 in the technology area of chemicals (excluding pharmaceuticals) and designated in 15 countries.

We contribute to the patent renewal literature in the following ways: First, we allow for a free parameter to capture the correlation of the initial value of patents between any two countries. Deng (2011) models the correlation between two countries as a function of their geographical distance. Second, to be able to estimate the ensuing large number of parameters (169), we introduce the composite marginal likelihood method to this literature. Third, to the best of our knowledge, we are the first to use the private patent value estimates from renewal models in a model of inventive investments. Fourth, prior work has concentrated on estimating the private value of patents without extending the analysis to social value. To do so, we extend the approach of Schuett and Schankerman (2021) whose welfare analysis builds on a linear Cournot model. By utilizing so-called ρ-linear (see Anderson and Renault, 2003) demand functions we provide a method to allow for different demand functions.

We find that the vast majority of the inventors of chemical patents applied for in 2000 would have opted for UP, had they had the possibility. The results suggest that an average European patent (EP) is worth €230K and the average gain in private value associated with the new UP option is €17K on average. 46% of this comes from a reduction in renewal fees, keeping geographical coverage of the patent and its length constant; 3% comes from increased geographical coverage, 45% from increased length of the patent, keeping geographical coverage constant, and the remaining 6% from a change in patent quality. We find that 62% of inventors would have invested more into R&D and thereby increased the quality of their patents, measured by the number of citations, by an average of 1.2% (+0.64 additional citations). All in all, the private value of patents increases by 7.3% with the introduction of UP. We then turn to the change in social value. Making different assumptions on the demand function of the consumers, we find that the welfare generated by the chemical patents applied for in 2000 increases between 0.4 to 1.9% with the introduction of UP. Consumer surplus decreases by 2.1 to 8.7%. We find that most national patent offices (NPOs) would receive significantly lower income coming from fees, with large variations across NPOs. We also find a number of new results pertaining to the value of individual EPs.

An earlier version of this essay circulated under the title “A counterfactual analysis of the European Unitary Patent”[5].

The summary of the essays is displayed in the Table 2.

---

[5] https://conference.druid.dk/acc_papers/mxd7utprups6p7qw5dy1agf7fzzq3t.pdf

Table 2: Overview of the three empirical essays

	Essay 1	**Essay 2**	**Essay 3**
Research questions	What is the value of patent protection in Finland?	What is the value of an additional patent citation?	What would have been the effects of the Unitary Patent if it was available?
Methods	Dynamic stochastic model of patent renewal decisions following Lanjouw (1998). Estimation based on a SMM using aggregate renewal data.	Dynamic stochastic model of patent renewal decisions. Estimation based on a SML estimator using renewal data and forward citations received every period.	Dynamic deterministic model of patent renewal, patent production function and a demand model. Estimation using a composite marginal likelihood.
Data sample	All Finnish patents granted to Finnish companies between 1990 and 2000	German patents applied for between 1995 and 2000 in the semiconductor industry	All European patents in chemicals (excl. pharmaceutical) granted in 2000 and designated in 15 countries
Main findings	i) Mean private value of patents: €9,047 for Mechanical Engineering; €8,658 for Chemistry; €7,145 for Instruments; €4,327 for Electrical Engineering; €8,791 for Other Fields. ii) Ratio of aggregate patent value to BERD: 0.67% in 2000 iii) Most of the learning occurs in the first four years	i) Mean private value of patents in the semiconductor industry: €54,696 ii) Mean value of an additional citation in the first year: €9,759 (+17.8% on the private value) iii) Random Forest algorithm predicts grant probability based on the text of patent abstract with an accuracy of 60.59%, above the baseline of 51.75%	i) Mean value for a chemical EP is €230K ii) essentially all inventors would have used UP had it been available iii) private value of patents increases by 7% (€17k) on average with UP iv) total welfare increases by only 0-2% as consumer surplus is reduced by 2-9%.
Contributions	i) Extend previous works on Finnish patents to more recent data ii) Estimate a return of Business R&D for Finnish companies iii) Decompose patent value by technology fields.	i) Extend the model to include arrival of citations ii) Estimate the model at the patent-level iii) include grant predictions based on patent-text data	i) Counterfactual analysis of an important institutional change ii) Introduce an alternative estimation technique to this type of models

REFERENCES

Abrams, David S, Ufuk Akcigit, and Jillian Grennan. 2013. "Patent value and citations: Creative destruction or strategic disruption?" National Bureau of Economic Research.

Aghion, Philippe, Ufuk Akcigit, and Peter Howitt. 2014. "What do we learn from Schumpeterian growth theory?" In *Handbook of Economic Growth*. Vol. 2, 515–563. Elsevier.

Aghion, Philippe, Ufuk Akcigit, Ari Hyytinen, and Otto Toivanen. 2018. "On the returns to invention within firms: Evidence from Finland." Vol. 108, 208–12.

Akcigit, Ufuk, and Sina T Ates. 2019. "What happened to US business dynamism?" National Bureau of Economic Research.

Alcácer, Juan, Michelle Gittelman, and Bhaven Sampat. 2009. "Applicant and examiner citations in US patents: An overview and analysis." *Research Policy*, 38(2): 415–427.

Ali-Yrkkö, Jyrki, Ari Hyytinen, and Mika Pajarinen. 2005. "Does patenting increase the probability of being acquired? Evidence from cross-border and domestic acquisitions." *Applied Financial Economics*, 15(14): 1007–1017.

Anderson, Simon P., and Regis Renault. 2003. "Efficiency and surplus bounds in Cournot competition." *Journal of Economic Theory*, 113: 253–264.

Austin, David H. 1993. "An event-study approach to measuring innovative output: The case of biotechnology." *The American Economic Review*, 83(2): 253–258.

Barney, Jonathan A. 2002. "A study of patent mortality rates: using statistical survival analysis to rate and value patent assets." *AIPLA Quaterly Journal*, 30: 317.

Baudry, Marc, and Beatrice Dumont. 2006. "Patent renewals as options: Improving the mechanism for weeding out lousy patents." *Review of Industrial Organization*, 28(1): 41–62.

Bernstein, Shai. 2015. "Does going public affect innovation?" *The Journal of Finance*, 70(4): 1365–1403.

Bessen, James. 2008. “The value of US patents by owner and patent characteristics.” *Research Policy*, 37(5): 932–945.

Bessen, James. 2009. “Estimates of patent rents from firm market value.” *Research Policy*, 38(10): 1604–1616.

Bessen, James, and Eric Maskin. 2009. “Sequential innovation, patents, and imitation.” *The RAND Journal of Economics*, 40(4): 611–635.

Bessen, James, Jennifer Ford, and Michael J Meurer. 2011. “The private and social costs of patent trolls.” *Regulation*, 34: 26.

Bilir, L Kamran, Petra Moser, and Irina Talis. 2011. “Do treaties encourage technology transfer? Evidence from the Paris convention.” *Wisconsin University Working Papers*, 20(11): 2014.

Blundell, Richard, Xavier Jaravel, and Otto Toivanen. 2021. “Inequality and Creative Destruction.” *Institute For Fiscal Studies Working Paper*.

Boldrin, Michele, and David K Levine. 2013. “The case against patents.” *Journal of Economic Perspectives*, 27(1): 3–22.

Carpenter, Mark P, Francis Narin, and Patricia Woolf. 1981. “Citation rates to technologically important patents.” *World Patent Information*, 3(4): 160–163.

Chaney, Paul K, Timothy M Devinney, and Russell S Winer. 1991. “The impact of new product introductions on the market value of firms.” *Journal of Business*, 573–610.

Cockburn, Iain, and Zvi Griliches. 1988. “The estimation and measurement of spillover effects of R&D investment-industry effects and appropriability measures in the stock market’s valuation of R&D and patents.” *The American Economic Review*, 78(2): 419–423.

Czarnitzki, Dirk, Bronwyn H Hall, and Raffaele Oriani. 2006. “The market valuation of knowledge assets in US and European firms.”

Danguy, Jérôme, and Bruno van Pottelsberghe de la Potterie. 2011. “Costbenefit analysis of the community patent.” *Journal of Benefit-Cost Analysis*, 2(2): 1– 43.

Danguy, Jérôme, Gaétan De Rassenfosse, and Bruno van Pottelsberghe de la Potterie. 2014. “On the origins of the worldwide surge in patenting: an industry perspective on the R&D–patent relationship.” *Industrial and Corporate Change*, 23(2): 535–572.

Dechezleprêtre, Antoine, Yann Ménière, and Myra Mohnen. 2017. “International patent families: From application strategies to statistical indicators.” *Scientometrics*, 111(2): 793–828.

De Marco, Antonio, Giuseppe Scellato, Elisa Ughetto, and Federico Caviggioli. 2017. “Global markets for technology: Evidence from patent transactions.” *Research Policy*, 46(9): 1644–1654.

Deng, Yi. 2007. “Private value of European patents.” *European Economic Review*, 51(7): 1785–1812.

Deng, Yi. 2011. “A dynamic stochastic analysis of international patent application and renewal processes.” *International Journal of Industrial Organization*, 29(6): 766–777.

De Rassenfosse, Gaétan, and Adam B Jaffe. 2018. “Are patent fees effective at weeding out low-quality patents?” *Journal of Economics & Management Strategy*, 27(1): 134–148.

Dernburg, Thomas, and Norman Gharrity. 1961. “A statistical analysis of patent renewal data for three countries.” *The Patent, Trademark & Copyright Journal of Research*, 5: 340.

Falk, Nathan, and Kenneth Train. 2017. “Patent valuation with forecasts of forward citations.” *Journal of Business Valuation and Economic Loss Analysis*, 12(1): 101–121.

Figueroa, Nicolás, and Carlos J Serrano. 2019. “Patent trading flows of small and large firms.” *Research Policy*, 48(7): 1601–1616.

Fink, Carsten, Mosahid Khan, and Hao Zhou. 2016. "Exploring the worldwide patent surge." *Economics of Innovation and New Technology*, 25(2): 114–142.

Furman, Jeffrey L, Markus Nagler, and Martin Watzinger. 2018. "Disclosure and subsequent innovation: Evidence from the patent depository library program." National Bureau of Economic Research.

Galasso, Alberto, and Mark Schankerman. 2010. "Patent thickets, courts, and the market for innovation." *The RAND Journal of Economics*, 41(3): 472–503.

Gambardella, Alfonso, Dietmar Harhoff, and Bart Verspagen. 2008. "The value of European patents." *European Management Review*, 5(2): 69–84.

Gambardella, Alfonso, Dietmar Harhoff, and Bart Verspagen. 2017. "The economic value of patent portfolios." *Journal of Economics & Management Strategy*, 26(4): 735–756.

Giuri, Paola, Myriam Mariani, Stefano Brusoni, Gustavo Crespi, Dominique Francoz, Alfonso Gambardella, Walter Garcia-Fontes, Aldo Geuna, Raul Gonzales, Dietmar Harhoff, et al. 2007. "Inventors and invention processes in Europe: Results from the PatVal-EU survey." *Research Policy*, 36(8): 1107–1127.

Griliches, Zvi. 1979. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics*, 10(1): 92–116.

Griliches, Zvi. 1981. "Market value, R&D, and patents." *Economics Letters*, 7(2): 183– 187.

Grönqvist, Charlotta. 2009*a*. "Empirical studies on the private value of Finnish patents." *Hanken School of Economics, PhD thesis.*

Grönqvist, Charlotta. 2009*b*. "The private value of patents by patent characteristics: Evidence from Finland." *The Journal of Technology Transfer*, 34(2): 159–168.

Guellec, Dominique, and Bruno van Pottelsberghe de la Potterie. 2007. *The economics of the European Patent System: IP policy for innovation and competition.* Oxford University Press.

Hall, Bronwyn H. 1999. “Innovation and market value.” National Bureau of Economic Research.

Hall, Bronwyn H, Adam Jaffe, and Manuel Trajtenberg. 2000. “Market value and patent citations: A first look.” National Bureau of Economic Research.

Hall, Bronwyn H, Adam Jaffe, and Manuel Trajtenberg. 2005. “Market value and patent citations.” *The RAND Journal of Economics*, 16–38.

Hall, Bronwyn H, and Christian Helmers. 2019. “The impact of international patent systems: Evidence from accession to the European Patent Convention.” *Research Policy*, 48(9): 103810.

Hall, Bronwyn H, and Dietmar Harhoff. 2012. “Recent research on the economics of patents.” *Annual Review Economics*, 4(1): 541–565.

Hall, Bronwyn H, and Rosemarie Ham Ziedonis. 2001. “The patent paradox revisited: An empirical study of patenting in the US semiconductor industry, 1979- 1995.” *The RAND Journal of Economics*, 101–128.

Harhoff, Dietmar, Francis Narin, Frederic M Scherer, and Katrin Vopel. 1999. “Citation frequency and the value of patented inventions.” *Review of Economics and Statistics*, 81(3): 511–515.

Harhoff, Dietmar, Frederic M Scherer, and Katrin Vopel. 2003*a*. “Citations, family size, opposition and the value of patent rights.” *Research Policy*, 32(8): 1343– 1363.

Harhoff, Dietmar, Frederic M Scherer, and Katrin Vopel. 2003*b*. “Exploring the tail of patented invention value distributions.” In *Economics, Law and Intellectual Property.* 279–309. Springer.

Haskel, Jonathan, and Stian Westlake. 2017. *Capitalism without capital*. Princeton University Press.

Hochberg, Yael V, Carlos J Serrano, and Rosemarie H Ziedonis. 2018. "Patent collateral, investor commitment, and the market for venture lending." *Journal of Financial Economics*, 130(1): 74–94.

Hsu, D. H., and R. H. Ziedonis. 2008. "Patents as quality signals for entrepreneurial ventures." *Academy of Management Proceedings*, 2008(1): 1–6.

Izhak, Olena, Tanja Saxell, and Tuomas Takalo. 2021. "Evaluating the US pharmaceutical patent policy." *Available at SSRN 3997462*.

Jaffe, Adam B, and Gaétan De Rassenfosse. 2019. "Patent citation data in social science research: Overview and best practices." In *Research Handbook on the Economics of Intellectual Property Law*. Edward Elgar Publishing.

Kogan, Leonid, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman. 2017. "Technological innovation, resource allocation, and growth." *The Quarterly Journal of Economics*, 132(2): 665–712.

Korkeamäki, Timo, and Tuomas Takalo. 2013. "Valuation of Innovation and Intellectual Property: The Case of iPhone." *European Management Review*, 10(4): 197– 210.

Kortum, Samuel, and Josh Lerner. 1999. "What is behind the recent surge in patenting?" *Research Policy*, 28(1): 1–22.

Kuhn, Jeffrey, Kenneth Younge, and Alan Marco. 2020. "Patent citations reexamined." *The RAND Journal of Economics*, 51(1): 109–132.

Kultti, Klaus, Tuomas Takalo, and Juuso Toikka. 2007. "Secrecy versus patenting." *The RAND Journal of Economics*, 38(1): 22–42.

Kultti, K, Tuomas Takalo, and Juuso Toikka. 2006. "Cross-licensing and collusive behavior." *Homo Oeconomicus*, 23: 181–193.

Lanjouw, Jean O, and Mark Schankerman. 2001. "Characteristics of patent litigation: A window on competition." *The RAND Journal of Economics*, 129–151.

Lanjouw, Jean O, and Mark Schankerman. 2004. "Patent quality and research productivity: Measuring innovation with multiple indicators." *The Economic Journal*, 114(495): 441–465.

Lanjouw, Jean O, Ariel Pakes, and Jonathan Putnam. 1998. "How to count patents and value intellectual property: The uses of patent renewal and application data." *The Journal of Industrial Economics*, 46(4): 405–432.

Lanjouw, Jean Olson. 1998. "Patent protection in the shadow of infringement: Simulation estimations of patent value." *The Review of Economic Studies*, 65(4): 671–710.

Lerner, Josh. 2002. "150 years of patent protection." *The American Economic Review*, 92(2): 221–225.

Lerner, Josh. 2009. "The empirical impact of intellectual property rights on innova- tion: Puzzles and clues." *The American Economic Review*, 99(2): 343–48.

Lerner, Joshua. 1994. "The importance of patent scope: An empirical analysis." *The RAND Journal of Economics*, 319–333.

Machlup, Fritz, and Edith Penrose. 1950. "The patent controversy in the nineteenth century." *The Journal of Economic History*, 10(1): 1–29.

Marco, Alan C, Joshua D Sarnoff, and AW Charles. 2019. "Patent claims and patent scope." *Research Policy*, 48(9): 103790.

Megna, Pamela, and Mark Klock. 1993. "The impact of intangible capital on Tobin's q in the semiconductor industry." *The American Economic Review*, 83(2): 265– 269.

Moser, Petra. 2005. "How do patent laws influence innovation? Evidence from nineteenth-century world's fairs." *The American Economic Review*, 95(4): 1214–1236.

Moser, Petra, Joerg Ohmstedt, and Paul W Rhode. 2018. "Patent citations — an analysis of quality differences and citing practices in hybrid corn." *Management Science*, 64(4): 1926–1940.

Murphy, William J, John L Orcutt, and Paul C Remus. 2012. *Patent valuation: Improving decision making through analysis*. Vol. 571, John Wiley & Sons.

Nicholas, Tom. 2008. "Does innovation cause stock market runups? Evidence from the great crash." *The American Economic Review*, 98(4): 1370–96.

Nikulainen, Tuomo, Raine Hermans, and Martti Kulvik. 2008. "Patent citations indicating present value of the biotechnology business." *International Journal of Innovation and Technology Management*, 5(03): 279–301.

Nordhaus, William D. 1969. *Invention, growth and welfare: A theoretical treatment of technological change*. Cambridge, Mass., M.I.T. Press.

Odasso, Cristina, Giuseppe Scellato, and Elisa Ughetto. 2015. "Selling patents at auction: An empirical analysis of patent value." *Industrial and Corporate Change*, 24(2): 417–438.

OECD. 2009. "OECD Patent Statistics Manual." OECD.

OECD, and Eurostat. 2018. *Oslo Manual 2018*. OECD Publishing.

Pakes, Ariel. 1985. "On patents, R & D, and the stock market rate of return." *Journal of Political Economy*, 93(2): 390–409.

Pakes, Ariel. 1986. "Patents as options: Some estimates of the value of holding European Patent stocks." *Econometrica*, 54(4): 755–784.

Pakes, Ariel, and Mark Schankerman. 1984. "The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources." In *R&D, patents, and productivity*. 73–88. University of Chicago Press.

Pakes, Ariel, Margaret Simpson, Kenneth Judd, and Edwin Mansfield. 1989. "Patent renewal data." *Brookings Papers on Economic Activity - Microeconomics*, 1989: 331–410.

Prager, Frank D. 1946. "Brunelleschi's patent." *Journal of the Patent and Trademark Office Society*, 28: 109.

Putnam, Jonathan. 1996. "The value of international patent protection." *Unpublished Ph. D. Dissertation, Yale University.*

Rahko, Jaana. 2014. "Market value of R&D, patents, and organizational capital: Finnish evidence." *Economics of Innovation and New Technology*, 23(4): 353–377.

Salminen, Vesa, Kimmo Halme, Juha Kettinen, Valtteri Härmälä, Anne-Mari Järvelin, Arho Suominen, Matthias Deschryvere, Henna Sundqvist-Andberg, Ilkka Vuorenmaa, Anniina Harju, et al. 2021. "Aineettomien oikeuksien tilanne Suomessa 2020: IPR-strategian taustoitus."

Sampat, Bhaven N. 2018. "A survey of empirical evidence on patents and innovation."

Sanders, Barkev S, Joseph Rossman, and L James Harris. 1958. "The economic impact of patents." *The Patent, Trademark & Copyright Journal of Research*, 2: 340.

Schankerman, Mark. 1998. "How valuable is patent protection? Estimates by technology field." *the RAND Journal of Economics*, 77–107.

Schankerman, Mark, and Ariel Pakes. 1985. "Estimates of the value of patent rights in European countries during the post-1950 period." National Bureau of Economic Research.

Schankerman, Mark, and Ariel Pakes. 1986. "Estimates of the value of patent rights in European countries during the post-1950." *Economic Journal*, 96(384).

Scherer, Frederic M. 1965. "Firm size, market structure, opportunity, and the output of patented inventions." *The American Economic Review*, 55(5): 1097–1125.

Scherer, Frederic M, and Dietmar Harhoff. 2000. "Technology policy for a world of skew-distributed outcomes." *Research Policy*, 29(4-5): 559–566.

Schmookler, J. 1966. *Invention and economic growth*. Harvard University Press.

Schuett, Florian, and Mark Schankerman. 2021. "Patent screening, innovation, and welfare." *Review of Economic Studies*, forthcoming.

Serrano, Carlos J. 2010. "The dynamics of the transfer and renewal of patents." *The RAND Journal of Economics*, 41(4): 686–708.

Serrano, Carlos J. 2018. "Estimating the gains from trade in the market for patent rights." *International Economic Review*, 59(4): 1877–1904.

Shapiro, Carl. 2000. "Navigating the patent thicket: Cross licenses, patent pools, and standard setting." *Innovation Policy and the Economy*, 1: 119–150.

Stenbacka, Rune, and Mihkel Tombak. 2020. "University-firm competition in basic research and university funding policy." *Journal of Public Economic Theory*, 22(4): 1017–1040.

Sullivan, Richard J. 1994. "Estimates of the value of patent rights in Great Britain and Ireland, 1852-1876." *Economica*, 37–58.

Takalo, Tuomas, and Otto Toivanen. 2018. "Economics of Finnish Innovation Policy." *Report for the Finland's Economic Policy Council.*

Takalo, Tuomas, and Vesa Kanniainen. 2000. "Do patents slow down technological progress? Real options in research, patenting, and market introduction." *International Journal of Industrial Organization*, 18(7): 1105–1127.

Takalo, Tuomas, Ari Hyytinen, and Alexis Stevenson. 2021. "Patenttien yksityinen arvo: Kirjallisuuskatsaus ja uusia tuloksia Suomesta." *Kansantaloudellinen Aikakauskirja*.

Toivanen, Otto, and Lotta Väänänen 2016. "Education and invention." *Review of Economics and Statistics*, 98(2): 382–396.

Toivanen, Otto, Paul Stoneman, and Derek Bosworth. 2002. "Innovation and the market value of UK firms, 1989-1995." *Oxford Bulletin of Economics and Statistics*, 64(1): 39–61.

Trajtenberg, Manuel. 1990. “A penny for your quotes: Patent citations and the value of innovations.” *The RAND Journal of Economics*, 172–187.

Van Pottelsberghe de la Potterie, Bruno, and Nicolas Van Zeebroeck. 2008. “A brief history of space and time: The scope-year index as a patent value indicator based on families and renewals.” *Scientometrics*, 75(2): 319–338.

Van Zeebroeck, Nicolas. 2011. “The puzzle of patent value indicators.” *Economics of Innovation and New Technology*, 20(1): 33–62.

Van Zeebroeck, Nicolas, and Bruno Van Pottelsberghe de la Potterie. 2011. “Filing strategies and patent value.” *Economics of Innovation and New Technology*, 20(6): 539–561.

Wang, Changtao. 2012. “Estimating the value of patent rights in Australia.” *School of Economics, UNSW*.

Zhang, Haiyang. 2010. “What is behind the recent surge in patenting in China?” *International Journal of Business and Management*, 5(10): 83.

ESSAY 1: PRIVATE VALUE OF PATENT PROTECTION IN FINLAND

Private value of patent protection in Finland*

Alexis Stevenson
Hanken School of Economics, Helsinki GSE and KU Leuven

Abstract

I estimate the private value of patents granted to Finnish companies in Finland between 1990 and 2000 using patent renewal data. The theoretical framework is a single-agent dynamic model of renewal decisions built on Lanjouw (1998, *The Review of Economic Studies*, **65.4** , 671-710). The model is estimated using aggregate patent data and a simulated method of moments estimator. Patent returns and patent value distributions are simulated for five distinct technology areas: Chemistry, Electrical Engineering, Instruments, Mechanical Engineering and Other Fields. I find a right-skewed distribution in all technology areas which suggests a large fraction of low-value patents and a small number of valuable patents. The average private value of patents is highest in Mechanical Engineering (€9,047) followed by Chemistry (€8,658), Instruments (€7,145) and Electrical Engineering (€4,327). The average value in the group "Other Fields" is €8,791. At the national level, the ratio of aggregate patent value to Business Enterprise R&D Expenditure (BERD) is about 0.7% in 2000.

---

*Financial support from Hanken School of Economics, the IPR University Center, Yrjö Janhsson Foundation and OP Group Research Foundation is gratefully acknowledged. I would like to thank Ari Hyytinen, Mattia Nardotto, Tuomas Takalo, Otto Toivanen and participants at the KU Leuven IO seminars and Helsinki GSE IO seminars for comments. I also thank Lasse Koivisto from the Finnish Patent and Registration Office for providing the dataset. Some of the results in this essay have been published as part of a report for the Finnish Government's analysis, assessment and research activities to support the preparation of the national IPR strategy Salminen et al. (2021) and in Takalo et al. (2021).

1 Introduction

Finland is one of the leading innovative economies in the world with an average share of R&D in GDP above 3% in the past decades. Finland ranks in the top 10 countries in the number of patent applications per GDP and per capita[1]. Patents play an important role in the protection of Intellectual Property (IP) for innovative companies and they are often used in economic research as a measure of innovation output. The value of patent protection is important information for firms and decision-makers even though it is not directly observable. This essay develops a structural model of patent renewal decisions following the revealed preference approach of Pakes (1986) and Lanjouw (1998). The model allows the estimation of the distribution of the private value of national patents granted to Finnish companies between 1990 and 2000 in five fields of technology: Chemistry, Electrical Engineering, Instruments, Mechanical Engineering and Other Fields.

I find some heterogeneity in the value of patents across technologies: The mean value of patent is €9,047 in the area of Mechanical Engineering; €8,791 for Other Fields; €8,658 for Chemistry; €7,145 for Instruments and €4,327 for Electrical Engineering. The distribution of values is right-skewed with mean values above the median. Learning effects are stronger in the first three to four years and tend to disappear after five to six years, in line with previous works. The ratio of Finnish patent value stock to Business Enterprises R&D is 0.67% for patents granted during the year 2000. This ratio is in the bottom bracket of previous estimations (Schankerman, 1998; Lanjouw, 1998; Bessen, 2008). As an example, Bessen (2008) finds a ratio of 3% for US patents. One possible reason explaining the low ratio is that firms willing to protect inventions in Finland have an alternative to national patents. They can apply for EPO patents since Finland has joined the European Patent Convention in 1996. In this essay, I only measure the value of national patents and do not consider EPO patents which is the focus of the third essay.

The private value of a patent is defined as the incremental value above and beyond the profits that are captured in the absence of patent protection (Murphy, Orcutt and Remus, 2012). Decision-makers rely on patent valuation to make informed decisions. These decisions could be acquiring an asset for a company by comparing the value of the asset to the cost, estimating damages in an infringement lawsuit, deciding on obtaining a patent and in which countries to obtaining it, using a patent for securitization etc... The value of a patent is also important information for public authorities for instance when

---

[1] See the report OECD (2017) and Takalo and Toivanen (2018) for the role of innovation in Finland.

they take into account intangible assets in merger control or measure the reward given by a patent system. Patent rights are rarely traded so it is difficult to get a direct estimation of the market value for a patent. Nevertheless, as it is an important measure, different methods have been developed in the literature to assess the patent quality. Multiple indicators are used such as the count of successful patent applications, citation-weighted patent counts, patent claims or the size of patent family (e.g Putnam, 1996) to name a few. In this regard, Lanjouw and Schankerman (2004) construct a composite indicator of the quality of patents using citations, number of claims and number of countries in which the invention is protected. Higham, De Rassenfosse and Jaffe (2021) test different post-grant outcomes often used as patent quality measures in the literature: Anomalous stock market returns, forward citations and renewal decisions. They find that the measurement of patent quality is sensitive to the post-grant outcome observed and the technology type. Other works exploit surveys asking owner of patents their willingness to sell their patent rights (e.g Giuri et al., 2007), rely on commercial transactions (e.g Serrano, 2010) or also look at the impact of patent arrival on the stock market valuation (e.g Hall, Jaffe and Trajtenberg, 2005; Kogan et al., 2017). A more comprehensive literature review of patent valuation methods can be found in the introductory chapter of this dissertation. The use of renewal decisions to estimate the private value of patents started with Pakes and Schankerman (1979) and it is the approach adopted in this essay.

Renewal data provide information on the value of patents by a revealed preference argument. A patent owner decides to renew a patent as long as the expected returns from the patent exceed the renewal costs. Every year, a patent holder has then to decide whether to pay a renewal fee to maintain the patent protection of the invention in force. If a renewal fee is not paid, the patent lapses: This means that the patent is cancelled and anybody can use for free the knowledge embodied in the patent. In most countries, a patent gives an exclusivity to the owner for a maximum length of 20 years from the filing date. The renewal decision can then be used to infer the distribution of private value of patents. In a framework with deterministic patent returns, Pakes and Schankerman (1984) and Schankerman and Pakes (1985) find a highly right-skewed distribution for the value of patents. Pakes (1986) extends the model to include learning with stochastic shocks. Lanjouw (1998) refines the model to include costs of litigation and the possibility of infringement. She also introduces a more flexible model of returns taking obsolescence into account. She estimates the distribution of the private value of patents for different technologies in West Germany between 1953 and 1988. Schankerman (1998) shows evidence of differences in private value of patent rights by sectors and nationalities of patent owners. Putnam (1996) and Deng (2011) look at the patenting decisions in an international context, respectively

PCT and EPO patents. They also both examine the joint decision of application and renewal. Serrano (2018) allows for the possibility of market for knowledge. Renewal models have been applied in different countries and contexts including patents granted in Finland (Grönqvist, 2009), in France using a binomial tree approach (Baudry and Dumont, 2006), in Australia (Wang, 2012) and in Great Britain and Ireland between 1852 and 1876 (Sullivan, 1994). This essay extends and updates the empirical study of Grönqvist (2009) by looking at a more recent cohort and by decomposing the value of patents by field of technology. The parameters of the model are estimated using a simulated method of moments (SMM) applied to Finnish patents granted between 1990 and 2000 where the moments are the patent hazard rates. Results are then compared with aggregate statistics on Business Enterprise R&D Expenditure (BERD) in Finland to construct a ratio of stock of patent value on BERD.

The essay is organised as follow. Section 2 sets the institutional background and describes the patent system in Finland. I present the data in Section 3 and introduce the theoretical framework in Section 4. Section 5 describes the estimation procedure and Section 6 shows the results. I offer concluding remarks in Section 7.

2 Institutional background

2.1 Patent application and examination

A patent is a territorial right granted to an inventor to exclude others from using, making or selling a disclosed invention for a certain period of time. To be patentable, the invention must be novel, imply an inventive step and have an industrial application with a commercial value. The following description of the patent life cycle in Finland borrows from Grönqvist (2009) and the Finnish Patent and Registration Office's (PRH) website.

The patent life starts with the application to the Finnish Patent and Registration Office (PRH). A patent applicant has to provide all the required documents describing the invention. At that stage, the applicant pays an application fee (€500 in 2021 for a "standard" application). She has to disclose the "prior art" related to the invention and decides which patents and scientific literature to cite. In most cases, patent agents help the applicant to submit the application. Once the application is submitted, patent examiners are chosen to evaluate it. The pre-examination process usually lasts for 6 to 9 months from the filing date. Patent examiners can decide to add references to the relevant prior art and are always the last to make the decisions regarding citations. Once the outcome of the pre-examination is known, the applicant has usually 6 months to answer and add complementary information if requested. The examiner decides then to grant the patent if the application meets the patentability requirements. On average, the duration between patent application filing and grant decisions is 3 years in Finland with small variations across technology classes. The applicant pays then the printing fee (€500 in 2021 for a “standard” patent) to publish the notification in the Patent Gazette. The date of publication is the date of grant. Within 9 months following the patent publication, anyone can lodge an opposition. If an opposition is lodged, the patent office re-examines the application. If the patent is not granted, the applicant has the right to appeal to the National Board of Patents and Registration (NBPR). If the Board rejects the appeal, the applicant has the possibility to appeal again to the Supreme Administrative Court.

2.2 Renewal decisions and patent expiration

The patent is considered granted when it is published. The publication document contains detailed information about the invention, the applicant and the inventor. Since 1990, the payment of renewal fees in Finland has started on the third year following the application. As the patent is on average granted 3 years after the filing date, the first payment of maintenance fees is generally the same year as the granting decision. For this reason, I model on this essay the renewal decisions once the patent is granted. The statutory limit which is the age beyond which the patent becomes part of the public domain is 20 years in Finland from the filing date. Therefore the model consists of $T = 17$ periods of renewal decisions, from year 4 to year 20 following the patent application. If the renewal fees are not paid, the patent expires. Patents can also be traded, transferred or licensed. As far as I know, there is no systematic and reliable data available on trade, licensing or change in ownership of patents in Finland and I therefore do not include these into my model.

3 Data

3.1 Data description

Patent data The data come from the Finnish Patent and Registration Office (PRH). It covers all the national patents issued in Finland to Finnish companies between January 1971 and December 2017. In this essay, I focus on the patents granted between 1990 and 2000. The sample contains information on patents, inventors and applicants including the application and grant date, industry to which the patented technology belonged to, the whole renewal history, the language of the patent, the identity of the examiner and the patent agent. I divide the patents into five technology areas based on the correspondence between industrial sectors (IPC classes) and technology areas (Schmoch, 2008). The five fields of technology are Electrical Engineering, Instruments, Chemistry/Pharmaceuticals, Mechanical Engineering/Machinery and Others. These groups are based on the primary technology field of the patent according to the International Patent Classification (IPC). Some patents are assigned to several IPC classes. According to PRH, the first IPC class describes the industry best (Grönqvist, 2009). Therefore, I consider only the first IPC class to assign patents in a technology category. Electrical engineering includes electrical machinery, audio-visual technology, telecommunications, IT and semi-conductors. Instruments includes optics, control technology, measurement technology, medical technology and nuclear engineering. Chemistry and pharmaceuticals include organic fine chemistry, pharmaceuticals, cosmetics, biotechnology, food chemistry, petrol industry, surface technology and metallurgy. Mechanical engineering include machine tools, engines, thermal processes, transport, space technology. The rest (Others) include consumer goods, special equipment and process engineering.

The number of patents granted by year and by technological areas to Finnish companies are shown in Figure 1. There is a clear increasing trend in the number of patents granted to Finnish companies in Finland between mid 1970's and mid 2000's. Since 2005, the number of patents granted every year has been quite stable at around 600. The shares of patents by technological area are relatively stable across time between 1990 and 2000. I restrict the study to the cohort 1990-2000 because I can observe the full life for each patent up to the maximum statutory limit of 20 years. In other words, a patent granted in 2000 will be renewed up to at most 2017 (3 years of examination and 17 years of renewal) which is observable in my dataset.

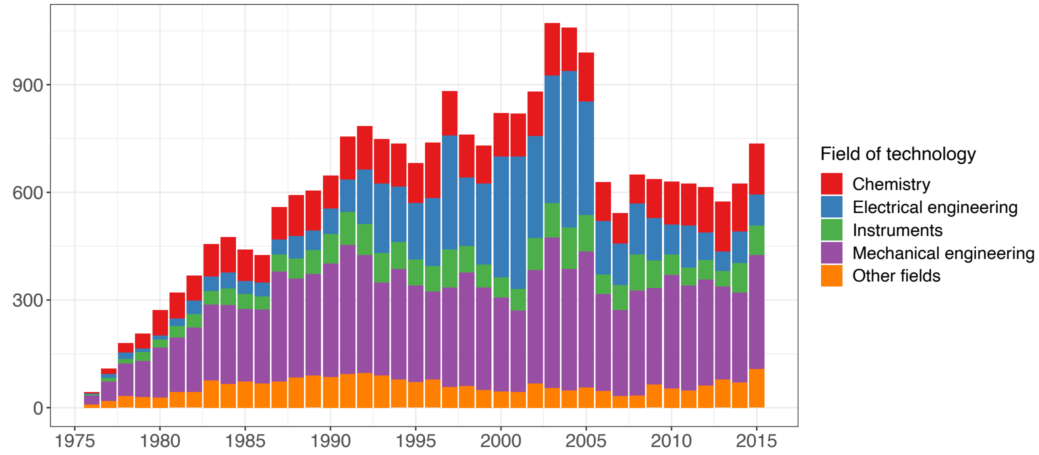


Figure 1: Number of patents granted to Finnish companies by technological areas

Renewal fee data Renewal fee data come from the Ministry of Trade and Industry reports[2] All these numbers are converted into EUR 2010 using the Consumer Price Index reported by Statistics Finland[3]. The fee scheme is increasing in age, starting at around a hundred of € in 2010 price level and rising to a little less than a thousand € as shown in Figure 2. The renewal fee schedule is increasing; this is a necessary condition to express the policy function in terms of thresholds, as we will see in the model.

The fee structure changed in 1990 which is the start of our observation period. Since 2000, the renewal fee scheme did not change significantly and today the renewal fee scheme is in line with the one shown in Figure 2. Renewal fees are updated by the Ministry of Trade and Industry mostly to adjust for inflation. As a comparison, in 2021, renewal fee scheme started at €125 (4th year) to €900 (20th year).

---

[2] This information is also available on the EPO's website

[3] Table 11xt - Consumer Price Indices, overall index, yearly data, 1972-2019. Statistics Finland

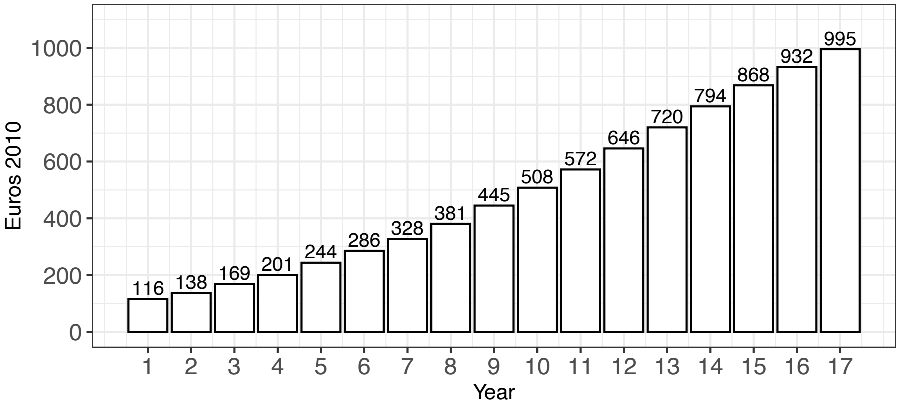


Figure 2: Average renewal fee in Finland for patents granted between 1990 and 2000, in EUR 2010

Descriptive statistics The panel includes 8285 patents granted to Finnish companies between 1990 and 2000. Table 1 shows some descriptive statistics for the number of applicants/inventors, examination period, number of IPC classes, number of renewal years, technology area and languages.

The average number of renewal years is relatively similar for Chemistry, Instruments, Mechanical Engineering and Other Fields: between 8.6 and 8.9. In Electrical Engineering, the average number if significantly lower at 7.7. These figures suggest that on average a patent is not worthwhile to be renewed the full term of 17 renewal years. Therefore, using a revealed preference argument, we would expect to find lower private values for Electrical Engineering patents than for patents in the other groups.

Table 1 shows also that around 40% of the patents are Mechanical Engineering, 25% are Electrical Engineering, 15% Chemistry, 10% Instruments and 10% Other fields. The examination period is on average 2.7 years (1001 days) and the number of inventor is on average 1.8.

Table 1: Descriptive Statistics for patents granted to Finnish firms between 1990 and 2000

Variables	**Mean**	**St.Dev**	**Median**	**Min**	**Max**	**N**
Patent characteristics						
Number of applicants	1.027	0.2161	1	1	8	8285
Number of inventors	1.841	1.2582	1	1	18	8285
Examination period (in days)	1001	485	877	209	5284	8285
Number of IPC classes	1.726	1.32	1	1	85	8285
Written in Swedish (d)	0.036	0.19	0	0	1	8285
Number of renewal years						
Chemistry	8.88	5.55	8	0	17	1314
Electrical Engineering	7.74	4.61	7	0	17	2081
Instruments	8.73	5.48	8	0	17	858
Mechanical Engineering	8.65	5.58	8	0	17	3226
Other fields	8.65	5.98	8	0	17	806
Technology area						
Chemistry (d)	0.1586	0.3653	0	0	1	8285
Electrical Engineering (d)	0.2512	0.4337	0	0	1	8285
Instruments (d)	0.1036	0.3047	0	0	1	8285
Mechanical Engineering (d)	0.3894	0.4876	0	0	1	8285
Other fields (d)	0.0973	0.2963	0	0	1	8285

Figure 3 shows the hazard rates by field of technology. The hazard rates are the probability that a patent will lapse at age t conditional on having paid the renewal fee up to and including age $t-1$. Hazard rates are also the moment conditions used in the estimation. We see variations in the hazard rates across technology fields; these are exploited in the estimation. For instance, a higher proportion of Electrical Engineering patents - conditional on being renewed in the previous period - tends to lapse around year 10.

Figure 4 shows the survival probability of patents. We can see that slightly less than 50% of the patents in the technology group of Chemistry are renewed for at least 10 years whereas the percentage is around 37.5% for Electrical Engineering patents. In accordance with the mean values in Table 1, these differences suggest a higher proportion of patents of lower value in Electrical Engineering area compared to Chemistry.

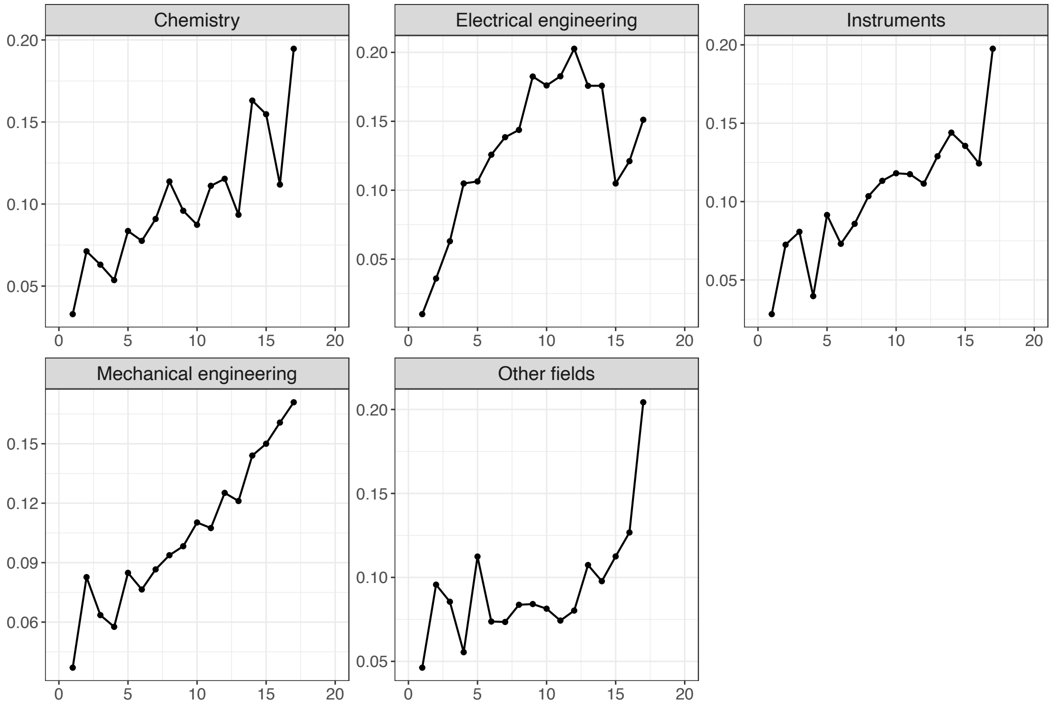
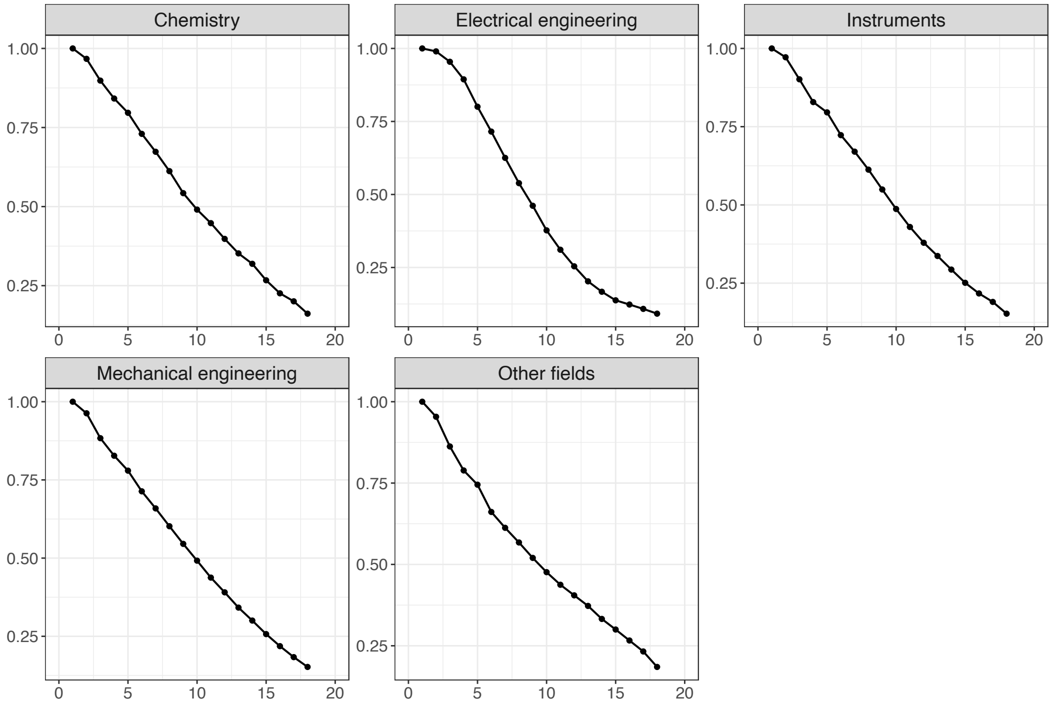


Figure 3: Hazard rates by technology area



4 Theoretical framework

The theoretical framework is based on the dynamic stochastic model of patent renewal decisions in Pakes (1986) and Lanjouw (1998). The results of an alternative specification with deterministic returns (no learning shocks) similar to Pakes and Schankerman (1984) and Grönqvist (2009) is presented in Appendix A.

4.1 Model

In this single agent dynamic model with finite horizon, I consider a risk-neutral firm which decides whether to renew a single patent i in period $t = 1, \ldots, T$. The first period of the model is the year of the first renewal decision. As shown in the data analysis, the first renewal decision is usually taken three years after the application date. T is the statutory limit for the protection. Renewal fees are defined as a sequence $\{c_t : t = 1, \ldots, T\}$ which is known to the patent-holder and increasing in time (see Figure 2). A patent i generates a sequence of returns: $\{r_{it} : t = 1, \ldots, T\}$. At the time of renewal decision in period t, current returns r_{it} are known by the firm but are unobserved by the econometrician. Returns are the state variables in this dynamic optimization problem. For simplicity, the index i is dropped in the following.

Formally, the problem of the firm is an optimal stopping problem where it decides - knowing the per-period return r_t - whether it renews the patent ($d_t = 1$) or lets it lapse ($d_t = 0$) in period t. d_t is then the control variable. The decision is taken by the firm in order to maximize the intertemporal flow of patent returns. If it drops the patent ($d_t = 0$), the return is zero forever so the value function is zero. 0 is then an absorbing state. When the patent is renewed ($d_t = 1$), the value consists of two parts: the net return of the period $r_t - c_t$ and the value of an option to renew the patent in the future $EV_t(r_{t+1}; \omega)$. ω is the vector of parameters to be estimated. The value functions $\{V_1(.), \ldots, V_T\}$ are recursively related via the following Bellman's equations:

$$V_t(r_t; \omega) = \max\{0, r_t - c_t + \beta E_t[V_{t+1}(r_{t+1}; \omega)|r_t, d_t]\}$$

where β is the real discount factor, not estimated in the model and fixed to 0.95 as in Lanjouw (1998).

The sequence of returns $r_1, \ldots, r_T$ is defined as a stochastic Markov process that allows for: i) Heterogeneity in the initial quality of the invention; ii) depreciation of the patent returns across time and even obsolescence if a major technological discovery happens in the same area, making the patented invention worthless; iii) a learning effect, i.e., a new use of the patent that can increase the value of the patent.

Initial return Following Lanjouw (1998), the returns r_0 before the first period are assumed to be zero for all patents i. Over time, the owner of the patent will learn the value of the innovation through a shock z_t that might increase the value of the patent protection.

Subsequent returns The per period return evolves as:

$$r_t = \begin{cases} \max\{\delta r_{t-1}, z_t\} & \text{with probability } \theta \\ 0 & \text{with probability } 1-\theta \end{cases}$$

where z_t is a learning shock drawn from a two-parameter exponential distribution, $\delta \in (0,1)$ is the factor of depreciation and $\theta \in (0,1)$ is the factor of obsolescence. If the owner of the patent does not to "learn" about new opportunities for the invention in period t (case of z_t low) and in absence of obsolescence, the return in period t is simply the return from the previous period depreciated by a factor $1-\delta$.

Obsolescence and patent depreciation Every year, the patent has a probability $1-\theta$ to become obsolete and therefore to have a value of 0. Obsolescence happens when major technological breakthroughs in the same area make the invention totally worthless. This obsolescence can also be seen as extreme depreciation. On top of obsolescence, the patent also depreciates every year at a fixed rate $1-\delta \in (0,1)$. This depreciation is the result of competing inventions due to the discovery by other firms of similar technologies which affect negatively the market power of the inventor. Infringements and imitation of the patent could be other reasons to explain the decrease in the returns to protection (Lanjouw, 1998).

Learning effect and complementarities z_t is a random variable that captures innovations that are complements to the patent and increase its profitability. This innovation shock, drawn in each period, captures new commercial opportunities or learning effects that lead to an increase in the value of patent. It is called a learning effect because the patent holder collects new information on the market throughout the time and can discover new ways of using the invention. Following the literature, z_t is drawn from a two-parameter exponential distribution. The probability density function of the stochastic learning process z_t is then:

$$q_t(z_t) = \frac{1}{\sigma_t} \exp\left(-(\frac{z_t}{\sigma_t} + \gamma)\right) \ , \ z_t \geq -\gamma\sigma$$

where $\sigma_t = \phi^{t-1}\sigma$
Note that the cumulative distribution function is then: $F(z_t) = 1 - \exp(-\frac{1}{\sigma_t}(z_t + \gamma\sigma_t))$, the mean is $\sigma_t(1-\gamma)$ and the standard deviation is σ_t.
$0 < \phi \leq 1$ captures the fact that the learning effects are higher in the first years of the patent life and the probability of major complementary innovations declines over time. The lower is ϕ, the faster is the decrease in opportunities. σ can then be interpreted as a measure of the potential quality of the invention. γ captures the fact that learning can take place some time after the patent is granted. If γ is high, there is a certain delay before the owner of the patent is able to internalize the flow of returns from the patent. In a sense γ is a measure of time to accumulate knowledge in order to fully internalize the returns from the patent.

4.2 Renewal decision rules

Pakes (1986) provides the regularity conditions for the existence of a solution to a similar patent problem and discusses the general form of the solution. The Markov assumption that returns at time t depend only on returns in the previous period is necessary to derive the decision rule. The decision rule is more specifically characterized in Appendix B and the approximation for the thresholds are used in the estimation procedure. The solution is such that, in every period t, there is a minimum threshold return $\overline{r}_t$ such that, if the return is higher than the threshold, the patent is renewed and if the return is below the threshold the patent owner let the patent lapse. Thresholds are functions of parameters ω to be estimated.
Since the maximum length of the patent is finite and equal to T, this dynamic problem can be solved by backward induction.
More formally, the patent holder renews the patent in period t if the return and the option value of owning the patent is higher than the renewal cost:

$$r_t - c_t + \beta E_t[V_{t+1}(r_{t+1}; \omega)|d_t] > 0$$

Therefore, the threshold $\overline{r}_t$ which is the minimum level of return r_t at which it becomes worthwhile to renew the patent is defined by:

$$\overline{r}_t = c_t - \beta E_t[V_{t+1}(r_{t+1};\omega)|d_t] \tag{1}$$

Because $E_t[V_{t+1}(r_{t+1};\omega)|r_t, d_t]$ is continuous and non-decreasing in r_t, there is a unique solution $\overline{r}_t$. Moreover, $E_t[V_{t+1}(r_{t+1};\omega)|r_t, d_t]$ and the sequence of renewal fees are non-decreasing in age. Pakes (1986) shows that these two characteristics imply $\overline{r}_t$ is non-decreasing in age too: $\overline{r}_1 < \overline{r}_2 < \ldots < \overline{r}_{T-1} < \overline{r}_T$.

5 Estimation

Roughly speaking, the aim of the estimation is to find the values of the structural parameters $\omega = (\delta, \theta, \sigma, \phi, \gamma)$ that yield model predictions for the hazard rates that are as close as possible to the observed hazard rates in the data (see Figure 3).

5.1 Simulated method of moments

The moments used in the estimation describe the expiration decisions of patent owners. They are simulated because they cannot easily be solved analytically due to the fact that returns are unobserved and serially correlated. The cumulative distribution function of r_{it} is:

$$1 - F_t(r) = Pr(r_{i,t} \geq r, r_{i,t-1} \geq \overline{r}_{t-1}, \ldots, r_{i,1} \geq \overline{r}_1) \tag{2}$$

The proportion of patents that are renewed up to age t is then all the patents for which the returns in periods $k \leq t$ exceed the minimal renewal thresholds $\overline{r}_k$. It can also be written as $1 - F_t(\overline{r}_t)$.

The moment conditions used here are the hazard rates which are the proportion of patents lapsing at time t over the patents that survive up to age $t-1$. Since Lanjouw (1998), the hazard rate π_t are usually used as moment conditions in the estimation of the renewal decision models. More formally, the simulated hazard rates are:

$$\pi_t(\omega) = \begin{cases} F_1(\overline{r}_1) & \text{for t} = 1 \\ \frac{F_t(\overline{r}_t) - F_{t-1}(\overline{r}_{t-1})}{1 - F_{t-1}(\overline{r}_{t-1})} & \text{for t} = 2, \ldots, 17 \end{cases} \tag{3}$$

Note that $t = 1$ is the first period once the patent is granted. I run five separate estimations for the five fields of technology and each estimation has 17 moments. The simulated moments $\pi(\omega)$ is then a 17-dimensional vector.

I use a simulated method of moment (SMM) estimator (McFadden, 1989) to estimate the parameters:

$$\begin{aligned}\hat{\omega}_S &= \arg\min_{\omega} ||\pi - \tilde{\pi}_S(\omega)||_W \\ &= \arg\min_{\omega} [\pi - \tilde{\pi}_S(\omega)]' \, W \, [\pi - \tilde{\pi}_S(\omega)]\end{aligned}$$

where π is a vector of hazard rates from the sample. $\tilde{\pi}_S(\omega)$ is a vector of simulated hazard rates as defined in Equation (3) and evaluated at the parameters ω from S simulations. W is the weighting matrix. W must be a semi-positive definite matrix. Following Lanjouw (1998) and Deng (2011), I use the weighting matrix $W = \text{diag}(\sqrt{n_t/N})$ where n_t is the number of simulated patent that survived until time t and N is the total number of simulated patents.

5.2 Computational details

I run 5 separate estimations for each technology field to estimate 5 vectors of parameters of the model $\omega = (\delta, \theta, \sigma, \phi, \gamma)$. The present discount factor is not estimated and set to $\beta = 0.95$ which is consistent with the literature. The different steps for the estimation are the following:

1. For an initial guess of parameters ω_0, I solve the model backward to calculate the thresholds $\overline{\boldsymbol{r}} = (\overline{r}_1, \ldots, \overline{r}_{17})$. These thresholds are derived using the formula displayed in Appendix B.

2. I generate the returns in the first period r_1^s (with $s = 1, \ldots, S$) based on the distributional assumptions of the stochastic Markov process with the number of simulations S. I choose $S = 50,000$. I do not find any gain from increasing the number of simulations.

3. I compute the predicted renewal decision in the first period $d_1^s = d_1^*(r_1^s; \omega)$. d_1^s is a binary variable (renew = 1, not renew = 0). It is constructed by comparing the simulated returns r_1^s with the threshold $\overline{r_1}$: $d_t^*(r_t; \omega) = \mathbb{1}(r_t > \overline{r_t})$

4. I generate the returns in the second period r_2^s for each simulated patent s based on the distributional assumptions.
5. I compute $d_2^s = d_2^*(r_2^s; \omega)$,
6. ... generate r_t^s and compute d_t^s for all periods t.
7. I construct the simulated hazard $\tilde{\pi}_t(\omega)$ for t = 1, ..., 17 as being the proportion of simulated patents lapsing in period t, conditional on surviving the previous period.
8. I construct the objective function $[\pi - \tilde{\pi}_S(\omega)]' \, W \, [\pi - \tilde{\pi}_S(\omega)]'$ where W is the weighting matrix, π is the vector of empirical moments observed in the data and $\tilde{\pi}_S(\omega)$ is the vector of simulated moments.
9. I find the parameters ω that maximize the simulated method of moments estimator using a Nelder-Mead algorithm [4].

Local minima As noted by previous works (Grönqvist, 2009; Deng, 2011), the objective function can be quite "rugged" and it can be difficult to find a global minimum. To take this issue into account, I run the estimations using different starting values. I choose an initial grid of points for starting values based on previous results (Pakes, 1986; Lanjouw, 1998; Grönqvist, 2009). I start with the grid of points for starting values displayed in Table 2. I then run a second estimation of multiple starting values around the ones that minimize the objective function.

Table 2: First grid for starting values

Parameters	**Lower bound**	**Higher bound**	**Step**	**Number of grid points**
$\boldsymbol{\delta}$	0.75	0.95	0.05	5
$\boldsymbol{\theta}$	0.85	0.95	0.05	3
$\boldsymbol{\gamma}$	0	0.8	0.2	5
$\boldsymbol{\sigma}$	500	13000	2500	6
$\boldsymbol{\phi}$	0	0.8	0.2	5

---

[4] Contrary to Serrano (2018), I find very little gain from using a simulated annealing algorithm but an increased computational intensive cost.

For each area of technology, I estimate the model for $5 \times 3 \times 5 \times 6 \times 5 = 2250$ vectors of starting values on the grid.

Standard errors and confidence intervals by bootstrap Standard errors of the parameters are computed as the empirical standard deviation of the bootstrap values (Cameron and Trivedi, 2005). Confidence intervals for the distribution of private value are computed by a percentile bootstrap. More specifically, let the original sample be $y = (y_1, \dots, y_n)$ where y_i is the number of renewal years of a patent i. Let $y^{*b} = (y_1^{*b}, \dots, y_n^{*b})$ be one bootstrap sample of the original with $b = 1, \dots, B$ and $B = 500$ bootstrap replications. In each bootstrap sample b, I estimate the bootstrap replication of the statistic of interest $\hat{\lambda}^{*b}$ with $b = 1, 2, \dots, B$. This statistic of interest can be the vector of parameters ω or some quantile of the private value distribution (e.g mean, median).

The bootstrap estimate of standard error for $\hat{\lambda}$ is:

$$\hat{se}_{boot} = \left[\sum_{b=1}^{B} (\hat{\lambda}^{*b} - \overline{\lambda}^{*})^2 / (B-1) \right]^{1/2}$$

with $\overline{\lambda}^{*} = \sum_{b=1}^{B} \hat{\lambda}^{*b} / B$

Confidence intervals for the quantiles of the distribution of private value are computed using percentile bootstrap method. The percentile method uses the shape of the bootstrap distribution. After generating $B = 500$ replications $\hat{\lambda}^{*1}, \dots, \hat{\lambda}^{*B}$ of a statistic of interest (e.g mean), I then use the percentiles of their distribution to define percentile confidence limits. (Efron and Tibshirani, 1994).

6 Results

6.1 Parameter estimates

Table 3 reports the parameter estimates. All the estimates are statistically significant and in line with the previous literature. The relatively low values for ϕ (except for "Other Fields") suggest that most of the learning occurs in the very first years. The implication of the parameters of the learning process are discussed in 6.4. There are differences in obsolescence (θ) across fields of technology with patents in Other Fields and Electrical Engineering having a higher probability of obsolescence (8-9%) than in Chemistry, Instruments or Mechanical Engineering (around 3-4%) The depreciation rates are quite similar across technology areas: lower than 5% ($\delta \geq 0.95$). The very low values estimated for γ indicate that learning take place immediately after the grant date. In other words, patent holders are able to internalize directly the flow of returns from the patent. We see large differences in the parameter σ which suggest very different learning dynamics. Patents in the groups Chemistry, Instruments and Mechanical Engineering have a high σ which means a higher probability of learning a higher value. In other words, patents in these three groups tend to benefit more from learning process especially in the first years of the patent life. On the other hand, the depreciation is faster for these 3 groups in comparison with "Electrical Engineering" and "Other Fields". These estimates seem to confirm the results of Lanjouw (1998) who finds a high value of σ for "Engines" and "Pharmaceuticals" (9,500 and 14,000) in comparison with "Computers" and "Textile" (5,000 and 4,000) with a higher rate of depreciation for Engines and Pharmaceuticals (6-7%) than for Computers and Textiles (4-5%).

Fit is assessed by the mean-squared difference between the empirical and the simulated hazard rates. I find the same order of magnitude for the mean-squared errors (MSE) and standard errors than other works in the literature (Grönqvist, 2009; Serrano, 2018). Table 3 shows also the variance of the hazard rates in the data: $V(\pi)$. As noted by Deng (2011), the variance of the hazard rates can be interpreted as the MSE of a "naive" model which predicts a constant hazard rate equal to the sample average. Comparing the MSE with the variance of hazard rates provides an indication of the performance of the model in comparison with the "naive model". The ratio MSE/$V(\pi)$ has then a similar interpretation to the $(1 - R^2)$ in a linear regression model. Therefore, as displayed in the table, the model improves the fitness of the data by about 78% for Chemistry, 83% for Electrical Engineering, 86% for Instruments, 65% for Mechanical engineering and 76% for Other Fields, in comparison with a "naive model".

Table 3: Parameter estimates 1990-2000

Parameters	**Chemistry**	**Electrical Engineering**	**Instruments**	**Mechanical Engineering**	**Other Fields**
$\boldsymbol{\delta}$	0.95202 (7.74×10^{-5})	0.99794 (1.42×10^{-3})	0.96035 (3.74×10^{-5})	0.94946 (1.65×10^{-3})	0.96329 (4.15×10^{-4})
$\boldsymbol{\theta}$	0.96877 (3.77×10^{-5})	0.92877 (3.19×10^{-2})	0.97294 (2.84×10^{-5})	0.96615 (3.25×10^{-2})	0.9172 (6.64×10^{-5})
$\boldsymbol{\phi}$	0.058363 (4.74×10^{-4})	0.2232 (7.58×10^{-3})	0.075881 (2.15×10^{-4})	0.049461 (5.50×10^{-3})	0.89875 (3.41×10^{-4})
$\boldsymbol{\sigma}$	27,869 (22.37)	3,114 (246.82)	17,518 (13.54)	35,055 (1336.98)	1,222 (6.11)
γ	0.038912 (3.65×10^{-5})	0.02473 (1.33×10^{-2})	0.047546 (6.75×10^{-5})	0.046829 (2.32×10^{-3})	0.04675 (2.67×10^{-4})
MSE	3.59×10^{-4}	4.89×10^{-4}	2.11×10^{-4}	4.64×10^{-4}	2.82×10^{-4}
$\boldsymbol{V(\pi)}$	0.0016	0.0030	0.0015	0.0013	0.0011
MSE/$\boldsymbol{V(\pi)}$	0.22	0.17	0.14	0.35	0.24

Note: *Standard Errors into parentheses - 500 bootstrap replications*

6.2 Comparison of predicted and observed hazard rates

Predicted and observed hazard rates are displayed in Figure 5 in green and red respectively. Graphically, it seems that the simulated moments fit reasonably well the moments in the data. The simulated hazard rates tend to capture well the trends but not necessarily the specific spikes.

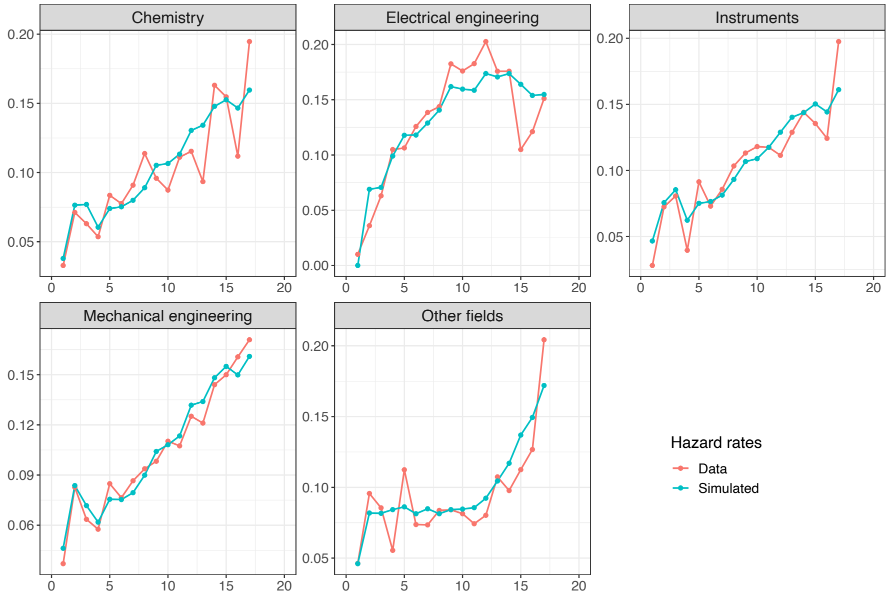


Figure 5: Hazard rates by technology area

6.3 Distribution for the value of patent rights

To infer the distribution for the value of patent rights, I perform a Monte-Carlo simulation for returns using the parameter estimates in Table 3. I generate $50,000$ patent return histories drawn according to the distributional assumptions described previously. The optimal length T^* of each simulated patent is determined by comparing simulated returns with the optimal thresholds $\overline{r}$. The net private value of patent i is then calculated as:

$$V_i = \sum_{t=1}^{T^*} \beta^{t-1}(r_t - c_t)$$

The Table 4 shows the percentile distribution of total private value for patents granted between 1990 and 2000. The value distribution is relatively right-skewed which is a common result in the literature. It indicates that there is a significant proportion of patents of relatively low value. The mean value is around €9,000 for patents in the group Chemistry, Mechanical Engineering and Other Fields. For Instruments, the mean value is slightly lower at around €7,000 and it is €4,000 for Electrical Engineering patents. For all technology areas, the median values are around half the mean value (except for "Other Fields" which is slightly higher). The median value is also very informative to complement the mean because the mean is more sensitive to the higher tail of the distribution that depends on the distributional assumptions. Indeed, patents with the highest values are renewed the full length, therefore their private values are mostly determined by the assumption on the distribution of the returns. Confidence intervals are reported using the percentile bootstrap method. Note that the confidence intervals for Instruments and Other Fields are not reported as they are not informative: very large and estimate outside of the confidence interval.

These results can be directly compared with Grönqvist (2009) who estimates the private value for patents granted to firms in Finland applied for between 1970 and 1983. Using a similar stochastic model, she finds a mean value of €4,575 in EUR 2010 for patents granted to firms. Her results are quite different in comparison to the weighted average value of around €7,500 found in this essay. Many reasons can explain the differences. First, the sample is different and the renewal fee scheme was not the same between 1970-1983 studied by Grönqvist and the period 1990-2000 studied here. As noted previously, a major change in the renewal scheme was introduced in 1990 with the payment of renewal fees starting three years after the filing date. Second, patenting behaviour during the decade 1990's might have been affected by Finland joining the European Patent Convention mid-1990's and the dominance of Nokia's patenting in Finland. Moreover, during the period 1970-1983, the number of patents granted in Finland was relatively low, which could be associated with some uncertainty regarding the patent system and the value of patented inventions. In a seminal paper, Pakes (1986) finds a mean value of €12,000 for patents in France with application date between 1951-1979, €16,000 in the UK and €35,000 in Germany. Lanjouw (1998) finds a mean value of €30,000 in EUR 2010 for patents in the group "Computer" with an application date of 1975, €20,000 for "Textiles" and €60,000 for "Engines". Serrano (2018) in a stochastic model with market for knowledge estimates the private value of US patents to be on average €56,000 in EUR 2010 for untraded patents and €180,000 for traded patents.
A more comprehensive comparisons of the different methods and results on patent valuation can be found in the introductory chapter of this thesis.

Table 4: Distribution of the private value of patent protection in EUR 2010: 1990-2000

Quantile	**Chemistry**	**Electrical Engineering**	**Instruments**	**Mechanical Engineering**	**Other Fields**
0.25	832	830	555	861	2,729
	[254 – 1,681]	[182 – 1,134]		[170 – 4,664]	
0.50	4,130	2,189	3,203	4,328	6,827
	[1,652 – 7,452]	[685 – 3,092]		[1,737 – 13,145]	
0.75	9,672	4,508	7,857	10,121	10,990
	[5,707 – 11,718]	[1,634 – 6,422]		[4,940 – 26,323]	
0.90	23,445	11,041	19,697	24,439	19,217
	[18,734 – 32,664]	[4,504 – 15,297]		[13,594 – 59,147]	
0.95	32,434	15,766	27,536	33,937	24,608
	[23,045 – 57,964]	[6,761 – 21,591]		[19,231 – 81,589]	
0.99	54,276	27,590	46,379	56,848	37,639
	[36,981 – 86,452]	[12,107 – 36,916]		[32,578 – 135,200]	
Mean	8,658	4,327	7,145	9,047	8,791
	[5,572 – 10,856]	[1,668 – 6,014]		[4,698 – 23,537]	

Note: *90% confidence intervals into brackets - percentile bootstrap, 500 replications*

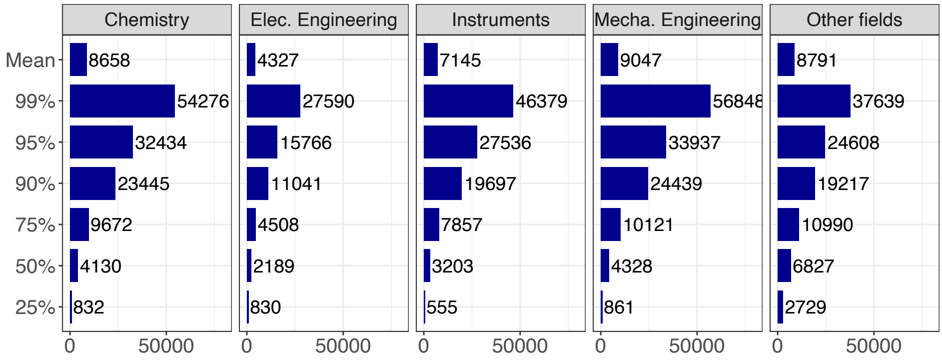


Figure 6: Private value of patents by technology fields, in EUR 2010

6.4 Complementarities and learning

Table 5 shows the average value of the learning effects z_t across years. The estimates are based on draws of 50,000 learning shocks using the estimates in Table 3. In line with Lanjouw (1998); Grönqvist (2009), the learning effects tend to disappear by five to six years and most of the learning is done in the first four years. As reported in Table 3, I find a very low value for γ. It suggests that learning effects take place directly from the patent grant and with no delay. It can be noted that ϕ is particularly high for "Other Fields", which indicates a long-lasting learning process is in contrast with the other technology groups. It is difficult to draw any conclusion for patents in "Other Fields" as it is a more heterogeneous group than the others. All in all, the short learning effect is common for national patents where patent holder are less willing to experiment and try new strategies to exploit their inventions than for EPO patents for instance (Deng, 2011).

Table 5: Average learning in monetary terms (EUR 2010)

Year	**Chemistry**	**Electrical Engineering**	**Instruments**	**Mechanical Engineering**	**Other Fields**
1	1568.1	869.2	1,270.1	1,657.8	1,523.3
2	90.4	192.1	95.2	80.9	856.5
3	5.3	43.2	7.3	4.1	491,7
4	0.31	9.7	0.5	0.2	282,05
5	< 0.1	2.1	< 0.1	< 0.1	157.71
6	< 0.1	0.5	< 0.1	< 0.1	90.6
7	< 0.1	< 0.1	< 0.1	< 0.1	51.35
8	< 0.1	< 0.1	< 0.1	< 0.1	16.64
9	< 0.1	< 0.1	< 0.1	< 0.1	5.33
10	< 0.1	< 0.1	< 0.1	< 0.1	1.7
11	< 0.1	< 0.1	< 0.1	< 0.1	0.5
12	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
13	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
15	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
16	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
17	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

6.5 Ratio of stock of patent value to R&D expenditure in Finland

To construct a measure of R&D returns to Finnish companies for the year 2000, I compute first an average value of patents decomposed by field of technology and patent length (Table 6). I simulate the value of 50,000 patents for each technology and each patent length using the structural parameters estimated (see Table 3). The average values are then multiplied by the number of patents granted in 2000 by technology and length. The total stock of patent value is €6 million for Finnish patents granted to Finnish companies in 2000. Second, the aggregate value is compared to the amount of Business Enterprise R&D in Finland.

Table 6: Average value of patent by number of renewal years (EUR 2010)

Patent Length	**Chemistry**		**Electrical Engineering**		**Instruments**		**Mechanical Engineering**		**Other Fields**		**Total (in M)**
	Value	**Count**	**Value**	**Count**	**Value**	**Count**	**Value**	**Count**	**Value**	**Count**	
0	0	3	0	2	0	2	0	5	0	2	0
1	578	6	752	29	394	4	617	8	984	1	0.03
2	1,231	2	1,456	67	771	6	1,526	12	2,288	5	0.15
3	2,322	10	1,572	83	1,669	6	2,620	21	3,693	4	0.23
4	2,649	10	1,776	18	1,916	3	3,007	16	5,073	3	0.13
5	3,315	6	2,189	19	2,447	2	3,736	8	6,411	2	0.11
6	3,950	6	2,620	8	2,988	3	4,427	12	7,666	2	0.12
7	4,261	7	2,866	8	3,285	7	4,724	23	8,763	0	0.18
8	4,696	6	3,233	5	3,728	2	5,159	21	9,795	2	0.18
9	5,581	3	3,882	13	4,547	0	6,053	12	10,683	2	0.16
10	6,435	6	4,529	12	5,349	3	6,921	15	10,717	1	0.22
11	7,292	6	5,122	13	6,168	2	7,787	15	10,836	3	0.27
12	8,553	1	5,961	5	7,316	1	9,076	7	10,838	2	0.13
13	9,952	3	6,846	6	8,593	0	10,520	11	11,117	1	0.20
14	11,543	11	7,757	5	10,018	2	12,170	11	11,224	1	0.33
15	13,398	1	8,912	9	11,635	1	14,109	8	11,458	2	0.24
16	15,221	9	9,774	8	13,213	1	15,995	13	12,096	2	0.46
17	27,734	25	14,845	27	24,185	12	28,952	42	17,500	10	2.77
Total		121		337		57		260	1	45	5.9

The aggregate value of patent stock (€6 million) seems quite low and corresponds to an average value of patent of around €7,300. The main limitation of this approach is the difficulty to capture the private value of “very valuable patents” which are renewed the full term and for which the private value rely essentially on the distributional assumptions. Therefore, the total stock should be interpreted as a lower bound that measures the value of “marginal” patents for which there exists a trade-off between renewing and not renewing.

In a second step, the total aggregate stock of value for patents granted in 2000 is then divided by the stock of R&D investment in 1996, expressed in EUR 2010. The R&D investment for companies (Business Enterprise R&D Expenditure) comes from OECD-STAT[5] converted to EUR 2010. The total BERD used includes only manufacturing and excludes services. There is an average of 2.7 years between the application and the grant decision. As a simple assumption, the total R&D expenditure used is the one in 1996 to take into account one year of R&D investment and three years of patent examination. The total BERD in EUR 2010 is around €1 billion, yielding a ratio of patent stock on R&D expenditure is 0.67% (See Table 7).

Bessen (2008) with a similar approach of averaging by patent length finds a ratio of around 3% for US patents. Other results range between 4% and 35%. For instance, Pakes (1986) calculates rates of return between 10-15% in the US with a slightly different model specification and not averaging by patent length. Similarly, Lanjouw (1998) finds an aggregate value of patent protection generated per year of around 10% of R&D expenditure. Therefore the ratio of patent stock on BERD for Finland is lower than other estimates based on European data and US data. One reason already mentioned is the lack of information on very valuable patents at the upper tail of the distribution: around 14% of the patents are renewed to full term. A second explanation is that not all R&D investments lead to a patent application and not all companies are patenting: There are others ways to protect intellectual property such as trade secrecy. Third, since the end of the 1990’s, Finnish companies increasingly applied to EPO patents, especially since 1996 when Finland has joined the European Patent Convention. Therefore, it is possible to have a patent protection in Finland with an EPO patents instead of a national patent granted by the Finnish Patent Office and Registration. According to WIPO Statistics, in 2000 Finnish applicants (individual and companies) had 264 patents granted by the European Patent Office and 999 by PRH. This number has increased and in 2019, 1622 EPO patents were granted to Finnish applicants and 453 by the Finnish Patent Office. Moreover, R&D investment in Finland can lead to patenting in other countries such as the US (618 patents granted to Finnish applicants in 2000) or Japan (149). Fourth, relying only on renewal costs and not taking into account other

---

[5] Business enterprise R-D expenditure by industry: https://stats.oecd.org/

costs such as expected litigation costs or patent agent costs suggests that the private values computed are lower bounds.

Table 7: Ratio of aggregate patent value to R&D expenditure in Finland

Sample	**Aggregate patent value in M EUR 2010**	**BERD (excl. services) in M EUR 2010**	**Ratio agg. value/BERD (in %)**
Granted in 2000	5.9	1,026	0.67%

7 Concluding remarks

This essay updates and extends the work of Grönqvist (2009) by measuring the private value of patents granted to firms in Finland between 1990 and 2000. The main findings are that the private value distribution is right-skewed in all technology areas which suggests a large fraction of low-value patents and a small number of valuable patents. The average private value of patents is higher in Mechanical Engineering (€9,047) followed by Chemistry (€8,658), Instruments (€7,145) and Electrical Engineering (€4,327). The average value in the group “Other fields” is €8,791. At the national level, the ratio of aggregate patent value to Business Enterprise R&D Expenditure (BERD) is 0.67% in 2000.

The renewal decision model is based on a revealed preference argument. The model seems to relatively accurately measure the value of “marginal patents” for which there is a trade-off between paying or not the renewal fees. Nonetheless, this model has some limitations and the private values estimated in this essay might be interpreted as lower bounds for various reasons. First of all, only renewal costs are taken into account even though other costs, such as the expected litigation costs, the cost associated with trade and transfer of the ownership, the expected licensing revenues, the application costs, etc... are important for the patent holders. Second, the strategic motives for patenting are not included in the theoretical framework. The model is a single agent model and neglects potentially important strategic interactions whereby the patents of a firm can reduce the rents of competitors. Additionally, the model does not capture the portfolio dimension and the possibility of complementarities between patents in a portfolio. In fact, firms tend to own multiple patents simultaneously for which complementarities exist. In other words, the value of two patents taken together and owned by the same company can be higher than the sum of the value of the patents in isolation. This dimension is not included in the model as the assumption is that firms only owns one patent. Third, the model may have trouble providing a reliable estimate for the most valuable patents. These patents are usually renewed the full term which means that the renewal decision does not give enough information to measure the difference in values for these valuable patents. Indeed, results at the upper tail rely heavily on the functional form assumptions. Fourth, the model is only looking at the private value of patents and does not take into account possible social returns and spillovers.

A Deterministic model

As an alternative specification, I estimate a deterministic model similar to Pakes and Schankerman (1984) and Schankerman and Pakes (1985) using a non-linear least square estimator. On the contrary to the stochastic model presented in this essay, the deterministic model has no learning shocks and the initial return is drawn from a log-normal distribution where the mean is μ and the standard deviation is σ_R.
In the deterministic model, the patent holder maximizes the discounted private value of patents by choosing the optimal patent length T:

$$\max_{T\in[1,\ldots,\overline{T}]} V(T) = \sum_{t=1}^{\overline{T}} \beta^{t-1}(r_t - c_t)$$

β is the present discount factor set to 0.95, r_t is the patent return in period t, c_t is the renewal fee paid in period t and $\overline{T}$ is the maximum patent length so 17 here.
The flow of returns is deterministic and assumed to be $r_t = r_0\,\delta^t$. Similarly to the stochastic model, δ is the depreciation rate to estimate.

Patent holder renews the patent in period $t \in \{1, \ldots, \overline{T}\}$if:

$$V(t) \geq V(t-1) \iff r_0\,\delta^t \geq c_t$$

$$P_t = Pr\left(r_0\delta^t \geq c_t\right) = 1 - Pr\left(r_0 < \frac{c_t}{\delta^t}\right)$$

P_t is the survival rate which is the proportion of patents that are still alive in period t. r_0 is log-normally distributed so $\log(r_0)$ is normally distributed. I estimate the following equation by non-linear least squares:

$$1 - \Phi\left(\ln(c_t) - t\ln\delta\right) = P_t$$

Φ is the cumulative distribution function of a normal distribution with mean μ and standard deviation σ_R.

Results are summarized in Table 8. The depreciation rates δ are quite high but in line with the results of the stochastic model (Table 3). Note that $\delta = 1$ which is the upper bound for Other Fields and Electrical Engineering. It suggests that the deterministic model is not able to fully rationalize the dataset for these two field of technology as the patent returns do not depreciate.

Table 8: Parameter estimates 1990-2000, deterministic model, S.E into brackets

Parameters	**Chemistry**	**Electrical Engineering**	**Instruments**	**Mechanical Engineering**	**Other Fields**
$\boldsymbol{\delta}$	0.9869	1.0000	0.9867	0.9573	1.0000
	(2.48×10^{-2})	(2.65×10^{-2})	(2.25×10^{-2})	(3.37×10^{-2})	(3.61×10^{-2})
$\boldsymbol{\mu}$	6.1998	5.8973	6.1741	6.4368	6.0321
	(2.35×10^{-1})	(2.10×10^{-1})	(2.09×10^{-1})	(3.21×10^{-1})	(3.29×10^{-1})
$\boldsymbol{\sigma_R}$	1.0214	0.6888	0.9982	1.249	1.1072
	(1.76×10^{-1})	(1.33×10^{-1})	(1.55×10^{-1})	(2.48×10^{-1})	(2.98×10^{-1})

The deterministic model shows lower results for mean (55-98%) and median value (20-50%) of patents than the stochastic model (See Table 9). The main reason for that is the different assumptions on how returns evolve. In the stochastic model, learning shocks allow patent holder to renew a low value patent in a given year because she expects a higher return in the future. This is not the case in the deterministic model where the patent will not be renewed. Another explanation is that the deterministic model does not seem to capture correctly the survival rate in this context as mentioned above with $\delta = 1$.

Table 9: Distribution of the private value of patent protection in EUR 2010: 1990-2000 - deterministic model

Quantile	**Chemistry**	**Electrical Engineering**	**Instruments**	**Mechanical Engineering**	**Other Fields**
0.25	327	276	318	364	162
0.50	1,693	969	1,610	2,187	1,317
0.75	5,726	2,541	5,341	8,159	5,398
0.90	14,684	5,451	13,605	22,710	15,286
0.95	23,414	8,285	21,631	38,431	25,200
0.99	51,802	16,165	47,400	96,388	58,993
Mean	5,490	2,129	5,082	8,872	5,647

B Renewal decision rules

The following section is based on Lanjouw (1998).

The value of the patent at age t is:

$$V(t, r_t) = \max\ \{0, r_t - c_t + \beta\theta E_t\, V(t+1, r_{t+1})\}$$

At time T At T, the value is $V(T, r_T) = \max\{0, r_T - c_T\}$ because T is the last period so $E_T\, V(T+1, r_{T+1}) = 0$. The minimum return r_t^* such as the patent is renewed at age T is then defined by $V(T, r_T) = 0$ which gives the condition: $\boxed{r_T^* = c_t}$

At time T-1 The value of the patent is:

$$V(T-1, r_{T-1}) = \max\ \{0, r_{T-1} - c_{T-1} + \beta\theta E_{T-1}\, V(T, r_T)\}$$

The expected value $E_{T-1}\, V(T, r_T)$ depends on whether δr_{T-1} is greater or lower than r_T^*.

- **Case 1:** $\delta r_{T-1} < r_T^*$ The renewal decision taken at age $T-1$ depends on the realization of z_T. The expected value is then:

  $$E_{T-1}\, V(T, r_T) = \int_{r_T^*}^{+\infty} (z_T - c_T) q_T(z_T) dz_T \tag{4}$$

  Recall that by assumption z_T follows a two-parameter exponential distribution with the probability density function defined by:

  $$q_t(z_t) = \frac{1}{\sigma_t} \exp\left(-(\frac{z_t}{\sigma_t} + \gamma)\right)$$

  By partial integration, we can prove that:

  $$\int_a^b z_t q_t(z_t) dz_t = a\sigma_t q_t(a) - b\sigma_t q_t(b) + \sigma_t \left[Q_t(b) - Q_t(a)\right] \tag{5}$$

  $Q_t(.)$ is the cumulative distribution function associated with σ_t.
  Note also that:

  $$Q_t(a) = \int_{-\gamma\sigma_t}^{a} q_t(z_t) dz_t = 1 - \sigma_t q_t(a) \tag{6}$$

Using equations (5) and (6) and because $c_T = r_T^*$, we can rewrite the expected value (4):

$$\begin{aligned}
E_{T-1}\,V(T,r_T) &= \int_{r_T^*}^{+\infty} (z_T - c_T)dQ_T(z_T)\\
&= r_T^*\sigma_T q_T(r_T^*) + \sigma_T[1-Q_T(r_T^*)] - c_T\sigma_T[1-Q_T(r_T^*)]\\
&= r_T^*[1-Q_T(r_T^*)] + \sigma_T[1-Q_T(r_T^*)] - c_T[1-Q_T(r_T^*)]\\
&= \sigma_T[1-Q_T(r_T^*)]
\end{aligned}$$

Following Deng's notation Deng (2011), we set:

$$h_{T-1}^0 = \int_{r_T^*}^{+\infty} (z_T - c_T)dQ_T(z_T) = \sigma_T[1-Q_T(r_T^*)]$$

- **Case 2: $\boldsymbol{\delta r_{T-1} \geq r_T^*}$** The patent holder will renew the patent regardless of z_T and as long as obsolescence does not occur. When $z_T < \delta r_{T-1}$, the return is $\max\{\delta r_{T-1}, z_T\} = \delta r_{T-1}$ and when $z_T \geq \delta r_{T-1}$, the return is z_T. Therefore, the value function is:

$$\begin{aligned}
E_{T-1}\,V(T,r_T) &= \int_{-\gamma\sigma_T}^{\delta r_{T-1}} (\delta r_{T-1} - c_T)dQ_T(z_T) + \int_{\delta r_{T-1}}^{+\infty} (z_T - c_T)dQ_T(z_T)\\
&= (\delta r_{T-1} - c_T)Q_T(\delta r_{T-1}) + \int_{r_T^*}^{+\infty} (z_T - c_T)dQ_T(z_T)\\
&+ \int_{r_T^*}^{\delta r_{T-1}} (c_T - z_T)dQ_T(z_T)\\
&= \int_{r_T^*}^{+\infty} (z_T - c_T)dQ_T(z_T) + (\delta r_{T-1} - c_T)Q_T(r_T^*)\\
&+ \int_{r_T^*}^{\delta r_{T-1}} (\delta r_{T-1} - z_T)dQ_T(z_T)\\
&= h_{T-1}^0 + h_{T-1}^1(r_{T-1})
\end{aligned}$$

So we set:

$$h_{T-1}^1(r_{T-1}) = (\delta r_{T-1} - c_T)Q_T(r_T^*) + \int_{r_T^*}^{\delta r_{T-1}} (\delta r_{T-1} - z_T)dQ_T(z_T)$$

$h_{T-1}^1(r_{T-1})$ is positive, so the minimum renewal return r_{T-1}^* such as the patent holder decide to renew his patent at $T-1$ satisties the condition:

$$r_{T-1} + \beta\theta h_{T-1}^0 - c_{T-1} = 0 \iff r_{T-1}^* = c_{T-1} - \beta\theta h_{T-1}^0$$

At time T-2

- **Case 1: $\boldsymbol{\delta r_{T-2} < r^*_{T-1}}$** The renewal decision taken at age $T-2$ depend on the realization of z_{T-1}. If $z_{T-1} \geq r^*_{T-1}$, the patent will be renewed in $T-1$. Moreover, if $z_{T-1} > \frac{r^*_T}{\delta}$, the patent will be renewed in $T-1$ and $T-2$; if $z_{T-1} < \frac{r^*_T}{\delta}$ and still $z_{T-1} \geq r^*_{T-1}$, the patent will be renewed in $T-1$ and might be renewed in $T-2$ depending on z_T.

  The functional form of $E_{T-2}V(T-1, r_{T-1})$ is then:

$$\begin{aligned}
E_{T-2}V(T-1, r_{T-1}) &= \int_{r^*_{T-1}}^{r^*_T/\delta} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{\frac{r^*_T}{\delta}}^{+\infty} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1}) \\
&= h^0_{T-2}
\end{aligned}$$

- **Case 2: $\boldsymbol{r^*_{T-1} < \delta r_{T-2} < r^*_T/\delta}$:**

$$\begin{aligned}
E_{T-2}V(T-1, r_{T-1}) &= \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{\delta r_{T-2}}^{r^*_T/\delta} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{r^*_T/\delta}^{+\infty} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1}) \\
&= \int_{r^*_{T-1}}^{r^*_T/\delta} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{r^*_T/\delta}^{+\infty} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1}) \\
&- \int_{r^*_{T-1}}^{\delta r_{T-2}} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1})
\end{aligned}$$

$$
\begin{aligned}
E_{T-2}V(T-1,r_{T-1}) &= h^0_{T-2} + \int_{\delta r_{T-2}}^{r^*_{T-1}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1} + z_{T-1} - \delta r_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&= h^0_{T-2} + [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1}] Q_{T-1}(r^*_{T-1}) \\
&+ \int_{r^*_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - z_{T-1}] dQ_{T-1}(z_{T-1}) \\
&= h^0_{T-2} + h^1_{T-2}(r_{T-2})
\end{aligned}
$$

- **Case 3: $r_{T-2} > r^*_T/\delta$**

$$
\begin{aligned}
E_{T-2}V(T-1,r_{T-1}) &= \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(\delta r_{T-2})] dQ_{T-1}(z_{T-1}) \\
&+ \int_{\delta r_{T-2}}^{+\infty} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1})
\end{aligned}
$$

$$
\begin{aligned}
&= \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} [\delta r_{T-2} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{-\gamma\sigma_{T-1}}^{\delta r_{T-2}} \beta\theta h^1_{T-1}(\delta r_{T-2}) dQ_{T-1}(z_{T-1}) \\
&+ \int_{\delta r_{T-2}}^{r^*_T/\delta} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1}] dQ_{T-1}(z_{T-1}) \\
&+ \int_{\delta r_{T-2}}^{r^*_T/\delta} \beta\theta h^1_{T-1}(z_{T-1}) dQ_{T-1}(z_{T-1}) \\
&+ \int_{r^*_T/\delta}^{+\infty} [z_{T-1} - c_{T-1} + \beta\theta h^0_{T-1} + \beta\theta h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1})
\end{aligned}
$$

$$\begin{aligned}
E_{T-2}V(T-1, r_{T-1}) &= h^0_{T-2} + h^1_{T-2}(r_{T-2}) + \int_{-\gamma\sigma_{T-1}}^{r^*_T/\delta} \beta\theta h^1_{T-1}(\delta r_{T-2}) dQ_{T-1}(z_{T-1}) \\
&+ \int_{r^*_T/\delta}^{\delta r_{T-2}} \beta\theta h^1_{T-1}(\delta r_{T-2}) dQ_{T-1}(z_{T-1}) \\
&+ \int_{\delta r_{T-2}}^{r^*_T/\delta} \beta\theta h^1_{T-1}(z_{T-1}) dQ_{T-1}(z_{T-1}) \\
\\
&= h^0_{T-2} + h^1_{T-2}(r_{T-2}) + \beta\theta h^1_{T-1}(\delta r_{T-2}) Q_{T-1}(r^*_T/\delta) \\
&+ \beta\theta \int_{r^*_T/\delta}^{\delta r_{T-2}} [h^1_{T-1}(\delta r_{T-2}) - h^1_{T-1}(z_{T-1})] dQ_{T-1}(z_{T-1}) \\
\\
&= h^0_{T-2} + h^1_{T-2}(r_{T-2}) + h^2_{T-2}(r_{T-2})
\end{aligned}$$

Here $h^1_{T-2}(r_{T-2})$ and $h^2_{T-2}(r_{T-2})$ are positive, so the minimum return threshold r^*_{T-2} such as the patent holder decide to renew his patent in $T-2$ satisfies the condition:

$$r^*_{T-2} + \beta\theta h^0_{T-2} - c_{T-2} = 0 \iff r^*_{T-2} = c_{T-2} - \beta\theta h^0_{T-2}$$

In the general case, h^0_t is solved recursively with $t = 1, \ldots, T-1$. Note that $h^0_T = 0$.

$$\boxed{h^0_t = \int_{r^*_{t+1}}^{+\infty} (z_{t+1} - c_{t+1}) dQ_{t+1}(z_{t+1}) + \beta\theta \sum_{v=0}^{T-(t+1)} \int_{r^*_{t+1+v}/\delta^v}^{+\infty} h^v_{t+1}(z_{t+1}) dQ_{t+1}(z_{t+1})}$$

For $v = 1$:

$$\boxed{h^1_t(r_t) = \left[Q_{t+1}(r^*_{t+1})\right] \left[\delta r_t - c_{t+1} + \beta\theta h^0_{t+1}\right] + \beta\theta \int_{r^*_{t+1}}^{\delta r_t} (\delta r_t - z_{t+1}) dQ_{t+1}(z_{t+1})}$$

For $1 < v < 20 - t$:

$$\boxed{h^v_t(r_t) = \beta\theta h^{v-1}_{t+1}(\delta r_t) Q_{t+1}(r^*_{t+v}/\delta^{v-1}) + \beta\theta \int_{r^*_{t+v}/\delta^{v-1}}^{\delta r_t} \left[h^{v-1}_{t+1}(\delta r_t) - h^{v-1}_{t+1}(z_{t+1})\right] dQ_{t+1}(z_{t+1})}$$

The minimum return threshold for renewal is then: $\boxed{r^*_t = c_t - \beta\theta h^0_t}$

References

Baudry, Marc, and Beatrice Dumont. 2006. "Patent renewals as options: Improving the mechanism for weeding out lousy patents." *Review of Industrial Organization*, 28(1): 41–62.

Bessen, James. 2008. "The value of US patents by owner and patent characteristics." *Research Policy*, 37(5): 932–945.

Cameron, A Colin, and Pravin K Trivedi. 2005. *Microeconometrics: Methods and applications.* Cambridge university press.

Deng, Yi. 2011. "A dynamic stochastic analysis of international patent application and renewal processes." *International Journal of Industrial Organization*, 29(6): 766–777.

Efron, Bradley, and Robert J Tibshirani. 1994. *An introduction to the bootstrap.* CRC press.

Giuri, Paola, Myriam Mariani, Stefano Brusoni, Gustavo Crespi, Dominique Francoz, Alfonso Gambardella, Walter Garcia-Fontes, Aldo Geuna, Raul Gonzales, and Dietmar Harhoff. 2007. "Inventors and invention processes in Europe: Results from the PatVal-EU survey." *Research Policy*, 36(8): 1107–1127.

Grönqvist, Charlotta. 2009. "Empirical studies on the private value of Finnish patents." *Hanken School of Economics, PhD thesis.*

Hall, Bronwyn H, Adam Jaffe, and Manuel Trajtenberg. 2005. "Market value and patent citations." *The RAND Journal of Economics*, 16–38.

Higham, Kyle, Gaétan De Rassenfosse, and Adam B Jaffe. 2021. "Patent quality: Towards a systematic framework for analysis and measurement." *Research Policy*, 50(4): 104215.

Kogan, Leonid, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman. 2017. "Technological innovation, resource allocation, and growth." *The Quarterly Journal of Economics*, 132(2): 665–712.

Lanjouw, Jean O, and Mark Schankerman. 2004. "Patent quality and research productivity: Measuring innovation with multiple indicators." *The Economic Journal*, 114(495): 441–465.

Lanjouw, Jean Olson. 1998. "Patent protection in the shadow of infringement: Simulation estimations of patent value." *The Review of Economic Studies*, 65(4): 671–710.

McFadden, Daniel. 1989. "A method of simulated moments for estimation of discrete response models without numerical integration." *Econometrica: Journal of the Econometric Society*, 995–1026.

Murphy, William J, John L Orcutt, and Paul C Remus. 2012. *Patent valuation: Improving decision making through analysis.* Vol. 571, John Wiley & Sons.

OECD. 2017. "OECD Reviews of Innovation Policy: Finland 2017."

Pakes, Ariel. 1986. "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks." *Econometrica*, 54(4): 755–784.

Pakes, Ariel, and Mark Schankerman. 1979. "The rate of obsolescence of knowledge, research gestation lags, and the private rate of return to research resources." National Bureau of Economic Research.

Pakes, Ariel, and Mark Schankerman. 1984. "The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources." In *R&D, patents, and productivity.* 73–88. University of Chicago Press.

Putnam, Jonathan. 1996. "The value of international patent protection." *Unpublished Ph. D. Dissertation, Yale University.*

Salminen, Vesa, Kimmo Halme, Juha Kettinen, Valtteri Härmälä, Anne-Mari Järvelin, Arho Suominen, Matthias Deschryvere, Henna Sundqvist-Andberg, Ilkka Vuorenmaa, Anniina Harju, et al. 2021. *Aineettomien oikeuksien tilanne Suomessa 2020: IPR-strategian taustoitus.* valtioneuvoston kanslia.

Schankerman, Mark. 1998. "How valuable is patent protection? Estimates by technology field." *the RAND Journal of Economics*, 77–107.

Schankerman, Mark, and Ariel Pakes. 1985. "Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period."

Schmoch, Ulrich. 2008. "Concept of a technology classification for country comparisons." *Final report to the World Intellectual Property Organisation, WIPO.*

Serrano, Carlos J. 2010. "The dynamics of the transfer and renewal of patents." *The RAND Journal of Economics*, 41(4): 686–708.

Serrano, Carlos J. 2018. "Estimating the gains from trade in the market for patent rights." *International Economic Review*, 59(4): 1877–1904.

Sullivan, Richard J. 1994. “Estimates of the value of patent rights in Great Britain and Ireland, 1852-1876.” *Economica*, 37–58.

Takalo, Tuomas, and Otto Toivanen. 2018. “Economics of Finnish Innovation Policy.” Mimeo.

Takalo, Tuomas, Ari Hyytinen, Alexis Stevenson, et al. 2021. “Patenttien yksityinen arvo: Kirjallisuuskatsaus ja uusia tuloksia Suomesta.” *Kansantaloudellinen Aikakauskirja.*

Wang, Changtao. 2012. “Estimating the value of patent rights in Australia.” *School of Economics, UNSW, SyAustralia.*

ESSAY 2: HOW MUCH ARE PATENT CITATIONS WORTH?

How much are patent citations worth? A simulation estimation based on patent renewal decisions [*]

Alexis Stevenson
Hanken School of Economics, Helsinki GSE and KU Leuven

Abstract

This essay presents and estimates a dynamic model of patent renewal decisions using data on patent applications in Germany between 1995 and 2000 in the semiconductor industry. It departs from the seminal work of Lanjouw (1998, *The Review of Economic Studies*, **65(4)**, 671-710) and the subsequent literature by introducing patent-level heterogeneity in both learning and grant probability: The arrival of patent citations are a signal of greater or lower valuation. In addition, patent holders form a grant prediction based on the content of the patent application that can affect pre-grant renewal decisions. This theoretical framework allows me to investigate the dynamic link between forward patent citations and private value of patents. The mean value of a patent in the semiconductor industry in Germany is €54,696. Moreover, an additional citation in the first year of a patent life increases the value of a patent by an average of 17.8% which is €9,759 in monetary terms.

---

[*] Financial support from Hanken School of Economics, the IPR University Center, Yrjö Janhsson Foundation and OP Group Research Foundation is gratefully acknowledged. I would like to thank Ari Hyytinen, Mattia Nardotto, Tuomas Takalo, Otto Toivanen and participants at the KU Leuven IO seminars and Helsinki GSE IO seminars for comments.

1 Introduction

Forward patent citations have been widely used in economic research as a measure of scientific and economic value for patents (see Jaffe and De Rassenfosse (2019) for a recent overview). Forward citations are the citations received by a patent from subsequent patent filings. Although the count of forward patent citations is commonly used to proxy for patent value, little is known about the dynamic relationship between additional citations and the private value of patents. In this essay, I estimate a renewal decision model for patents applied for in Germany between 1995 and 2000 in the semiconductor industry. The model includes the possibility for patent holders to learn about the value of their inventions with citations that the patent receives. In a counterfactual analysis, I simulate the effect of an additional citation in the first year on the private value of patents. Results suggest that an incremental citation in the first year is associated with an average increase in value of 17.8% which is €9,759 in monetary terms. The mean value of a patent in the semiconductor industry in Germany is €54,696.

The early literature looking at patent citations finds a positive correlation between the number of forward citations that the patent receives and some measures of private value (Carpenter, Narin and Woolf, 1981) and social value of inventions (Trajtenberg, 1990). The positive association has been confirmed by many empirical studies using different approaches. Harhoff et al. (1999) and Harhoff, Scherer and Vopel (2003) find a positive correlation between the level of citations and values reported in surveys for US and German patents. The most highly cited patents are very valuable and a single citation implies an average value of about $1 million. Hall, Jaffe and Trajtenberg (2000, 2005) find that patents held by companies with relatively high stock market values are more frequently cited, all other things being equal. Lanjouw and Schankerman (2004) construct a composite indicator of patent quality and find that forward citations are a good predictor for renewal decisions and litigation. More recent studies have highlighted this positive association (Kogan et al., 2017; Moser, Ohmstedt and Rhode, 2018). Although patent citations are widely used in the economics of innovation as a proxy for patent value, it is commonly acknowledged that the relationship is noisy and might even be ambiguous. Bessen (2008) finds that patent citations explain little variance in patent values; his results suggest limitations in the use of this metric. Recent studies have started to question the interpretation of patent citations. Kuhn, Younge and Marco (2020) underline the possibility of biased results of citations-based measures. They document a change in the data generating process of patent citations in the US with a strong increase in the number of citations across years. It is mainly due to a small proportion of patents with an overwhelming number of references. Abrams, Akcigit and Grennan (2013) find that the relation between private values based on licensing fees and patent citations is non-monotonic with an inverse-U relationship. The positive correlation between citations and patent values holds only for low-value inventions. On the other hand, the high-value inventions are protected through aggressive strategies that reduce follow-on innovation and explain a negative relationship between citations and patent values above a certain threshold.

This essay contributes to the literature on the link between patent value and citations by quantifying the change in patent value associated with an additional citation. Few papers estimate the value of an additional citation. Bessen (2008) develops a deterministic model of patent renewal and finds that at the sample median of citations, an additional patent citation increases the private value of a US patent by about 1 to 7% depending on the specification (three to five thousands dollars). Using another approach, Hall, Jaffe and Trajtenberg (2005) find that an additional citation for a single patent increases the market value of the firm owning the patent by 3% which corresponds to $327,000 dollars on average. This essay contributes to this literature by estimating a renewal decision model taking into account that citations can influence the distribution of learning shocks and then the private value of patents. This work is also related to a number of research articles looking at patenting behavior in the semiconductor industry (e.g., Hall and Ziedonis, 2001; Reitzig, 2003; Cheng et al., 2010). It is an important sector in the economy as semiconductors are key components for electronic devices. This sector is characterised by a large volume of patents and has attracted attention in the industrial organization and economics of innovation literature; however, patent renewal models have not been applied specifically to this technology before.

I develop a dynamic stochastic model of patent renewal decisions. The sample is all the patents applied for in Germany between 1995 and 2000 in the technology area of semiconductor. Every period, a patent holder has to decide whether to pay a renewal fee to extend the life of the patent. The maximum legal length is 20 years from the filing date. The stochastic renewal model used in this essay is based on the idea that it is costly for a patent owner to renew the patent protection. Therefore, the owner decides optimally to renew the patent as long as the expected returns from the patent exceed the renewal costs. The owner of the patent expects that the stream of returns will cover the maintenance fees through the use of technology, licensing or commercialization. The optimal solution for the patent holder has the form of a stopping rule which indicates whether to pay the renewal fee in each period. Pakes and Schankerman (1984) and

Schankerman and Pakes (1986) assume that the patent returns decay deterministically over time. Pakes (1986) extends the model to include learning shocks; this is the so-called stochastic renewal model. In other words, the patent owner is uncertain about the sequence of returns if the patent is kept in force. Pakes's results show that most of the uncertainty related to the returns to patent protection occurs before the fifth year of the patent's life. Lanjouw (1998) refines the model to include the costs of litigation and the possibility of infringement. She also introduces a more flexible model of returns taking into account obsolescence, which happens when an invention becomes worthless. She estimates the distribution of the private value of patents for different technologies in West Germany. Other researchers found differences in private values by owners and patent characteristics in Europe (Schankerman, 1998) and the US (Bessen, 2008). Putnam (1996) and Deng (2011) look at the patenting decisions in the international context, respectively PCT patents and EPO patents. They also examine the joint decision of application and renewal. Serrano (2018) allows for the possibility of trading patents, measured by the re-assignment of patents. Renewal decision models have been applied in different countries and contexts including patents granted in France using a binomial tree approach (Baudry and Dumont, 2006), in Australia (Wang, 2012) and in Great Britain and Ireland between 1852 and 1876 (Sullivan, 1994).

This essay extends the literature in a number of directions. First, it includes the possibility that citations affect the learning shocks. In other words, a patent holder could decide to renew a worthless patent in a given year because the citations that the patent receives today inform her of possible commercial opportunities in the future. Conversely, a patent holder could decide not to renew a patent because the citations received informed her of potential competitors. The direction and magnitude of the effect of citations on private value is then uncertain and will be estimated in the structural model. Notice that the patent owner is myopic regarding the citations and do not form expectations on the number of citations in the future[1]. Second, I estimate the model at the patent-level and not at the aggregate level, which is the standard approach in this literature. Third, I include a patent-level predicted grant probability in the dynamic model. These predicted probabilities are computed off-line applying machine learning algorithms on patent text and other patent characteristics. They are used to model pre-grant renewal decisions.

Section 2 introduces the data and presents some descriptive evidence of a positive association between the number of citations that the patent receives and the renewal probabilities. Section 3 describes the model. Section 4 explains the estimation proce-

---

[1] A future work could relax this assumption.

dure. Results are presented in section 5 and section 6 concludes.

2 Data

2.1 Data description

Patent data. Data come from the European Patent Office database: PATSTAT. The analysis focuses on a highly innovative technology, semiconductors. Patents in semiconductors are isolated based on the correspondence of IPC classes and technology classification of ISI-OST-INPI developed by Schmoch (2008). The sample is all patents in the technology class semi-conductors, granted in Germany for which the application date is between 1995 and 2000. Moreover, the sample includes only patents written in English: these constitute 87.1% of the patent applications in this technology field. Patent applications written in German are excluded to ensure a homogenous corpus when predicting grant probability using text in patent abstracts. The variable *renewal* is constructed using the complete history of events for the patents. More precisely, lapsing information are derived from the following legal events: “application deemed withdrawn due to non-payment of renewal fee” (code R119 in PATSTAT), “ceased/non-payment of the annual fee” (code DE 8339), “expiry of right” (DE R071) and “complete revocation” (DE 8331).

The variable for forward citations at the patent-level is constructed by counting the number of patents citing a patent application or a patent granted document at different time window from the filing date. On average, patents in the sample receive 5.06 citations in the time window of 20 years after the filing date (see Table 1).

Renewal fee data. Renewal fee data are collected from the German Patent and Trademark Office. I use the Harmonised Index of Consumer Prices (HICP) developed by Eurostat to express renewal fees in year 2010[2]. Note that the first renewal decision starts three years after the filing of the application: this is the first period of the model. The cost to renew a patent in the first year is €62 (see Figure 1) and it increases up to €2,034 for period 17 (which is 20 years from filing date).

---

[2] https://ec.europa.eu/eurostat/web/hicp/data/database

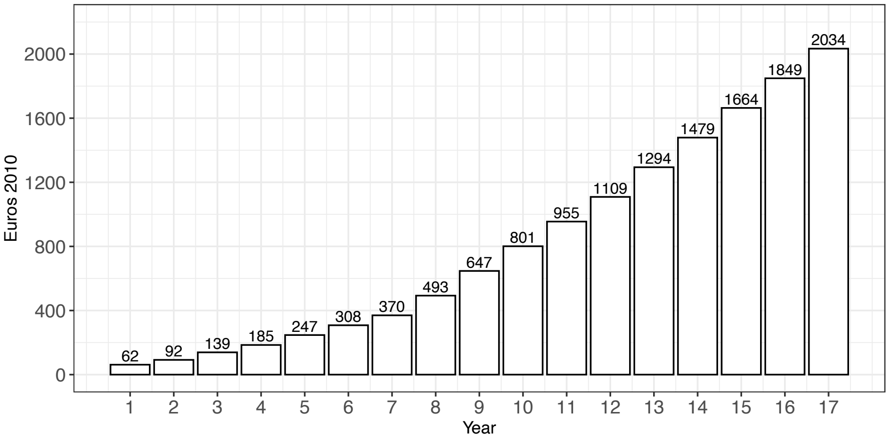


Figure 1: Renewal fees for patents in Germany applied for between 1995 and 2000, in Euros 2010

Descriptive statistics. The panel includes 3,380 German semiconductor patents. Table 1 shows some descriptive statistics for forward citations with different time windows from the application date, the number of applicants/inventors, the examination period, the number of IPC classes and the number of renewal years. The examination period, called also grant duration, is constructed as the difference between the grant date and the date of filing the patent application. The examination period is on average 1,987 days, i.e., 5.44 years. Importantly, on average two renewal decisions are taken before the grant decision of the patent office. These two pre-grant renewal decisions depend on the predicted grant probability of the patent. In the model, I capture this dimension by including a predicted probability that the patent will be granted for the two pre-grant renewal decisions. To accommodate the pre-grant renewal decisions, Deng (2011) uses the proportion of patents granted as an estimate of the probability of a patent being granted. I extend the approach to include patent-level predicted probabilities computed using machine learning algorithms on a standard binary classification problem (granted/not granted).

On average a patent in the sample is renewed for 11.38 years. As shown in Figure 2, 832 patents in the sample are renewed the full term or 17 renewal years (or 20 years from the filing date). Therefore the survival rate for the maximum length is 25% (see Figure 3).

Table 1: Descriptive Statistics for patents granted in Germany between 1995 and 2000 - semiconductor

Variables	**Mean**	**St.Dev**	**Median**	**Min**	**Max**	**N**
Forward citations (3 years)	0.334	0.97	0	0	17	3,380
Forward citations (5 years)	1.146	2.39	0	0	36	3,380
Forward citations (10 years)	2.98	5.49	1	0	64	3,380
Forward citations (15 years)	4.28	7.80	2	0	134	3,380
Forward citations (20 years)	5.06	10.46	2	0	335	3,380
Number of applicants	1.074	0.37	1	1	10	3,380
Number of inventors	2.43	1.63	2	0	14	3,380
Examination period (in days)	1,987	1,819	1,317	259	7,891	3,380
Number of IPC classes	2.07	1.22	2	1	10	3,380
Number of renewal years	11.38	4.99	12	0	17	3,380

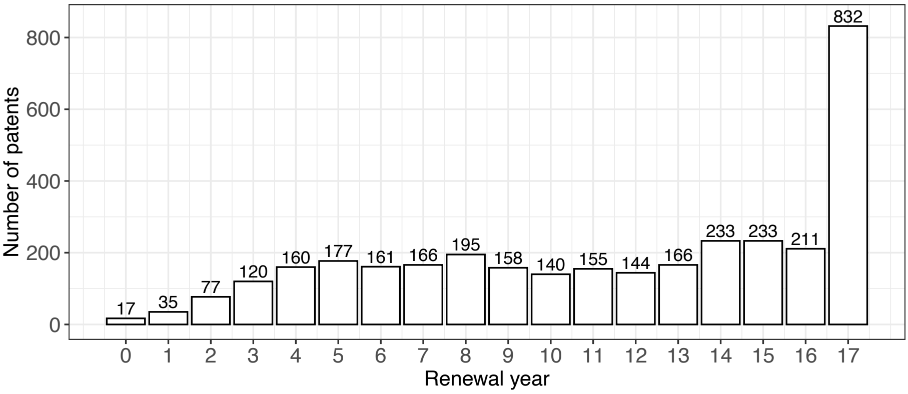


Figure 2: Number of patents by renewal years

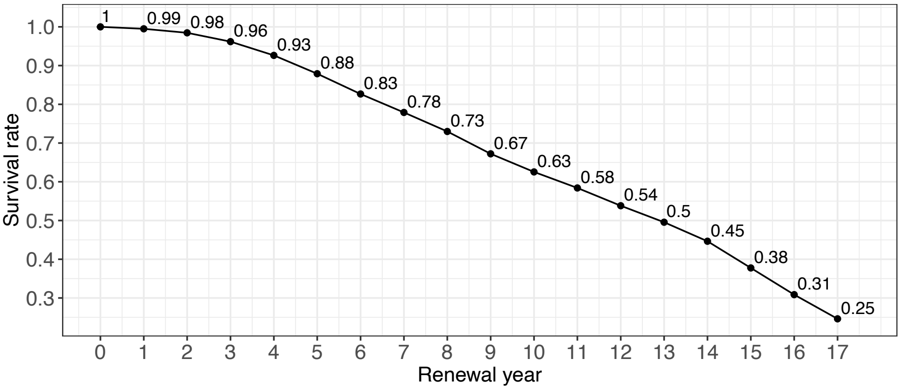


Figure 3: Survival rate of patents

2.2 Descriptive evidence

It is not clear how citations are associated with renewal decisions. As noted by Maurseth (2005), on the one hand patent citations can suggest a high scientific value and then be associated with a higher survival rate of a patent. As an example, citations can provide information on the development of the innovation, possible new applications in other areas or suggest ideas to improve an innovation. In that case, citations are seen as knowledge flows or spillovers. On the other hand, a high number of citations and thereby citing patents may indicate strong competing innovations which might lead to faster obsolescence and a shorter patent life. It is thus not fully obvious how citations affect renewal decisions. I provide empirical evidence of the dynamic relationship between citations and renewal decisions.

Table 2 reports the number of citations at 5, 10, 15 and 20 years from the filing date for three groups: "all patents", "patents expired before" a given age (5, 10, 15 and 20) and "patents renewed more or equal to" (5, 10, 15, 20). The group "all patents" consists of the full sample of 3,380 semiconductor patents with a filing date between 1995 and 2000. Note that for age 20, the group "renewed more or equal to" consists only of patents renewed 20 years as it is the maximum term. The table indicates that the mean level of citations received up to years 5, 10, 15 and 20 are always higher for patents renewed longer ("renewed more or equal to") then for shorter patents ("expired before"). Looking at the p-values for t-test of equality of means between "expired before" and "renewed more or equal to", we see a statistically significant difference in the mean level of citations at 10% level for age 10 and 1% level for age 15 and 20. Table 2 suggests that there is a positive and significant association between number of citations received and patent length for age 10, 15 and 20.

Table 2: Mean number of patent citations received by renewal decisions

Age	**All patents**	**Expired before**	**Renewed more or equal to**	**p-value, equality of means**
5	1.146	1.116	1.148	0.879
10	2.984	2.537	3.150	0.059
15	4.283	3.650	4.928	0.0049
20	5.059	4.235	6.209	0.0002

Following the approach of Serrano (2010) on US patents, I regress the binary renewal decision in years 10, 15 and 20 from the filing date on the total number of patent citations received at different time windows: 0-10, 10-15, 15-20. I include in the regression dummies for the grant year to control for the increasing trend in the number of patent citations notably due to the development of computerised search for patents and to take into account differences in the length of the time window during which citing inventions could have taken place. The results of the logistic regression with the binary decision renew/not renew and the independent variables of number of citations are displayed in Table 3. The results suggest that there is a significant positive association between number of citations and renewal decisions. To express it in other terms, at the sample mean of citations (2.98 for year 10, 4.28 for year 15 and 5.06 for year 20), one additional citation in a given time window (less than 10, 10-15 15-20) increases the probability of being renewed up to years 10, 15, 20 by 1 to 2 percentage point. It suggests a positive relationship between patent citations received and patent value.

To conclude, this analysis suggests that frequently cited patents tend to be renewed longer. Nevertheless, nothing can be said about the direction of the relationship: The number of citation received can affect the renewal decisions but the renewal decisions (lapsing) can affect the subsequent citations received. The next section presents a structural model to capture the dynamic mechanism behind this relationship.

Table 3: Logistic regressions

	Dependent variables:		
	Renewal 10y	Renewal 15y	Renewal 20y
All Citations up to 10 years	0.036^{***}		
	(0.010)		
Citations between 10-15		0.049^{***}	
		(0.014)	
Citations between 15-20			0.116^{***}
			(0.022)
Constant	-0.456^{*}	-0.844^{***}	-1.836^{***}
	(0.265)	(0.279)	(0.363)
Grant year dummies?	Yes	Yes	Yes
Observations	3,380	3,380	3,380
Note:			*p<0.1; **p<0.05; ***p<0.01

3 A model of renewal decisions with dynamic citations

The starting point of the model is Lanjouw (1998). She considers the problem of a patent owner who has to decide every period t whether to pay a renewal fee c_t to extend the protection of a patent indexed by i. I extend the model in a number of directions. First, following the approach of Deng (2011), I include patent grant predictions to model pre-grant renewal decisions. Second, I depart from the literature by adding the possibility for forward citations to affect the valuation of patent rights. More precisely, in a counterfactual simulation, I quantify the effect of an additional citation in the first year on the private value of a patent protection. Third, I use a simulated maximum likelihood estimator at the patent-level instead of the aggregate level which is the standard approach for dynamic stochastic models in this literature.

3.1 Renewal decisions

In this single agent dynamic model with finite horizon, patent owners decide to renew their patent i in period $t = 1, \ldots, T$ in order to maximize the expected discounted sum of patent returns. The first period of the model consists of the year when the first renewal decision is taken, which is three years from the application date. As shown in the descriptive analysis, the grant decision takes place usually five years after the application date which corresponds to the second period in the model. Therefore, most of the time, renewal decisions start even before a patent is granted and it is still at the stage of an application. T is the statutory limit for the protection. Renewal fees are defined as a sequence $\{c_t : t = 1, \ldots, T\}$ which are known to the patent-holder and are increasing in time. A patent i generates a sequence of returns: $\{r_{it} : t = 1, \ldots, T\}$. At the time of the renewal decision for the period t, current returns r_{it} are known by the firm and are unobserved by the econometrician. Returns are the state variables in this dynamic optimization problem. Each patent is associated to a vector of forward citations $x^i = \{x_{i1}, \ldots, x_{iT}\}$ where x_{ik} is the stock of citations received up to the period k by a patent i. When patent holders decide on renewal decisions in period t, they only observe the stock of citations in that period and are uncertain about the arrival of future citations. More formally, the problem of the firm is an optimal stopping problem where it decides - knowing the per-period return r_{it} and the stock of citations x_{it} - whether it renews the patent ($d_{it} = 1$) or let it lapse ($d_{it} = 0$) in period t. d_{it} is then the decision variable.

3.2 Patent returns

Following Lanjouw (1998), the sequence of returns $r_{i1}, \ldots, r_{iT}$ is defined as a stochastic Markov process that allows for: depreciation of the patent returns across time, obsolescence if a major technological discovery happens in the same area which makes the patented invention worthless, learning effects that can increase the value of the patent. I depart from the literature by introducing observable heterogeneity into the learning shocks. The stock of citations is used as a proxy for the information on potential quality of the patent.

Growth of returns. Patent returns evolve by depreciation over time, technological obsolescence and learning. Patent returns in $t+1$ are determined according to:

$$r_{i,t+1} = \begin{cases} \max\{\delta r_{i,t}, z_{i,t}\} & \text{with probability} \quad \theta \\ 0 & \text{with probability} \quad 1-\theta \end{cases}$$

$1-\delta \in (0,1)$ measures the patent return depreciation and $1-\theta \in (0,1)$ is the probability for the patent to become obsolete ($r_{i,t} = 0$). Obsolescence is radical in the sense that the returns are zero for the whole patent lifetime. $z_{i,t}$ is a learning shock drawn from an exponential distribution. It represents possible complementary innovations that increase the returns to the patent. If the owner of the patent is not able to learn about new opportunities for the invention in period t and in the absence of obsolescence, the return in period t is simply the return in the previous period depreciated by a factor $\delta \in (0,1)$. Following Lanjouw (1998), the first return $r_{i,1}$ is equal to $z_{i,1}$ so $r_{i,0} = 0$.

Learning effect and citations. $z_{i,t}$ is a random variable that captures innovations to the use of the patent. This innovation shock, drawn in each period, captures new commercial opportunities or learning effects that lead to an increase in the value of the patent. It is called a learning effect because the patent holder collects new information on the market and can discover new ways of using the invention that might be successful. $z_{i,t}$ is drawn from a two-parameter exponential distribution. Following the literature, the probability density function of the stochastic learning process $z_{i,t}$ is then:

$$q_t(z_{i,t}) = \frac{1}{\sigma_{it}} \exp\left(-(\frac{z_{i,t}}{\sigma_{it}} + \gamma)\right) \ , \ z_{i,t} \geq -\gamma\sigma_{it}$$

Note that the cumulative distribution function is then:

$$F_t(z_{i,t}) = 1 - \exp\left(-\frac{1}{\sigma_{it}}(z_{i,t} + \gamma\sigma_{it})\right)$$

The mean is $\sigma_{it}(1-\gamma)$ and the standard deviation is σ_{it}.

The assumption of a two-parameter exponential distribution is standard in the literature. The model departs from the literature by assuming that the stock of forward citations x_{it} in period t provides information on the potential quality of the invention to the inventor. The distribution of the learning effect depends then on the stock of citations which is the novelty of this model. More precisely, let's define:

$$\sigma_{it} = \phi^{t-1}\,\overline{\sigma_{it}} \quad \text{where} \quad \overline{\sigma_{it}} = \sigma_0 + \sigma_1 x_{it}$$

$0 < \phi \leq 1$ captures the fact that the learning effects are higher in the first years of the patent life and major complementary innovation declines over time. The lower is ϕ, the faster is the decrease in opportunities. The stock of citations x_{it} is defined as the number of citations received by a patent or a patent application from the application filing year to the end of the period t. The model is myopic for citations in the sense that patent holders do not form any expectations on the number of citations received. This assumption could be relaxed in future works. σ_0 can then be interpreted as a measure of the potential quality of innovation which is common to all patents. γ captures the fact that learning can take place after the patent grant. If γ is high, there is a delay before the owner of the patent is able to internalize the flow of returns from the patent. In a sense γ is a measure of time to accumulate knowledge in order to fully internalize the returns from the patent. A high γ implies a higher probability of returns being zero for some time.

By introducing individual heterogeneity in σ_{it}, I allow a patent with a very low return but a relatively high number of citations to be renewed. If σ_1 is positive, a rise in the stock of forward citations shifts the mean and standard deviation of learning and it implies a higher probability to learn a higher value.

Figure 4 shows an example of how a change in the level of citations (here in the first year) can affect the distribution of learning. In this example I assume $\sigma_1 \geq 0$ which means that an additional citation will increase the value of the learning shock drawn.

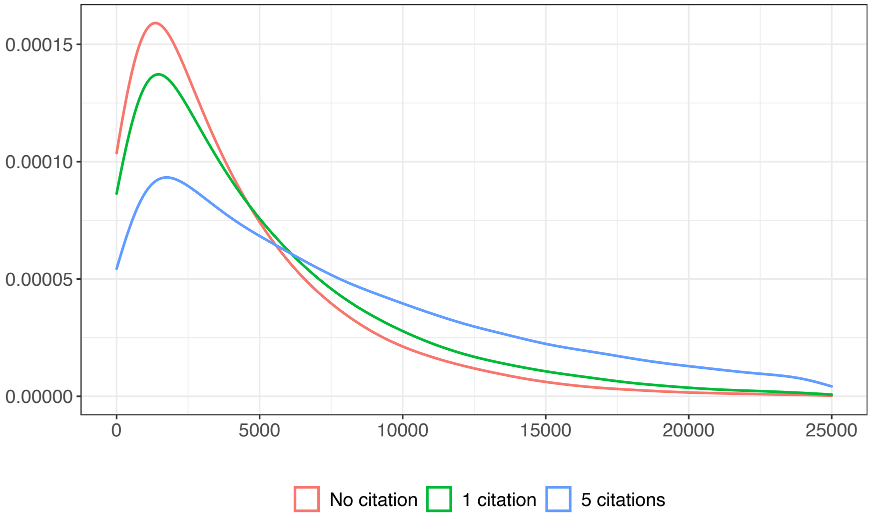


Figure 4: Example of citations affecting learnings. Exponential distribution with parameters $\phi = 0.5, \sigma_0 = 4000, \sigma_1 = 1000$. First year.

By introducing functional form assumptions and dynamic citations in the model, I am able to separately identify parameters capturing a common effect of learning (σ_0) from the effect of citations (σ_1).

Under this specification, the transition density function for returns is defined by:

$$g(r_{i,t+1}|r_{it}) = \begin{cases} \theta & \text{if} \quad r_{i,t+1} = 0 \\ (1-\theta)F_t(\delta r_{it}|r_{it}, x_{it}) & \text{if} \quad r_{i,t+1} = \delta r_{i,t} \\ (1-\theta)\,(1 - F_t(\delta r_{it}|r_{it}, x_{it})) & \text{if} \quad r^i_{i,t+1} > \delta r_{i,t} \end{cases}$$

The vector of structural parameters to estimate is then: $\omega = (\delta, \theta, \phi, \gamma, \sigma_0, \sigma_1)$

Value functions. If the patent lapses in period t ($d_{it} = 0$), the return is zero forever so the value function is zero. Zero is then an absorbing state. When the patent is renewed ($d_{it} = 1$), the value consists of two parts: the net return of the period $r_{it} - c_t$ and the value of an option to renew the patent in the future $EV_t(r_{i,t+1}; \omega)$. The value functions $\{V_1(.), \ldots, V_T\}$ are recursively related via the following Bellman equations:

$$V_t(r_{it};\omega) = \begin{cases} \max\{0, r_{it} - c_t + \beta E_t[V_{t+1}(r_{i,t+1};\omega)|r_{it}, d_{it}, x_{it}]\} & \text{for } t \neq 2 \\ \max\{0, r_{it} - c_t + \pi_i \beta E_t[V_{t+1}(r_{i,t+1};\omega)|r_{it}, d_{it}, x_{it}]\} & \text{for } t = 2 \end{cases}$$

where $\beta \in (0,1)$ is the real discount factor, not estimated in the model and fixed to 0.95, π_i is a patent-level grant prediction, and $E[.|.]$ is the expectation operator over the sequence of patent returns conditional on current patent return and current stock of citations. More precisely, the option value of a patent is then defined as:

$$E_t[V_{t+1}(r_{i,t+1};\omega)|r_{it}, d_{it}, x_{it}] = \int V_{t+1}(r_{i,t+1};\omega) g(r_{i,t+1}|r_{it}, d_{it}, x_{it}) dr_{i,t+1}$$

with $E_T[V_{T+1}(r_{T+1};\omega)|r_t, d_t, x_t] = 0$

3.3 Patent-level grant prediction

The predicted grant probability π_i for patent application i is computed using a number of machine learning algorithms: Random Forest, XGBoost, Support-vector machine (SVM), Naive-Bayes, Logistic regression, Neural networks and LogitBoost. It is a standard problem of binary classification where the two classes are “Granted” and “Not Granted”. The two classes are fairly balanced: 51.75% of the patent applications filed between 1995 and 2000 in the semiconductor field are granted which corresponds to the 3,380 patent granted in the sample.

The procedure to compute patent-level grant prediction is the following. First, I convert each patent abstract into a bag-of-words representation which is a count of word in the patent abstract. I follow the standard steps of cleaning and pre-processing: making all characters to lower case, removing punctuation and numbers, removing stopwords that are frequent but provide little information, word stemming to get word’s root, removing sparse terms to drop infrequent terms. Different thresholds for sparsity are tested and I choose the one providing the best results in terms of accuracy. Text-based variables are supplemented with non-textual patent data: IPC classes at the class level (e.g A01), application year, month, week and size of the patent family. The initial dataset consists of 6,560 observations and 432 variables.

I use seven different machine learning algorithms: Random Forests (RF), XGBoost,

Support Vector Machine (SVM), Naive-Bayes, Logistic regression, Neural Network (NNET), LogitBoost (see Murphy (2012) for a complete description of the algorithms). For each learning algorithm, a range of possible values for the hyperparameters are defined and the model is built for each possible combination of the hyperparameters. The hyperparameters selected are maximizing the accuracy. The accuracy of the different models is displayed in Figure 5. It is defined as the proportion of patents for which the prediction is correct. To avoid the problem of overfitting, I randomly split the dataset into a training (80% of the observations) and testing (remaining 20% the observations) subsets. I run each model on the training set with a $K = 10$-fold cross validation, repeated 3 times. All learning algorithms were implemented using the R-package *caret* for machine learning. Accuracy displayed in Figure 5 are computed on the testing subset. The highest accuracy is obtained with Random Forest (60.59% of accuracy). It is significantly better than the accuracy in the baseline model (51.75%) which corresponds to a situation with only information on the proportion of patents granted in the training subset.
Table 4 shows the distributions of predicted probabilities for patent applications eventually granted and not granted. For the patent applications that are eventually not granted, the predicted probability of being granted is 24% whereas for patents that are ultimately granted, the average predicted probability of being granted in 77%. The table suggests that only a few patents that were eventually granted received a low predicted grant probability. Similarly, only few patents that were not granted received a high predicted grant probability.

This approach is a simple way to compute predicted probabilities that the patent will be granted based only on a small set of information available at the time of the patent application. It has some obvious limitations and actually unusual words that are not kept in the dataset may be very important to predict a grant probability. Empirical research based on patent text analysis show that the first occurence of a new word or word combination in patents can be a good indicator of novelty (Arts, Hou and Gomez, 2021) which is an important feature to grant a patent. The use of machine learning and more specifically natural language processing on the patent corpus is increasingly popular for predictive analytics (e.g Dutt and Krishna (2019) who forecast the grant duration of patents, Liu et al. (2017) who forecast patent citations and their types, Wongchaisuwat, Klabjan and McGinnis (2017) for predicting litigation likelihood and time for litigation).

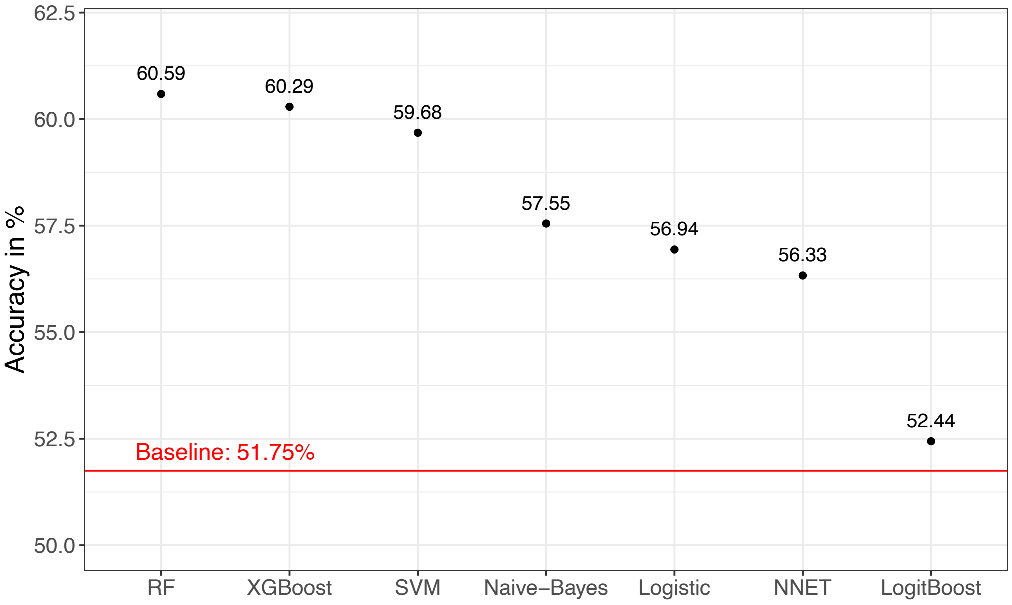


Figure 5: Accuracy on testing set. 10-fold CV, repeated 3 times

Table 4: Predicted grant probabilities using Random Forests on initial sample

Sample	**Min**	**25%**	**Median**	**75%**	**Max**	**Mean**	**N**
Not granted	0.002	0.16	0.19	0.25	0.90	0.24	3,180
Granted	0.11	0.77	0.82	0.86	0.97	0.77	3,380

4 Estimation

The estimation is executed at the patent level. Previous research relies on estimations using renewal proportions (Pakes, 1986) or hazard proportions (Lanjouw, 1998; Deng, 2011; Serrano, 2018).

4.1 Solution in terms of thresholds

Pakes (1986) shows that this dynamic problem can be solved backward with the computation of thresholds in each period. The thresholds $\overline{r}_{it}$ are the minimum level of return r_{it} for which it becomes worthwhile to renew the patent i in period t. The thresholds are functions of parameters ω but also of the history of forward citations $x_i = x_{i1}, \ldots, x_{iT}$. The main difference with the previous literature is that the vector of thresholds $\overline{r}$ are patent-specific and not common for all patents. The regularity conditions still apply.

In a standard model, Pakes (1986) shows that the value function $V_t(r_t; \omega)$ is continuous and weakly increasing in the current return of the patent holder r_t. The option value $EV_t(r_{t+1}|r_t, d, x_t; \omega)$ is weakly decreasing in t. Therefore for every patent i and every period t, there is a threshold $\overline{r}_{it}$ such that only the patents with per-period returns above $\overline{r}_{it}$ will be renewed. When including the citation history in the value function, it is not necessarily the case that $\overline{r}_{it}$ is non-decreasing in t. For some values of parameters and some citation history, it is possible to find $\overline{r}_{it} > \overline{r}_{i,t+1}$. As an example, it would be the case if the effect of citations on learning and the number of citations are large enough to have an option value $EV_t(r_{t+1}|r_t, d, x_t; \omega)$ increasing in t. I make sure this situation does not arise during the estimation for any of the patent to ensure consistency of the model.

Since the maximum length of the patent is finite and equal to T, this dynamic problem can be solved backwards. These thresholds are solved for each period and each forward citation history. Pakes and Pollard (1989) provide the conditions that ensure identification of this problem. The variation in the schedule of renewal fees across time together with the renewal decisions on patents are used to identify the parameters. Moreover, σ_1 is identified using variation in citation history across patents and time.
The patent holder renews the patent at time t if the return and the option value of owning the patent is higher than the renewal cost:

$$r_{it} - c_t + \beta EV_t(r_{i,t+1}|r_{it}, d_{it}, x_{it}; \omega) > 0$$

Therefore, the threshold $\overline{r}_{it}$, i.e., the minimum return r_{it} for which it is worthwhile to renew the patent is defined by:

$$\overline{r}_{it} = c_t - \beta EV_t(r_{i,t+1}|r_{it}, d_{it}, x_{it}; \omega) \tag{1}$$

4.2 Simulated maximum likelihood estimation

The parameters of the model $\omega = (\delta, \theta, \phi, \gamma, \sigma_0, \sigma_1)$ are estimated using a simulated maximum likelihood estimator.

4.2.1 Step 1: Recovering the thresholds

The first step of the estimation is to recover the patent-specific thresholds $\overline{r}_{it}$ that are functions of the vector of parameters ω and citation history x_i. I discretize the state space r_{it} and use linear interpolation as used by Keane and Wolpin (1994) in a dynamic model. The model is solved by backward induction to compute the value functions and the option values in each point on a grid of points. By linear interpolation, I calculate the thresholds $\overline{r}_{it}$ as defined in Equation (1). I choose a step size of 20 (€) between each point and do not find any gain from reducing the step size. The interpolation method gives the same thresholds as the ones computed with the approximation method in Pakes (1986) and Lanjouw (1998) and in the first essay of this dissertation.

4.2.2 Step 2: Constructing the Log Likelihood

The maximum likelihood cannot be easily solved analytically, so I construct a simulated maximum likelihood. In the data, for each patent i, we observe the renewal history y_i as well as the citation history x_i. From the model, the probability that a patent i is renewed exactly y_i years is defined as:

$$f(y_i|x_i, \omega) = Pr(r_{i,y_i+1} \leq \overline{r}_{i,y_i+1},\ r_{i,y_i} \geq \overline{r}_{y_i},\ r_{i,y_i-1} \geq \overline{r}_{i,y_i-1}, \ldots, r_{i,1} \geq \overline{r}_{i,1})$$

Computing $f(y_i|x_i, \omega)$ involves solving a multiple integral of dimension y_i. It is computationally costly to obtain exact value of these probabilities so they are simulated. More precisely, I use Monte-Carlo simulation with $s = 1, \ldots, S$ vector of draws with corresponding return histories r_i^s for each patent i observed in the data. The direct frequency simulator for $f(y_i|x_i,\omega)$ is the Monte Carlo integral estimate:

$$\hat{f}(y_i|x^i,\omega) = \frac{1}{S}\sum_{s=1}^{S} \mathbb{1}\left(\hat{y}_i^s(r_i^s, x^i, \omega) == y_i\right)$$

It is a simple accept-reject simulator. $\hat{y}_i^s(r^s, x^i, \omega)$ is the predicted number of renewal years using vector of draws to compute the returns and compare them to the thresholds obtained in step 1. $\mathbb{1}$ is the indicator function equals to 1 when the predicted number of renewal years equates the observed number of renewal years. The number of draws is $S = 1000$ for each patent. S is large enough to ensure the simulated likelihood not to be zero. The approximate choice probabilities are used in a maximum likelihood estimator to maximize the product of probabilities of the observed renewal.
I then construct the following log-likelihood:

$$\ln \mathcal{L}(\omega) = \sum_{i=1}^{I} \ln \hat{f}(y_i|x_i,\omega) \tag{2}$$

The inverse of the Log-likelihood in equation (2) is minimized using a Nelder-Mead solver to estimate $\hat{\omega}$. The starting values are chosen using a grid of points for the parameter σ_0 and σ_1 as well as results from a standard model without citations similar to the one presented in the first essay.

4.2.3 Distribution of the SML estimator

Under some regularity conditions, the estimator in equation (2) is asymptotically equivalent to the maximum likelihood estimator if $S, I \to \infty$ and $\sqrt{N}/S \to 0$ (Cameron and Trivedi, 2005). It has a limit normal distribution with the variance-covariance matrix:

$$\hat{V}(\hat{\omega})_{kl} = \left(\sum_{i=1}^{I} \frac{\partial \hat{f}_i(\hat{\omega})/\partial\omega_k}{\hat{f}_i(\omega)} \frac{\partial \hat{f}_i(\hat{\omega})/\partial\omega_l}{\hat{f}_i(\omega)}\right)^{-1} \tag{3}$$

Standard errors are computed as the squared root of the diagonal elements of the variance-covariance matrix in equation (3). The derivatives $\partial\hat{f}_i(\hat{\omega})/\partial\omega_k$ are computed as a two-sided numerical differentiation.

5 Results

5.1 Parameter estimates

Table 5 reports the parameter estimates. All the estimates are positive and statistically significant. The depreciation rate is $1 - \delta = 8\%$ which is broadly similar to estimates found in other studies. Every period, around $1 - \theta = 4\%$ of patents become worthless. The relatively low value for ϕ (0.1986) suggests that learning shocks are slowing down quickly with most of the learning arising in the first few years. γ (0.00406) is close to 0 and indicates that learning takes place without delay. In other words, inventors are able to quickly fully internalize the flow of returns from the patent. σ_0 (45,670) is relatively high compared to other studies. It indicates a higher probability of learning a higher value. Despite the high standard errors, the parameter σ_1 is statistically significant and positive. It means that an additional citation has a positive effect on learning. These results can be compared with previous works and notably Lanjouw (1998). She estimates a model for German patents with an application date in 1975. Her results are broadly in line with the estimates in Table 5. For Computers and Engines patents, she finds depreciation rates between 5 and 7% and slightly higher obsolescence rates between 7 and 12%. Specifically for Engines patents, the learning dynamic seems relatively similar to that found here, with γ close to zero and a high value for the other learning parameters, e.g. $\sigma = 9,534$. The difference in sample and model specification can naturally explain the differences in parameter estimates to Lanjouw (1998).

The fit of the model can be assessed by different measures such as the mean-squared error (MSE) of hazard rates, the mean-squared error (MSE) of survival rates and the Log-Likelihood value. MSE of hazard rates is computed as the mean squared difference between the empirical and the simulated hazard rates. The hazard rates are the proportion of patents lapsing in a given year, conditional on surviving the previous year. Hazard rates are often used as moment conditions in the estimation of this type of models. The MSE of hazard rates found (4.11×10^{-4}) is similar in magnitude to those reported in other works. As an example, Lanjouw (1998) compute a MSE for hazard rates between 7×10^{-4} and 6.4×10^{-3}, depending on the technology group. The MSE of the survival rates is the mean squared difference between the empirical and simulated survival rates. Survival rates are defined as the proportion of patents still alive in a given year. The empirical survival rates are displayed in Figure 3. To compare, Pakes (1986) finds a MSE for survival rate of 1.48×10^{-4} for patents granted in Germany.
The value for the Log-Likelihood can also be used to get an indication of the fit of the

model. Therefore, it is possible to compare the value of the Log-Likelihood with the Log-Likelihood of a "naive" model where all patents would have a constant probability to be renewed equal to the sample average: $3380 \log(1/18) = 9769.45$. In that regard, the model performs better with a lower log-likelihood (8996.02) than the "naive" model.

Table 5: Parameter estimates

Parameters	**Values**
Depreciation $\boldsymbol{\delta}$	$0.92025\ (1.53 \times 10^{-3})$
Obsolescence $\boldsymbol{\theta}$	$0.9626\ (8.54 \times 10^{-4})$
First parameter of learning $\boldsymbol{\phi}$	$0.1986\ (1.94 \times 10^{-3})$
Second parameter of learning $\boldsymbol{\gamma}$	$0.00406\ (8.51 \times 10^{-4})$
Common effect on learning $\boldsymbol{\sigma_0}$	45,670 (1025.56)
Citation effect on learning $\boldsymbol{\sigma_1}$	8,075 (937.99)
MSE hazard rates	4.11×10^{-4}
MSE survival rate	4.57×10^{-4}
Log-Likelihood	8996.02
Note:	*Standard errors into brackets*

5.2 Survival and hazard rates by citation received

The survival rates and hazard rates predicted by the model (in red) and observed (in blue) are shown in Figure 6. To assess more precisely how well the model captures the effect of citations on renewal decisions, the rates are displayed for three subsamples. The first subsample includes all the patents receiving between 0 and 5 citations in the patent's lifetime. It consists of 2,447 patents or 72.39% of the total sample. The second subsample includes all the patents receiving between 6 and 10 citations, i.e., 491 patents (14.53% of the total sample). The last subsample includes all the patents receiving between 11 and 30 citations, in other words 375 patents (11.09%). Graphically, we can see small differences in survival rates in the three subsamples. Patents receiving more citations tend to be renewed slightly longer. The model seems to fit quite well the survival rates. The differences between the three subsamples are more striking for hazard rates. Patents receiving between 0 and 5 citations tend to be dropped more quickly than patents in the other two subsamples, especially starting from year 10.

Surprisingly, a high proportion of surviving patents are dropped in the last few years before the maximum patent term. The model seems to capture relatively well the trend in the hazard rates and the differences in rates induced by new citations received.

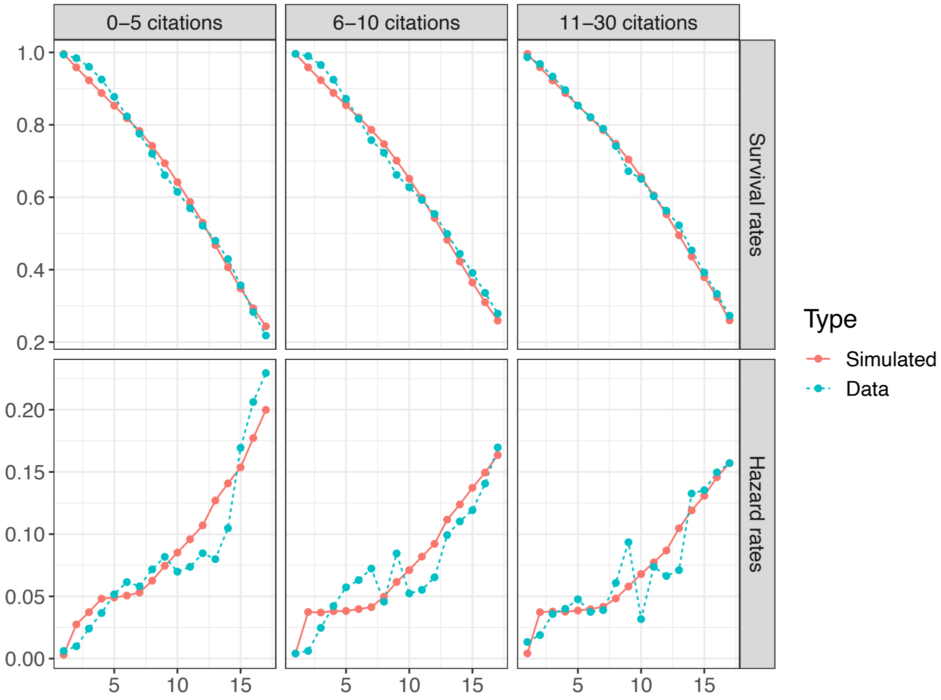


Figure 6: Hazard rates and Survival rates

5.3 Private value of patents and additional citations

Private value of patents To infer a distribution for the value of patent rights, I perform Monte-Carlo simulations for returns using the parameter estimates in Table 5. I generate $S = 1000$ histories of returns for each patent in the sample. Returns are drawn according to the distributional assumptions described previously. The optimal length T^* for each simulated patent is determined by comparing the simulated returns with the vector of thresholds $\bar{r}_i$. The net private value of a simulated patent k is then calculated as:

$$V_k = \sum_{t=1}^{T^*} \beta^{t-1}(r_{kt} - c_t) \tag{4}$$

Counterfactual. The counterfactual simulation measures the effect of an additional citation in the first year on the private value of patents. The simulation exercise described in the previous paragraph is executed with a new citation history x_i^{new} where all patents receive an additional citation in the first year: $x_i^{new} = (x_{i1} + 1, \dots, x_{iT} + 1)$. The private value is computed using equation (4). In this counterfactual, the additional citation affects the learning shocks which in turn affects the optimal number of renewal years T^*.

Table 6 shows the distribution of the private value for patents in the baseline model (real data) and in the counterfactual.

Table 6: Distribution of the private value of patent protection in euro 2010

Quantile	**Baseline**	**Additional citation First year**	**Difference**
0.25	14,094	16,888	2,794
0.50	33,698	40,087	6,389
0.75	73,013	86,236	13,223
0.90	130,798	153,639	22,841
0.95	176,712	206,997	30,285
0.99	288,600	336,026	47,426
Mean	54,696	64,455	9,759

The mean value of German patents in the semiconductor industry is €54,696 and the median value is lower at €33,698. The distribution is then right skewed which is a standard result in the literature. These results can be compared with other works. The results of the baseline model are broadly similar to the estimates of Lanjouw (1998) who finds a mean value of approximately €20,000 for German patents in the group “Textiles”, €27,000 for German patents in the group “Computers” and €58,000 for German patents in the group “Engines” (all expressed in EUR 2010). Interestingly, the distribution for the baseline model is almost identical to the distribution for German patents with an application date of 1975 in the group “Engines” (Lanjouw, 1998). Pakes (1986) estimates the private value of patents granted in Germany between 1952 and 1972. He finds a median value of €13,000 and a mean value of €34,229 (expressed in EUR 2010). The lower results can be explained by the fact that the sample is older and it also includes all patents of any technology group. The results found in this essay are around seven times higher than the mean private value computed for patents granted in Finland in the first essay. Note that the population in Germany was sixteen times the population in Finland in 2000. Using population as a measure of market size, the mean value of patent right in Finland is then higher relative to the size of the market. The estimated value is also broadly in line with the private value computed by Serrano (2018) for patents granted in the US between 1988-1997: €56,000 for untraded patents. Other works tend to find significantly higher mean private value for patents in the US and EPO patents. Bessen (2008) finds €92,000 for US patents issued in 1991, Barney (2002) finds €110,000 for US patents issued in 1986 and Deng (2011) finds €940,000 for EPO patents in Electronics between 1980 and 1985. A more comprehensive comparison of the different works can be found in the introductory chapter of this dissertation.

The results of the counterfactual shows that an additional citation is associated with an average gain of 17.8% on the private value which is €9,759 in monetary terms. This result is higher than the finding by Bessen (2008). He finds that each additional citation increases the private value by about 1 to 7% for patents in the US. (7% allowing for non-linearity in the effect of citations). In monetary terms, it corresponds to an increase in patent value between three and five thousands dollars. The difference in my results are certainly explained by the fact that in the counterfactual I only consider “strong citations” that arrived directly in the first year. Moreover, the number of citations tend to be much higher in the US than in Europe (Kuhn, Younge and Marco, 2020).

5.4 Complementarity and learning

Table 7 shows the value of learning effects z_t across years for the two scenarios. It is based on draws of 10,000 learning shocks for each patent in the sample using the estimates in Table 5. We can see that having one additional citation in year 1 increases the value of the learning shock by around €1600 in the first year and €300 in the second year. In line with the results in the literature, the learning effects tend to disappear by six to seven years.

Table 7: Average learning in monetary terms (Euro 2010)

Year	**Baseline**	**Additional citation**
1	9,565.2	11,162.1
2	2,024.8	2,342.0
3	428.4	491.4
4	90.1	102.7
5	18.8	21.3
6	3.9	4.4
7	0.8	0.9
8	0.2	0.2
9	< 0.1	< 0.1
10	< 0.1	< 0.1
11	< 0.1	< 0.1
12	< 0.1	< 0.1
13	< 0.1	< 0.1
14	< 0.1	< 0.1
15	< 0.1	< 0.1
16	< 0.1	< 0.1
17	< 0.1	< 0.1

6 Conclusion

This essay investigates the relationship between forward citations and private value of patents. The dynamic stochastic model includes the possibility for an inventor to receive information on the value of the invention through citations. These dynamic citations affect the learning shocks and therefore the renewal decisions and the private value of patents. Estimating the model on using data on German semiconductor patents, I find that an additional citation increases the value of a patent by around 17.8% (€9,759). The result suggests that receiving a citation gives positive information to the patent holder, who then renews a given patent for a longer period of time. The effects are stronger when the additional citation is received in the first year of the patent lifetime. I also find that a German semiconductor patent is quite valuable with an average private value of €54,696.

This essay quantifies and explores how inventors are able to learn the true value of their inventions. Further research could also decompose the learning effects based on the type of citations. A self-citation could be a sign of learning from inside the firm whereas a citation from other inventors can be a sign a learning from the market or competitors. These two type of citations could have very different effects on learning and therefore the private value of patents. A next step could be to include this dimension. Additionally, information on the origin of citations (examiner or applicant) as well as non-patent literature could be exploit to further study the link between citations and patent value. Lastly, another avenue would be to try different specifications and distributional assumptions to include the stock of patent citations.

References

Abrams, David S, Ufuk Akcigit, and Jillian Grennan. 2013. “Understanding the link between patent value and citations: Creative destruction or defensive disruption.” *NBER Working Paper.*

Arts, Sam, Jianan Hou, and Juan Carlos Gomez. 2021. “Natural language processing to identify the creation and impact of new technologies in patent text: Code, data, and new measures.” *Research Policy*, 50(2): 104144.

Barney, Jonathan A. 2002. “A study of patent mortality rates: Using statistical survival analysis to rate and value patent assets.” *American Intellectual Property Law Association Quaterly Journal*, 30: 317.

Baudry, Marc, and Beatrice Dumont. 2006. “Patent renewals as options: Improving the mechanism for weeding out lousy patents.” *Review of Industrial Organization*, 28(1): 41–62.

Bessen, James. 2008. “The value of US patents by owner and patent characteristics.” *Research Policy*, 37(5): 932–945.

Cameron, A Colin, and Pravin K Trivedi. 2005. *Microeconometrics: Methods and applications.* Cambridge University Press.

Carpenter, Mark P, Francis Narin, and Patricia Woolf. 1981. “Citation rates to technologically important patents.” *World Patent Information*, 3(4): 160–163.

Cheng, Yin-Hui, Fu-Yung Kuan, Shih-Chieh Chuang, and Yun Ken. 2010. “Profitability decided by patent quality? An empirical study of the US semiconductor industry.” *Scientometrics*, 82(1): 175–183.

Deng, Yi. 2011. “A dynamic stochastic analysis of international patent application and renewal processes.” *International Journal of Industrial Organization*, 29(6): 766–777.

Dutt, Raman, and Vinita Krishna. 2019. “Forecasting the Grant Duration of a Patent using Predictive Analytics.” *International Journal of Computer Applications.*

Hall, Bronwyn H, Adam B Jaffe, and Manuel Trajtenberg. 2000. “Market value and patent citations: A first look.” National Bureau of Economic Research.

Hall, Bronwyn H, Adam Jaffe, and Manuel Trajtenberg. 2005. “Market value and patent citations.” *The RAND Journal of Economics*, 16–38.

Hall, Bronwyn H, and Rosemarie Ham Ziedonis. 2001. “The patent paradox revisited: An empirical study of patenting in the US semiconductor industry, 1979-1995.” *The RAND Journal of Economics*, 101–128.

Harhoff, Dietmar, Francis Narin, Frederic M Scherer, and Katrin Vopel. 1999. “Citation frequency and the value of patented inventions.” *Review of Economics and Statistics*, 81(3): 511–515.

Harhoff, Dietmar, Frederic M Scherer, and Katrin Vopel. 2003. “Citations, family size, opposition and the value of patent rights.” *Research Policy*, 32(8): 1343–1363.

Jaffe, Adam B, and Gaétan De Rassenfosse. 2019. “Patent citation data in social science research: Overview and best practices.” In *Research Handbook on the Economics of Intellectual Property Law.* Edward Elgar Publishing.

Keane, Michael P, and Kenneth I Wolpin. 1994. “The solution and estimation of discrete choice dynamic programming models by simulation and interpolation: Monte Carlo evidence.” *The Review of Economics and Statistics*, 648–672.

Kogan, Leonid, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman. 2017. “Technological innovation, resource allocation, and growth.” *The Quarterly Journal of Economics*, 132(2): 665–712.

Kuhn, Jeffrey, Kenneth Younge, and Alan Marco. 2020. “Patent citations reexamined.” *The RAND Journal of Economics*, 51(1): 109–132.

Lanjouw, Jean O, and Mark Schankerman. 2004. “Patent quality and research productivity: Measuring innovation with multiple indicators.” *The Economic Journal*, 114(495): 441–465.

Lanjouw, Jean Olson. 1998. “Patent protection in the shadow of infringement: Simulation estimations of patent value.” *The Review of Economic Studies*, 65(4): 671–710.

Liu, Xin, Junchi Yan, Shuai Xiao, Xiangfeng Wang, Hongyuan Zha, and Stephen Chu. 2017. “On predictive patent valuation: Forecasting patent citations and their types.” Vol. 31.

Maurseth, Per Botolf. 2005. “Lovely but dangerous: The impact of patent citations on patent renewal.” *Economics of Innovation and New Technology*, 14(5): 351–374.

Moser, Petra, Joerg Ohmstedt, and Paul W Rhode. 2018. “Patent citations—An analysis of quality differences and citing practices in hybrid corn.” *Management Science*, 64(4): 1926–1940.

Murphy, Kevin P. 2012. *Machine learning: A probabilistic perspective.* MIT press.

Pakes, Ariel. 1986. “Patents as Options: Some Estimates of the Value of Holding European Patent Stocks.” *Econometrica*, 54(4): 755–784.

Pakes, Ariel, and David Pollard. 1989. “Simulation and the asymptotics of optimization estimators.” *Econometrica: Journal of the Econometric Society*, 1027–1057.

Pakes, Ariel, and Mark Schankerman. 1984. “The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources.” In *R&D, patents, and productivity.* 73–88. University of Chicago Press.

Putnam, Jonathan. 1996. “The value of international patent protection.” *Unpublished Ph. D. Dissertation, Yale University.*

Reitzig, Markus. 2003. “What determines patent value? Insights from the semiconductor industry.” *Research Policy*, 32(1): 13–26.

Schankerman, Mark. 1998. “How valuable is patent protection? Estimates by technology field.” *the RAND Journal of Economics*, 77–107.

Schankerman, Mark, and Ariel Pakes. 1986. “Estimates of the value of patent rights in European countries during the post-1950.” *Economic Journal*, 96(384).

Schmoch, Ulrich. 2008. “Concept of a technology classification for country comparisons.” *Final report to the World Intellectual Property Organisation, WIPO.*

Serrano, Carlos J. 2010. “The dynamics of the transfer and renewal of patents.” *The RAND Journal of Economics*, 41(4): 686–708.

Serrano, Carlos J. 2018. “Estimating the gains from trade in the market for patent rights.” *International Economic Review*, 59(4): 1877–1904.

Sullivan, Richard J. 1994. “Estimates of the value of patent rights in Great Britain and Ireland, 1852-1876.” *Economica*, 37–58.

Trajtenberg, Manuel. 1990. “A penny for your quotes: Patent citations and the value of innovations.” *The RAND Journal of Economics*, 172–187.

Wang, Changtao. 2012. “Estimating the Value of Patent Rights in Australia.” *School of Economics, UNSW, SyAustralia.*

Wongchaisuwat, Papis, Diego Klabjan, and John O McGinnis. 2017. “Predicting litigation likelihood and time to litigation for patents.” 257–260.

ESSAY 3: AN ANALYSIS OF THE EUROPEAN UNITARY PATENT

The Incentive and Welfare Effects of the European Unitary Patent*

Alexis Stevenson
Hanken School of Economics, Helsinki GSE and KU Leuven

Tuomas Takalo
Bank of Finland and Helsinki GSE

Otto Toivanen
Aalto University School of Business, Helsinki GSE, KU Leuven and CEPR

Abstract

The harmonization of the European patent (EP) system through the upcoming Unitary Patent (UP) is one of the largest recent changes in a major intellectual policy regime. Using a model of patent renewals and data for chemical patents granted in 2000 by the European Patent Office, we find that i) the average European patent (EP) is worth €230K; ii) essentially all inventors would have used UP had it been available; iii) private value of patents increases by 7% on average with the largest contributions coming from increased patent length and reduced fees and very little from improved quality of inventions and expanded territorial scope of patent protection; iv) private value of patents is 54-57% and consumer surplus 43-46% of total welfare; v) total welfare increases only 0-2% as consumer surplus is reduced 2-9%. There are large differences between countries in the changes induced by UP.

---

*Financial support from Hanken School of Economics and the IPR University Center is gratefully acknowledged. We would like to thank Mercedes Delgado, Ari Hyytinen, Mari Komulainen, Mattia Nardotto, Johan Reindl, Florian Schuett, Geert Van Moer and participants at the KU Leuven IO seminar, Helsinki GSE IO seminar, RISE2 workshop, DRUID Academy, NHH Bergen and NICE 2022 (Oslo) for comments. We also thank Adrian Kovalcic for advice on the PATSTAT data. An earlier version of this essay circulated under the title “A counterfactual analysis of the European Unitary Patent”. All errors are ours.

1 Introduction

The establishment of the European patent system in the early 1970s was a major change in the European and global intellectual property rights regime. The European Patent Convention (EPC) in 1973 created the European Patent Office (EPO) which provides a legal framework for the granting of European patents (EPs). An EP has a single harmonised application and granting procedure but remains essentially a bundle of national patents. Over the past 50 years the European patent system has evolved with increased integration and harmonisation[1], but the implementation of a *real* European patent has remained elusive until recently. The introduction of the Unitary patent (UP henceforth) is the first major overhaul and a big step towards the original objective and, at the same time, one of the most significant changes in the global intellectual property regime this millennium. The new UP system is finally expected to be operational in 2022, creating the possibility of a single patent providing protection in several countries.[2] We analyse the incentive and welfare effects of introducing the UP.

The existing evaluations of UP (see below) and its proponents have stressed that its major benefit is the 'streamlining' of the application process and the reduction in costs by allowing inventors to apply for a single patent instead of multiple national patents, as is the case with EP. This change means that inventors save on legal and translation costs, and face a single schedule of renewal fees instead of multiple national renewal fee schedules. The fact that the introduction of UP gives inventors an option on top of the current EP regime and thereby strengthens intellectual property rights has gained far less attention. The alternative that the new UP regime offers is between taking an EP just like in the current regime and thereby tailor patent protection by country (i.e., in which countries to take out a patent, and within each country, for how long) at the cost of higher renewal fees and legal and translation costs, and the UP whereby patent protection is unified in length across all participating countries and renewal fees are lower. We quantify the private and social effects of this major institutional change, taking into account the increased cost-effectiveness of the patent protection and the effects of the change on patent quality.

We build a three-part model to evaluate the expected effects of UP. The first part is

---

[1] Plomer (2020) provides a full history of the transformation of the European patent system

[2] The introduction of the UP is linked to the creation of the Unified Patent Court (UPC) which will have jurisdiction over UPs and EPs. All the participating members have to ratify the UPC Agreement Act. The process took a big step forward in July 2021 when the German Federal Constitutional Court rejected to applications for a preliminary injunction against the UP.

a single-agent dynamic model of renewal decisions for the existing EPs. The second part is a patent production function linking the level of R&D to the private value of patents. The second part allows us to evaluate how the introduction of UP will affect patent quality at the intensive margin, i.e., regarding existing patents. The last part is a mapping between private value and consumer surplus. We estimate the model using renewal data for EPs applied for in 2000 in the technology area of chemicals (excluding pharmaceuticals).[3] We use the estimated parameters to simulate the counterfactual effects of the UP on the (i) length and territorial scope of patents and thereby their private value; (ii) quality of existing patented inventions (intensive margin); and (iii) surplus of European consumers.

We find that the vast majority of the inventors of chemical patents applied for in 2000 would have opted for UP, had they had the possibility. The average gain in private value is €16,803. 46% of this comes from a reduction in renewal fees, keeping geographical coverage of the patent and its length constant; 3% comes from increased geographical coverage, 45% from increased length of the patent, keeping geographical coverage constant, and the remaining 6% from a change in patent quality. We find that 62% of inventors would have invested more into R&D and thereby increased the quality of their patents, measured by the number of citations, by an average of 1.2% (+0.64 additional citations). All in all, the private value of patents increases by 7.3% on average with the introduction of UP. We then turn to the change in social value. Making different assumptions on the demand function of the consumers, we find that the welfare generated by the chemical patents applied for in 2000 increases between 0.4 to 1.9% with the introduction of UP. Consumer surplus decreases by 2.1 to 8.7%. We find that most national patent offices (NPOs) would receive significantly lower income coming from fees, with large variations across NPOs. We also find a number of new results pertaining to the value of individual EPs.

We can also shed light on how the gains from UP introduction are distributed among the participating countries. We find that the relative change in patent value due to UP is decreasing in the value of inventions under IP: thus e.g. Austria benefits by over 10% whereas Sweden and Ireland only by some 6% relative to the value of patents by the inventors of these countries under EP (under particular assumptions about the demand curve). Consumer surplus changes have a very different distribution: First,

---

[3] We chose chemical patents because the chemical industry relies on patents (Mansfield, 1986; Levin et al., 1987; Cohen, Nelson and Walsh, 2000) and the year 2000 because by then, due to a change in the application procedure, a large fraction of patent applications are designated to all EPC Member States and we still observe the patents to the statutory maximum term of 20 years.

the increase in consumer surplus is not linked to consumer surplus attained under EP. Second, changes are negative for all countries. Third, the differences are large, with Greek and Danish consumers losing 20%, but French, British and German consumers only a few per cent. Finally, the welfare gain is (weakly) positively correlated with the level of welfare under EP. Portugal gains the most (almost 2%), and Greece the least (1.2%).

We build on several existing literatures, the first of which has as its objective the evaluation of the effect of IPR on incentives to invent. It is generally acknowledged that this is a difficult task (e.g. Williams, 2017; Moser, 2021). Most studies use changes in patent policy as natural experiments to tackle this question (e.g. Sakakibara and Branstetter, 2001; Lanjouw and Cockburn, 2001; Lerner, 2002; Moser, 2005; Qian, 2007). Budish, Roin and Williams (2015) use variation induced by the length in clinical trials. A few papers look specifically at the implications of harmonising patent protection. Studies in this literature mostly focus on implications of strengthening patent protection for the less innovative South versus the more innovative North (e.g. Helpman, 1993; Lai and Qiu, 2003; McCalman, 2001; Bilir, Moser and Talis, 2011). Our approach differs from existing studies in that we provide an ex-ante evaluation of a forthcoming change in IPR, but note that our method could be applied ex-post, too. We are not aware of prior empirical work that would build a welfare analysis on a renewal model of patents, but e.g. Cornelli and Schankerman (1999) provide a (theoretical and) simulation analysis of the welfare effects of different patent renewal systems.[4]

Our study obviously has its limitations, among which are the following: First, our quantification of incentive effects builds on the standard incentive theory of patents according to which stronger patent protection increases incentives to invest. There are both empirical and theoretical results suggesting that this intuitive relation does not necessarily hold. For example, we abstract away from sequential innovation (Green and Scotchmer, 1995).[5] Second, we ignore the potential savings in legal and translation costs of obtaining a patent; this may bias our counterfactual estimates downwards. Third, we also ignore the effects of the UP system on litigation (see e.g. Schuett and

---

[3] See e.g. Todd and Wolpin (2006) for an ex-ante evaluation, albeit of a very different policy. Unlike them, we do not have access to post-treatment (=introduction of UP) data.

[4] The main interest of Cornelli and Schankerman (1999) is on the shape of the optimal renewal fee schedule.

[5] Theoretically, the effects of stronger patents in the process of cumulative innovation are often found to be negative (see, e.g. Bessen and Maskin 2009). However, the studies providing quasi-experimental evidence (Galasso and Schankerman, 2015; Sampat and Williams, 2019) find more ambiguous results on the effect of patents on follow-on invention, with differences possibly being explained by them concentrating on different fields of invention. See Williams (2017) for a discussion.

Schankerman, 2021). The change in the regime includes the establishment of the Unified Patent Court. The UPC is the only court to handle cases relating to UP, but for EP, there is a seven year transition period, after which they, too, will be handled only by the UPC. It is quite difficult to assess the effect of foregoing the incorporation of a change in how litigation is organised.[6] Fourth, we ignore any effects that UP may have outside Europe e.g. through changed incentives to invent. Fifth, we abstract away from the effects at the extensive margin, i.e., regarding the number of patents. Since the UP system makes patenting more cost effective, it is likely to increase the propensity to patent which may affect innovation and welfare adversely (see e.g. Hunt, 2006; Bessen and Hunt, 2007). However, the last problem may be mitigated by the fact that we have chosen to study chemical patents: the traditional incentive theory of patents is more likely to hold for them than in the case of more complex technologies. Finally, we exclude considerations of strategic patenting (see e.g. Choi and Gerlach, 2019, for a theoretical treatment) from our analysis.

The prior literature includes studies of the European patent system. Hall and Helmers (2019) analyze the patenting behavior of firms following the accession of 14 countries to the EPC in the last decade. Danguy and de la Potterie (2011) estimate the effect of UP on renewal fee incomes for NPOs and the EPO. They find that if the UP system fully replaces the EP system, the total income will be higher and most patent offices should be better off (except Germany). They extend this work in Danguy and de la Potterie (2014) where they simulate the effects of UP on the financial income of NPOs and EPO but now taking into account that the UP system will coexist with the EP system. Under various assumptions on the renewal fee scheme of UP - not known at that time - they find that an average UP would generate more income for patent offices than an average EP. Our results suggest that fee income would only go up if there was a significant positive effect at the extensive margin. Our work is also related to papers looking at the effects of fees on patenting behavior (De Rassenfosse and van Pottelsberghe de la Potterie, 2013, for a survey). We contribute by providing what to the best of our knowledge is the first comprehensive counterfactual analysis of a major institutional change in the patent system in Europe, taking in particular the effect of the change in fee structure into account.[7]

---

[6] According to Lanjouw and Schankerman (2001), the probability of a randomly drawn US patent (granted between 1978-1999) to be sued is 1.7%. Using data on West German patents applied for between 1953 and 1980, Lanjouw (1998) finds that the probability of a patentee winning a litigation trial is round 80-90%.

[7] Deng (2007*a*) compares the value of national patents from the 1970s to the value of EP patents from the 1980s and finds the latter to be much more valuable, but does not provide a counterfactual analysis.

We build on the literature on patent renewal and more specifically on a deterministic model of patent renewal introduced in Pakes and Schankerman (1984) and Schankerman and Pakes (1986*a*) and used e.g. in Bessen (2008) and Schankerman (1998). In this literature, models are based on the idea that it is costly for a patent owner to renew the patent to keep the legal protection in place. Therefore, the owner decides optimally to renew the patent as long as the expected returns from the patent exceed the renewal costs. The owner of the patent expects that the stream of returns will cover the maintenance fees through the use of technology, licensing or commercialization. The optimal solution for the patent holder has the form of a stopping rule which indicates whether to pay the maintenance fee in each period.

Pakes (1986) extends the model to include learning shocks. In other words, there is uncertainty for the patent owner regarding the sequence of returns that the patent generates if it is kept in force. Earlier research has found that most of the uncertainty related to the returns to patent protection occurs before the fifth or sixth year of the patent's life. Lanjouw (1998) refines the model to include the costs of litigation and the possibility of infringement. She also introduces a more flexible model of returns taking into account obsolescence, which happens when an invention becomes worthless. She estimates the distribution of the private value of patents for different technologies in West Germany. Other researchers found differences in private values by owners and patent characteristics in Europe (Schankerman, 1998) and the US (Bessen, 2008). Serrano (2018) allows for the possibility of trading patents, measured by the re-assignment of patents. Renewal decision models have been applied in different countries and contexts including patents granted in France using a binomial tree approach (Baudry and Dumont, 2006), in Australia (Wang, 2012) and in Great Britain and Ireland between 1852 and 1876 (Sullivan, 1994). In an important precursor to our work, Deng (2011) extends the framework to the context of EPs. We follow Bessen (2008) in modeling patent value using individual level data and several patent characteristics: patent family size, the nationality of the applicant, the number of forward citations, the number of patent claims and IPC classes.

We contribute to the patent renewal literature by first, allowing a free parameter to capture the correlation of the initial value of patents between any two countries.[8] Second, to be able to estimate the ensuing large number of parameters (169), we introduce the composite marginal likelihood method to this literature (for an overview, see Varin, Reid and Firth, 2011). Third, we use the private patent value estimates from the re-

---

[8] Deng (2011) models the correlation between two countries as a function of their geographical distance.

newal model in a model of inventive investments. Fourth, prior work has concentrated on estimating the private value of patents without extending the analysis to social value. To do so, we extend the approach of Schuett and Schankerman (2021) whose welfare analysis builds on a linear Cournot model. By utilizing so-called ρ-linear (see Anderson and Renault, 2003) demand functions we provide a more flexible method and execute the welfare calculations using several different parameterizations.

The rest of the paper is organized as follows. We present the European patent system in more detail and discuss the distinction between EP and UP in section 2. In section 3 we describe the data source and provide some descriptive statistics. We introduce the theoretical framework in section 4. Section 5 is reserved for us presenting our main estimation and counterfactual results. We offer conclusions in section 6.

2 Institutional background

The new European patent system will include three layers: national patents, EPs and the upcoming UPs. We focus on the decisions between EPs and UPs.

2.1 European patents

Since 1977, the EPO has offered a unified patent application and examination procedure for all signatory States to EPC. In 1978, only seven members were contracting States and 3,572 patents were filed. In 2019, 38 countries were contracting States[9] and 181,479 applications were filed. The terminology "European" is misleading because the European dimension exists only at the examination stage of the patent application: EP does not provide supranational protection, but rather a bundle of national patents. In fact, an EP is subject to national patent law, including the payment of renewal fees in States where the patent is in force. This fragmented and complex post-grant procedure

---

[9] Contracting States to the EPC (with dates of entry into force): Belgium (1977), Germany (1977), France (1977), Luxembourg (1977), Netherlands (1977), Switzerland (1977), UK (1977), Sweden (1978), Italy (1978), Austria (1979), Liechtenstein (1980), Greece (1986), Spain (1986), Denmark (1990), Monaco (1991), Portugal (1992), Ireland (1992), Finland (1996), Cyprus (1998), Turkey (2000), Bulgaria (2002), Czech Republic (2002), Estonia (2002), Slovakia (2002), Slovenia (2002), Hungary (2003), Romania (2003), Poland (2004), Iceland (2004), Lithuania (2004), Latvia (2005), Malta (2007), Norway (2008), Croatia (2008), Republic of Macedonia (2009), San Marino (2009), Albania (2010), Serbia (2010).

results in a more expensive patent system than in the US or in Japan (van Pottelsberghe de la Potterie and François, 2009). It is one of the arguments raised in the long-lasting debate as to why Europe should introduce a harmonised patent system. Notice though that a potential advantage of this system, also from a welfare point of view, is that the (successful) applicant can tailor the patent protection by choosing the countries where the patent is validated (see below) and for how long the patent is kept in force through renewal decisions.

Application and Examination. In the first stage, the applicant files an application for an EP in one of the three official languages (English, French or German). At the time of the application, the applicant pays a standard filing cost including a European search fee and an examination fee. Within twelve months after the filing date, the applicant is free to choose the Member States in which to seek for protection and pays per-country designation fees. Since 1999, all countries are designated by default, so most applicants decide to designate the full set of EPC Member States.[10] Moreover, the designation fee scheme encourages applicants to seek protection in the full set of States as the per-country designation fees are identical for each country up to a maximum of seven, after which additional designation countries are free of charge. The period of examination lasts usually two to six years. During the examination period the EPO conducts a formality check and then produces a search report describing the state of prior art. The patent examiners evaluate if the EPO requirements for patentability (novelty, inventive step and industrial application) are met. The search report and the application are published in the EPO Bulletin 18 months after the priority date of the patent application. The applicant may request the examination within six months after the publication of the application. Not requesting the examination is equivalent to withdrawing the patent.

Validation and renewal decisions. After the examination period, the patent is approved or denied. Traditionally, the EPO grants 60-65% of the patent applications, refuses 5%, and 30-35% are withdrawn by the applicant during the search and examination process (Lazaridis and de la Potterie, 2007). If the patent is granted, the assignee decides whether to pay an extra cost (mainly translation costs for extension/validation) to be able to validate and then transfer the granted patent into national laws in a given (member) country. We call these costs validation costs. In practice, applicants do

---

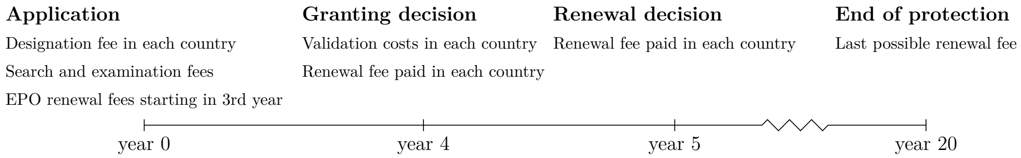
[10] In reality, some applicants decide to opt-out from some States for litigation reasons. In the first approximation, we ignore these cases.

not validate in all designated states. The validation costs differ between countries and patents. For instance, some translations, notably Danish, Swedish and Finnish, are more expensive. The translation service is usually provided by a local attorney and depends on the size of the patent (number of pages) and the patent characteristics. Since the London Agreement in 2008, translation costs have decreased. Signatory countries to the London Agreement do not require that the applicants obtain a full translation of the patent into the local language; only the claims of the EP are required to be translated. We ignore this as we focuse on patents applied for in 2000. Moreover, some States do not require a translation at all (Austria, Belgium, France, Germany, Ireland, Luxembourg, Monaco, Switzerland or United Kingdom). According to Harhoff et al. (2009), translations are not required in 60% of validation cases. Also other administrative validation costs differ by country. Some countries have additional validation costs (fee) whereas others do not charge a fee (Belgium, Luxembourg,Monaco, Switzerland and the United Kingdom). Some countries charge an additional page-based fee when the patent document is longer than a certain size (Austria, Denmark, Finland, Spain and Sweden) (Harhoff et al., 2009).

Once the patent is validated in a given country, it gives the same right as the national patent and is valid for up to 20 years from the filing date. Thereafter, the national patent laws apply, including the requirement to pay a yearly patent maintenance fee in order to keep the patent in force. The fee scheme and varies across countries (see appendix A.1 for renewal fees for the patents in our sample). Renewal fees are collected by national patent offices which retrocede half of the revenue to the EPO. Harhoff et al. (2009) shows that the level of renewal fees, validation costs as well as translation costs have an impact on the validation and renewal decisions. Our model includes this trade-off in the choice of validation countries. Note that the payment of renewal fees starts on the third year from the filing date. Therefore, a patent application can be still under examination when the first renewal decisions are taken. Following the approach of Deng (2007*b*), we model renewal decisions starting from the grant date.

Figure 1 is a simplified presentation of the patent lifetime (the timeline is indicative). In practice different routes exist such as first and second filings, and PCT applications. Guellec and Van Pottelsberghe de la Potterie (2007) provides an thorough description of the different filing procedures at the European Patent Office. We focus on validation and renewal decisions once the patent is granted; this usually happens 4 to 5 years after the patent application.

Figure 1: Lifetime and costs of a European patent (example)



2.2 The unitary patent

Principle. The unitary patent system is expected to start in 2022 and will become an additional option alongside the current national patents and EPs. As mentioned, it has been discussed in one form or another for more than four decades. The centralised pre-grant phase described above will remain the same under the new regime. Thus, there won't be any difference in the quality of the search and examination conducted by the EPO for EPs and UPs. The difference with the EP will be in the post-grant procedure with the introduction of a unique procedure, currency, deadline and no obligation to use a representative. Once the EP is granted, the applicant will be allowed to "request for unitary effect" at the EPO. This request will be free of charge and must be filed in the month following the publication of the grant in the European Patent Bulletin. Moreover, a condition to be eligible for the unitary effect is that the EP has to be granted in at least the same set of States covered by the UP system. After the request, the EP will become a UP. Whereas the EP is validated and renewed separately in each State, the UP will be renewed once a year in the full set of States covered by the new regime and will have its own renewal fee schedule.

Scope of UP. The UP intends to give protection in up to 25 EU Member States (EU27 except Spain and Croatia) which are part of the enhanced cooperation in the creation of unitary patent protection. Note that the UK government stepped out of the project in July 2020 after ratifying the UPC in April 2018. According to the EPO, it is very likely that other countries will join the Unitary Patent System in the following years. The territorial scope of UP is then likely to increase but the UP will have a fixed coverage based on the date of registration of the patent. In other words, multiple generations of UPs with different coverage are expected to be in force at the same time. This point is important as different combinations of EP and UP will be possible. Even with a Unitary patent, it will still be necessary to go through validation or extension in EPC states that are not in the UP system. For simplicity, we look at EPs granted in 2000 in 15 countries and our counterfactual policy focuses on these 15 countries (including the UK). We thereby rule out the possibility of a combination between EP and UP in our model, as well as a combination between national patents and European patents. A possible consequence of the co-existence of these systems is an increasing number of duplicate patent filings simultaneously at different patent offices. Double patents at the national and European levels already exist (von Graevenitz and Garanasvili, 2018).

Costs of UP. UP system will significantly decrease the cost of patenting compared to EP because the validation costs will be decrease and the (unique) renewal fees will be lower. Similarly to EP, if renewal fees are not paid on time, the UP will lapse.[11] The renewal fee scheme is set to be equal to the sum of EP renewal fees in the four most popular countries in 2015 for EP patent protection (Germany, France, the UK and the Netherlands). According to the EPO, it costs €170,000 to obtain a EP for ten years in the 25 states covered by the UP, whereas it will cost only approximately €35,000 to obtain the same coverage with a UP. In the long run, a UP will not require the translation of the patent (translation fees are a major reason for the high cost of EP; see van Pottelsberghe de la Potterie and François, 2009). Nevertheless, in a six-year transitional period (which may be extended to up to 12 years), translation will still be required; we therefore ignore (differences in) translation costs in our counterfactual exercise. UP, similar to EP, will have to be filed in the so-called procedural languages: English, French or German. Patents in English will need to be translated into one of the other procedural languages. French and German language patents will be translated in English. To compensate applicants for the added cost during the transitional period, the EPO will launch a scheme to cover costs related to the translation of the patent application for EU-based SMEs, natural persons, non-profit organizations and universities that are resident in a contracting Member State.

Unified Patent Court. The new regime is linked to the creation of the Unified Patent Court. The UPC will have jurisdiction on both EP and UP and we therefore assume in our counterfactual that there are no differences in the litigation practices

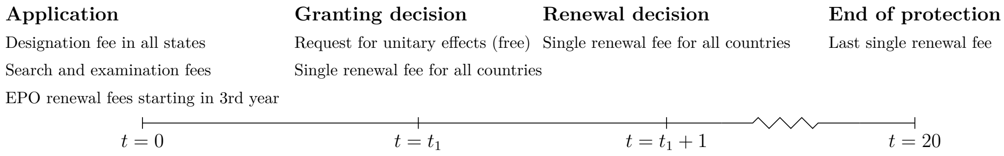
---

[11] Nevertheless, it is still possible to pay within six months of the due date with a penalty of 50% of the belated renewal fee.

of EP and UP. The creation of the UPC will have effects on litigation costs as it will provide a unified court to centralize litigation. One can expect that the creation of the Court will have an effect on the value and incentives to innovate. Also UP can be licensed in whole or part of the territories of the EU Member States. It is likely that some patent owners will take into account the future cost of litigation when they decide which route (national, EP, UP) to choose. The fact that UP can be revoked in a single action in all participating countries may also reduce the appeal in respect of high-value patents. In contrast, a standard EP could only be revoked on a national basis, one State at a time.

Figure 2 is a simplified presentation of the patent lifetime under the UP

Figure 2: Lifetime and costs of a Unitary Patent



3 Data

3.1 Patent data

The patent data come from the EPO PATSTAT database (spring 2021) and record all EP applications and granted EPs. The data include information on the designation (decision at the time of the application) and validation (decision at the time of the grant) decisions as well as the full renewal history. PATSTAT also provides patent characteristics that are relevant for the returns: The number of forward citations, the number of inventors/applicants, the number of claims, IPC classes and patent family size. Our sample consists of all EPs applied for in 2000 in the field of chemistry (excluding pharmaceutical patents), and designated in the set of 15 Member States[12]. 26% of chemistry patents were designated in the 15 countries in 1995 and 86% in 2000. As previously mentioned, the reason of this rise is that the designation fee scheme changed in the end of the 1990's to encourage applicants to seek protection in the full set of States.

We focus on patents granted in 2000 for two reasons. First, we are able to observe the full life for these patents. Second, in contrast to earlier years, most of the patents in 2000 cohort have the same coverage: 86% of the 16,492 patents are designated in 15 countries.

We focus on chemical patents (excluding pharmaceuticals) because this is an industry that make intensive use of intellectual property. To isolate patents in the technology area of chemistry we use the ISI-OST-INPI classification updated by Schmoch (2008) and included in PATSTAT. We define a patent as belonging to a technology area if at least one IPC code of the patent belongs to this technology area.

3.2 Renewal fee schemes

Renewal fees for each country are extracted from EPO's reports "National Law relating to the EPC"[13] for each relevant year. Fees are expressed in 2010 euros using the Harmonized Indices of Consumer Prices (HICP) of Eurostat and reported in Table A.1. Note that there exist other costs for EPs such as representation costs (attorney fees, other service providers), translation costs incurred for validation and/or publication. In the model, we only take into account renewal fees.

Figure 3 shows the total fee paid in each country for a full term (20 year) EP. The total cost in 15 countries for the full term is more than €100,000 in renewal fees, but there is considerable variation between countries, from more than €15,000 in Germany to less than €3,000 in Portugal.

---

[12] Austria (AT), Belgium (BE), Switzerland (CH), Germany (DE), Denmark (DK), Spain (ES), France (FR), Great Britain (GB), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU) the Netherlands (NL), Portugal (PT), Sweden (SE). We removed three States that joined the Convention during the period we are studying: Finland (1996), Cyprus (1998), Turkey (2000) as the number of EPs in these countries is very low in 2000. The proportion of patents designated in the 15 countries increased over time.

[13] https://www.epo.org/law-practice/legal-texts/national-law/archive.html

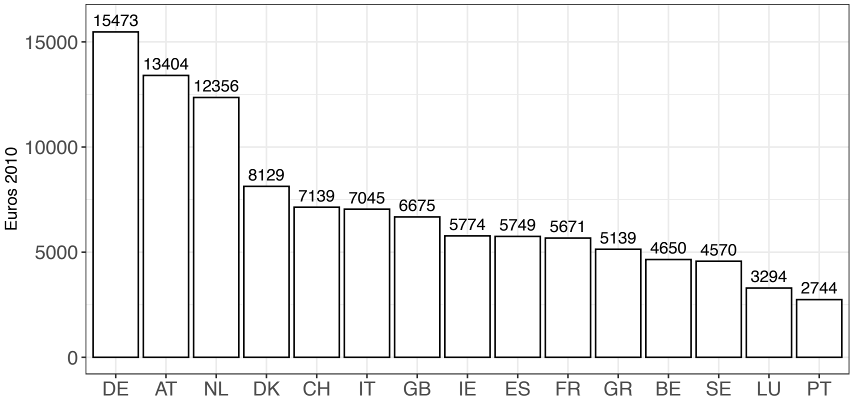


Figure 3: Total renewal costs for a 20-year protection in a given country, in euro 2010

The renewal fee structure for UP is already known and published. To take into account the fact that in 2000 the territorial scope was narrower than today, we compute the “equivalent” renewal fee scheme for UP in the counterfactual, by keeping the same ratio of renewal cost between EP and UP. The renewal fee structure used for the counterfactual is displayed in Table 1. The actual fees for 2021, covering 38 countries, are displayed in columns 2 and 3; in the fourth column we display their ratio in per cent; and our adjusted fee schedules are presented in columns 5 and 6.

Table 1: Renewal fees UP - real and counterfactual

Period	Fees EP 2021	Fees UP 2021	UP fee/EP fee, %	Fees EP 15 countries	Fees UP 15 countries
1	2,506	315	12.57%	1,400	176
2	3,250	475	14.62%	1,839	269
3	3,861	630	16.32%	2,203	359
4	4,615	815	17.66%	2,660	470
5	5,554	990	17.82%	3,113	555
6	6,463	1,175	18.18%	3,643	662
7	7,526	1,460	19.40%	4,205	816
8	8,655	1,775	20.51%	4,865	998
9	9,854	2,105	21.36%	5,676	1,213
10	11,028	2,455	22.26%	6,485	1,444
11	12,189	2,830	23.22%	7,254	1,684
12	13,569	3,240	23.88%	8,272	1,975
13	14,912	3,640	24.41%	9,343	2,281
14	16,166	4,055	25.08%	10,277	2,578
15	17,729	4,455	25.13%	11,491	2,887
16	19,227	4,855	25.25%	12,720	3,212

3.3 Variables

Renewal decisions. We use the legal status information in PATSTAT to construct the renewal variable. This variable indicates the number of years the patent is renewed. It ranges from 0 which means the patent is granted in a country but not validated, to 16 years which means that the patent is renewed every year up to the statutory limit, i.e., 20 years after filing date. Only a minority of patents are renewed for more than 16 years. This situation happens when the examination period is shorter than 4 years. In these cases, we code them as being renewed for 16 years. We thus assume that the examination period is equal to four years for all the patents in our sample.

We use two sources of information to construct the renewal variable: Information on lapsing and information on renewal. In some countries, the grace period after lapsing for non-payment of renewal fees can be quite long. A lapse event coded in PATSTAT does not necessarily mean that a patent expired. On the other hand, renewal information in PATSTAT is not fully reliable. We follow Harhoff et al. (2009) who write: "Following the advice of an EPO expert, information on patent lapses were preferred over renewal information, in case both databases contained conflicting results".

As can be seen from Table 2, there is significant variation in renewal over countries: the longest patents are found in Germany (mean 10 years) and the shortest in Luxembourg, Greece, Denmark and Portugal (all less than 5 years on average). There are also considerable differences in the distribution, with more than a quarter of patents being renewed for at least 15 years in Germany and 14 years in France and Great Britain. In Luxembourg and Greece, a quarter of patents is renewed for at least 5 years.

Validation decisions. As noted by Hall and Helmers (2019), it is not easy to determine from PATSTAT whether a patent has been validated in a country after being granted by the EPO. The legal status of PATSTAT do not provide directly this information because not all the national patent offices record the payment of validation fee. Moreover, some countries do not charge a validation fee. We again adopt the approach of Harhoff et al. (2009). We assume that non-validation is indicated by a lapse of the patent in the 365 days following the grant of the patent. Table 2 reveals (Nb country validated) that on average, a chemical EP applied for in 2000 is validated in 6 countries and 25% in at least 8 of the 15 countries we consider. As shown in Table A.2 in the appendix, there is a significant variation in validation across countries: from 20.8% in Luxembourg to 89.1% in Germany for EPs in our sample. These validation and maintenance rates are in line with those obtained by Danguy and de la Potterie (2011) who consider a larger sample of EPs.

Number of forward citations. The number of citations is often used to proxy for the value of patent and the scientific contribution of an invention. Many studies find a positive association between forward citations and the value of patents (e.g. Trajtenberg, 1990; Lanjouw and Schankerman, 2004). The descriptive statistics for the number of citations 3 years, 5 years and 10 years after patent application are shown in Table 2. On average, a patent in the sample receives 3.0 citations in the first 10 years after the patent application date. As is clear from the table, European patents do not receive many citations.

Number of claims. The claims define in technical terms the scope of the protection. The number of claims is sometimes used as a measure of the patent scope (e.g. Marco, Sarnoff and Charles, 2019). The higher is the number of claims, the broader the scope of the patent Og et al. (2020). The relationship between the number of claims and patent value is not necessarily linear and excessive claims can be associated with lower returns. As shown in Table 2, the average number of claims in the sample is 14.8.

IPC classes. We follow the existing literature and use the number of IPC (International Patent Classification) subclasses (e.g A101B) for each patent as a measure of the technological breadth of the invention (Lerner, 1994). The IPC subclasses are assigned by the examiner. The average number of IPC classes is 5.4 with a quarter of patents having more than 7 classes.

Patent family size According to the EPO, a simple patent family (DOCDB patent family in PATSTAT) is a “collection of patent documents that cover a single invention” and therefore all members of a patent family will have exactly the same priorities. In PATSTAT, the priorities taken into account are the first filings, the provisional first filings and the equivalents to first filings. Continuation and divisions are considered to cover the same content as the parent application and are therefore in the patent family regardless of the priorities they claim. Putnam (1996) is one of the first to use the size of patent family as a proxy for the value of patents. In our sample, chemical patents have an average of 11.83 members in their patent family.

3.4 Descriptive statistics

The cost of patent validation and renewal decisions is the reason why not all the patent holders choose to validate a granted patent in all the designated countries. A large proportion of patents is not renewed for the full patent term. Tables 2 and A.2 provide some evidence of differences in the set of validated countries and renewal decisions, as well as differences in total cost of renewal across countries. A patent in the sample is validated on average in 5.9 countries. Germany, Great Britain, France and Italy are the countries with the highest validation rates and renewal rates. There is a substantial number of countries for which the average validation rate is relatively low.

Table 2: Descriptive statistics chemical EPs granted in 2000

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Patent characteristics							
Citations 3y	16,492	1.460	6.276	0	0	1	448
Citations 5y	16,492	1.911	7.919	0	0	1	623
Citations 10y	16,492	3.004	11.169	0	0	3	783
Nb of IPC classes	16,492	5.385	4.107	1	3	7	45
Nb of applicants	16,492	1.092	0.344	1	1	1	8
Nb of inventors	16,492	3.185	2.120	1	2	4	24
Nb of claims	16,492	14.772	10.921	1	8	19	247
Patent family size (docdb)	16,492	11.833	9.079	1	7	14	126
Renewal and validation decisions							
Germany	16,492	9.918	4.956	0	6	15	16
France	16,492	8.938	5.156	0	5	14	16
Great Britain	16,492	8.773	5.168	0	4	14	16
Netherlands	16,492	5.548	4.883	0	2	8	16
Austria	16,492	4.602	4.375	0	1	7	16
Italy	16,492	7.116	5.158	0	3	11	16
Spain	16,492	6.173	5.041	0	2	9	16
Sweden	16,492	4.616	4.422	0	1	7	16
Switzerland	16,492	5.242	4.811	0	1	8	16
Belgium	16,492	5.253	4.720	0	2	8	16
Denmark	16,492	4.168	4.193	0	1	6	16
Luxembourg	16,492	3.597	3.685	0	1	5	16
Greece	16,492	3.689	3.760	0	1	5	16
Portugal	16,492	3.843	3.887	0	1	5	16
Ireland	16,492	4.181	4.204	0	1	6	16
Nb of countries validated	16,492	5.949	4.205	0	3	8	15

4 Theoretical framework

Renewal decisions at the EPO are complex. We do not attempt to provide an exhaustive model of renewal and validation decisions, but concentrate to what to our understanding are the key decisions.

4.1 The renewal decision model

4.1.1 Private value of EP

The main assumption of the model is that patent holders decide on validation and renewal strategies by comparing the expected returns with the renewal costs, following the deterministic approach of Pakes and Schankerman (1979); Schankerman and Pakes (1986*b*) and Bessen (2008). Consider an inventor seeking to validate and renew an EP in multiple countries. The granted patent protects a single invention i indexed by $i = 1, \dots, I$ in country j, indexed by $j = 1, \dots, J$. The return to invention i in country j in period $t = 1, \dots, \overline{T}$ is defined by R_{ijt} where $\overline{T}$ is the statutory maximum duration of the patent.

The model is deterministic in the sense that the inventor knows perfectly the full sequence of returns from the time the patent is granted. We assume that returns for patents in a country j depreciate every period at the constant rate $\delta_j \in (0, 1)$ known by the patent holder and to be estimated. Patent return for invention i in country j in period t is then:

$$R_{ijt} = \delta_j^{t-1} R_{ij1} \quad \text{where } R_{ij1} \text{ is the return in the first period}$$

The renewal cost C_{jt} in a country j in period t is known for the full life of the patent. The private value of patent protection is the value to the owner of the patent. This information is not observed by the researcher but is observed by the patent holder. Following Putnam (1996) and Deng (2011) who analyze patent renewal in an international context, the private value of a EP covering an invention i in a country $j \in 1, \ldots, J$ is:

$$V(R,T) = \sum_{j=1}^{J}\sum_{t=1}^{T_j} \max_{T_1,\ldots,T_J} \beta^{t-1}(\beta R_{ijt} - C_{jt}) \tag{1}$$

The owner decides in each country j how many periods $T_j \in [0, 1, 2, \ldots, \overline{T}]$ she will renew the patent, balancing patent returns with costs. Note that $T_j = 0$ means that the patent is not validated in country j because the patent holder decides not to pay the first renewal fee. Costs are paid at the beginning of each period whereas returns are received at the end of each period. Returns are discounted by the discount factor β which is assumed to be known and, following the literature, fixed to 0.95.

4.1.2 Renewal and validation decisions

We can use an assumption of our model and a feature of the renewal data to come up with a way of characterizing the renewal and validation decisions. The assumption of the model is that revenues are (weakly) decreasing over time and the institutional feature is that renewal fees are strictly increasing over time. Together, the above assumption and the feature of the data mean that $\beta R_{ijt} - C_{jt}$ is decreasing in time (patent age) and the optimal length of a patent is determined by the the last period where $\beta R_{ijt} - C_{jt} \geq 0$ holds.

The patent holder renews a patent i in country j in period t as long as:

$$\beta R_{ijt} \geq C_{jt} \Longrightarrow R_{ij1} \geq \frac{C_{jt}}{\beta \delta_j^{t-1}} \tag{2}$$

We take the log of these expressions and define $r_{ijt} = \log(R_{ijt})$ and $c_{jt} = \log(C_{jt})$. The number of years a patent is renewed in a country j is denoted y_{ij}. y_{ij} is linked to the unobserved returns r_{ij} by

$$y_{ij} = \begin{cases} 0 & \text{if} \quad -\infty < r_{ij0} \leq c_{j1} - \log\beta \\ 1 & \text{if} \quad c_{j1} - \log\beta < r_{ij0} \leq c_{j2} - \log\delta_j - \log\beta \\ \ddots & \\ \overline{T} & \text{if} \quad c_{j\overline{T}} - (\overline{T}-1)\log\delta_j - \log\beta < r_{ij0} < +\infty \end{cases} \tag{3}$$

The log of the initial return in a country j (r_{ij}) is a latent variable assumed to be determined by a linear model with a deterministic observed part and a random part unobserved by the researcher:

$$r_{ij1} = X_{ij}^{'}\gamma_j + \epsilon_{ij} \tag{4}$$

where $X_{ij}^{'}$ is a K dimensional vector of observed covariates that include patent characteristics which affect the quality of the invention. The covariates are the forward citations 10 years after filing, family size (= the number of countries in which the invention has been protected, with EPO countries counting as one), the number of claims, the number of IPC classes, and dummies for the applicant being from country $j = 1, .., J$. γ_j is a vector of parameters to be estimated that measure the "source of returns". ϵ_{ij} is a random component assumed to follow a multivariate normal distribution with mean $\mu \in \mathbb{R}^J$ and covariance matrix $\Sigma \in S_{++}^J$ where S_{++}^J is the space of symmetric positive definite $J \times J$ matrices. Unobservable (to the econometrician) parts of return to a patent may be correlated across countries. We further assume that model satisfies the exogeneity condition $E(X_{ij}\epsilon_{ij}) = 0 \quad \forall j$. The assumption that the logarithm of returns is normally distributed is supported by surveys showing that the distribution of patent value is highly right skewed (Gambardella, Harhoff and Verspagen, 2008).

$$(\epsilon_{i1}, \ldots, \epsilon_{iJ}) \sim N \left[\begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_J \end{pmatrix}, \begin{pmatrix} \sigma_1^2 & \rho_{12} & \cdots & \rho_{1J} \\ \rho_{12} & \sigma_2^2 & \cdots & \rho_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{1J} & \rho_{2J} & \cdots & \sigma_J^2 \end{pmatrix} \right]$$

The correlations between ϵ_{ij} allow us to capture the degree of to which patent value is correlated between any pair of countries. due to e.g. correlated demand. Estimating the parameters of the covariance matrix for J-countries imply the estimation of $\frac{J(J+1)}{2}$ parameters. In our case $J = 15$, making the estimation of the covariance matrix parameters computationally challenging.

4.1.3 Estimation and Identification

The parameter vector to be estimated is $\theta = (\mu, \Sigma, \delta, \gamma)$ where γ is a $K = 19$ dimensional vector of estimates for covariates, μ is a J = 15 dimensional vector of mean initial returns, δ is a J-dimensional vector of decay rates and Σ is a $\frac{J(J+1)}{2}$ dimensional vector of all error variances-covariances stacked.

Let us define a series of thresholds in (3) using (4) as

$$
\begin{aligned}
&\kappa_{ij}^{0}(\theta) = -\infty \\
&\kappa_{ij}^{1}(\theta) = c_{j1} - \log\beta - X_{ij}'\gamma_j \\
&\kappa_{ij}^{2}(\theta) = c_{j2} - \log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\ldots \\
&\kappa_{ij}^{k}(\theta) = c_{jk} - (k-1)\log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\ldots \\
&\kappa_{ij}^{\overline{T}}(\theta) = c_{j\overline{T}} - (\overline{T}-1)\log\delta_j - \log\beta - X_{ij}'\gamma_j \\
&\kappa_{ij}^{\overline{T}+1}(\theta) = +\infty
\end{aligned}
$$

Note that for a given invention i in a country j, the unknown thresholds satisfy the condition: $\kappa_{ij}^{0}(\theta) < \kappa_{ij}^{1}(\theta) < \ldots < \kappa_{ij}^{\overline{T}+1}(\theta)$ because the renewal fees are increasing over time.

Let $\phi_{\mu,\Sigma}(\epsilon_{i1}, \ldots, \epsilon_{iJ})$ be the multivariate probability density function with:

$$(\epsilon_{i1}, \ldots, \epsilon_{iJ}) \sim \mathcal{N}(\mu, \Sigma)$$

The likelihood function for an invention i that is renewed m_1 period(s) in country 1, m_2 period(s) in country 2, ..., m_J period(s) in country J is

$$
\begin{aligned}
L_i(\theta) = {} & Pr(y_{i1} = m_1, y_{i2} = m_2, \ldots, y_{iJ} = m_J) \\
= {} & \int_{\epsilon_{i1}=\kappa_{i1}^{m_1}(\theta)}^{\epsilon_{i1}=\kappa_{i1}^{m_1+1}(\theta)} \int_{\epsilon_{i2}=\kappa_{i2}^{m_2}(\theta)}^{\epsilon_{i2}=\kappa_{i2}^{m_2+1}(\theta)} \ldots \int_{\epsilon_{iJ}=\kappa_{iJ}^{m_J}(\theta)}^{\epsilon_{iJ}=\kappa_{iJ}^{m_J+1}(\theta)} \phi_{\mu,\Sigma}(\epsilon_{i1}, \ldots, \epsilon_{iJ}) d\epsilon_{i1}, \ldots, d\epsilon_{iJ}.
\end{aligned}
$$

The likelihood involves the computation of a J-dimensional integral for each invention which is computationally difficult for large J. To circumvent this issue, we use the composite marginal likelihood (CML) method described below.

Composite marginal Likelihood (CML). The composite likelihood methods were first introduced by Besag (1975) under the term of pseudo-likelihood and then popularised by Lindsay (1988) as composite likelihood methods. The approach consists of constructing a likelihood object based on the likelihood of marginal or conditional events. Paleti and Bhat (2013) compare simulated maximum likelihood (SML) with the use of a composite marginal likelihood (CML). They show that using SML is cumbersome and prone to simulation errors. Furthermore, they find that CML recovers parameters as well as the SML estimation approach and with a substantially reduced computational cost (see also Bhat, Varin and Ferdous (2010)). This method has been applied widely in statistics but has gained little attention in economics and econometrics. Mullahy (2016) propose a composite marginal likelihood approach to estimate multivariate probit models with bivariate probit. In our setting, the approach requires us to replace the full likelihood function by a surrogate likelihood constructed from pair-wise bivariate ordered probits. Therefore, the full pair-wise approach of CML requires to evaluate $J \times (J-1)/2$ pairs.

The standard pairwise CML likelihood function for invention i is:

$$L^i_{CML}(\theta) = \prod_{j=1}^{J-1} \prod_{j'=j+1}^{J} Pr(y_{ij} = m_j, y_{ij'} = m_{j'}) \tag{5}$$

where the probability that an invention i is renewed m_j periods in country j and m_k periods in country k is:

$$\begin{aligned} Pr(y_{ij} = m_j, y_{ik} = m_k) =& Pr\left(\kappa_{ij}^{m_j} \leq \epsilon_{ij} \leq \kappa_{ij}^{m_j+1} \quad \cap \quad \kappa_{ik}^{m_k} \leq \epsilon_{ik} \leq \kappa_{ik}^{m_k+1}\right) \\ =& \Phi_2\left(\frac{\kappa_{ij}^{m_j+1} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k+1} - \mu_k}{\sigma_k}, \rho_{jk}\right) - \Phi_2\left(\frac{\kappa_{ij}^{m_j} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k+1} - \mu_k}{\sigma_k}, \rho_{jk}\right) \\ & - \Phi_2\left(\frac{\kappa_{ij}^{m_j+1} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k} - \mu_k}{\sigma_k}, \rho_{jk}\right) + \Phi_2\left(\frac{\kappa_{ij}^{m_j} - \mu_j}{\sigma_j}, \frac{\kappa_{ik}^{m_k} - \mu_k}{\sigma_k}, \rho_{jk}\right) \end{aligned}$$

Φ_2 is the bivariate standard normal cumulative distribution with covariance ρ.

The pairwise marginal likelihood function is then:

$$L_{CML}(\theta) = \prod_{i=1}^{I} L_{CML}^{i}(\theta)$$

Identification. The renewal fees provide information on scaling of the latent variable in models of patent renewal. Therefore, unlike in the standard ordered probit, no restriction on variance parameters is needed. In essence, as the renewal fees are measured in euros, it follows both that no coefficient is needed and that one obtains a natural interpretation of other variables and their coefficients in monetary terms. Furthermore, we assume X_i does not contain a constant term so the standard normalization $\mu = 0$ becomes unnecessary in this case.

Standard Errors. Standard errors are computed using a bootstrap with 200 replications.

5 Estimation results

Figure 4 shows mean initial (log) returns of patents in a given country on the x- and decay rates on the y-axis. The highest initial returns are earned in Germany (i.e., for patents giving protection in the German market), Great Britain, The Netherlands and France. The differences across countries are large: The mean initial return to a patent in Germany is five times that of the lowest in Greece, for patents having identical characteristics. It is also noticeable that the initial return for patent protection in The Netherlands is on par with that in France and higher than in Italy or Spain despite the Netherlands being a smaller country. We also estimate large differences in decay rates. Three of the four countries with the highest initial returns also have the highest decay rates, meaning that patents in Germany, Great Britain and France lose value more slowly than in other countries. Figure 4 shows that Germany, Italy, Spain, France and Great Britain have the highest variation in initial returns, i.e., more heterogeneity in the quality of inventions. The differences across countries in heterogeneity of returns is also sizeable, with Germany having a 40% higher standard deviation of returns than Denmark. Figure 5 further shows that the association between mean initial returns and standard deviation is weaker than that between initial returns and the decay rate, as some countries such as The Netherlands have relatively high mean initial returns but a low standard deviation. The estimation results are displayed in Table A.3.

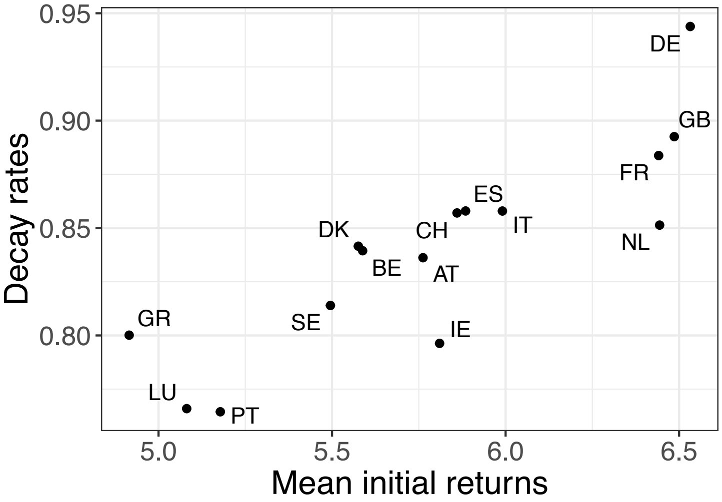


Figure 4: Mean initial return and decay rate

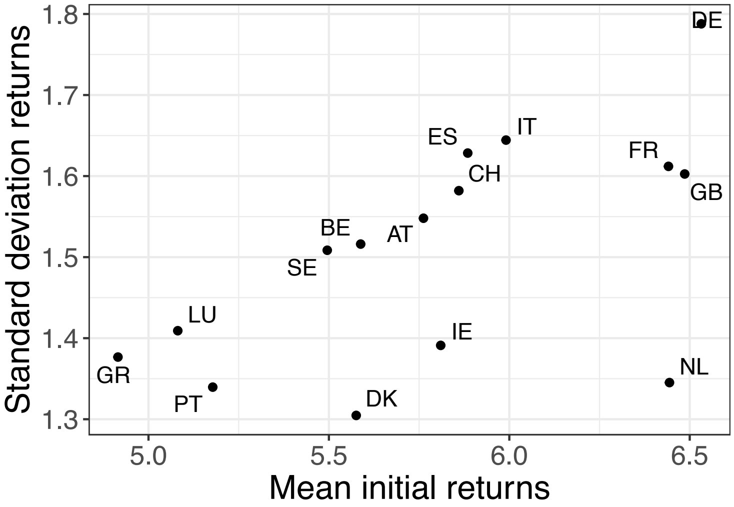


Figure 5: Mean initial return and its standard deviation

The left part of Figure 6 shows that *Family size*, forward *Citations* at 10 years and the number of *IPC classes* are positively associated with the initial returns. The coefficients can be interpreted as semi-elasticities. For instance, a one country increase in family size is associated with a 4.3% increase in the return in the first period. The coefficient for the number of *Claims* is negative.

The right part of Figure 6 shows coefficients measuring the effect of applying for a patent in the country of the applicant. In most countries, patent holders receive a higher initial return in their countries of residence: The effect is largest for German inventors. For Luxembourg and Greece, this positive association does not exist.

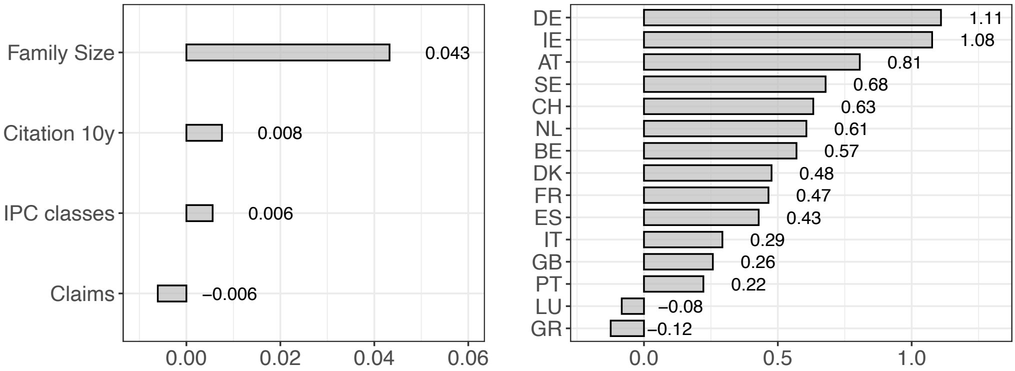
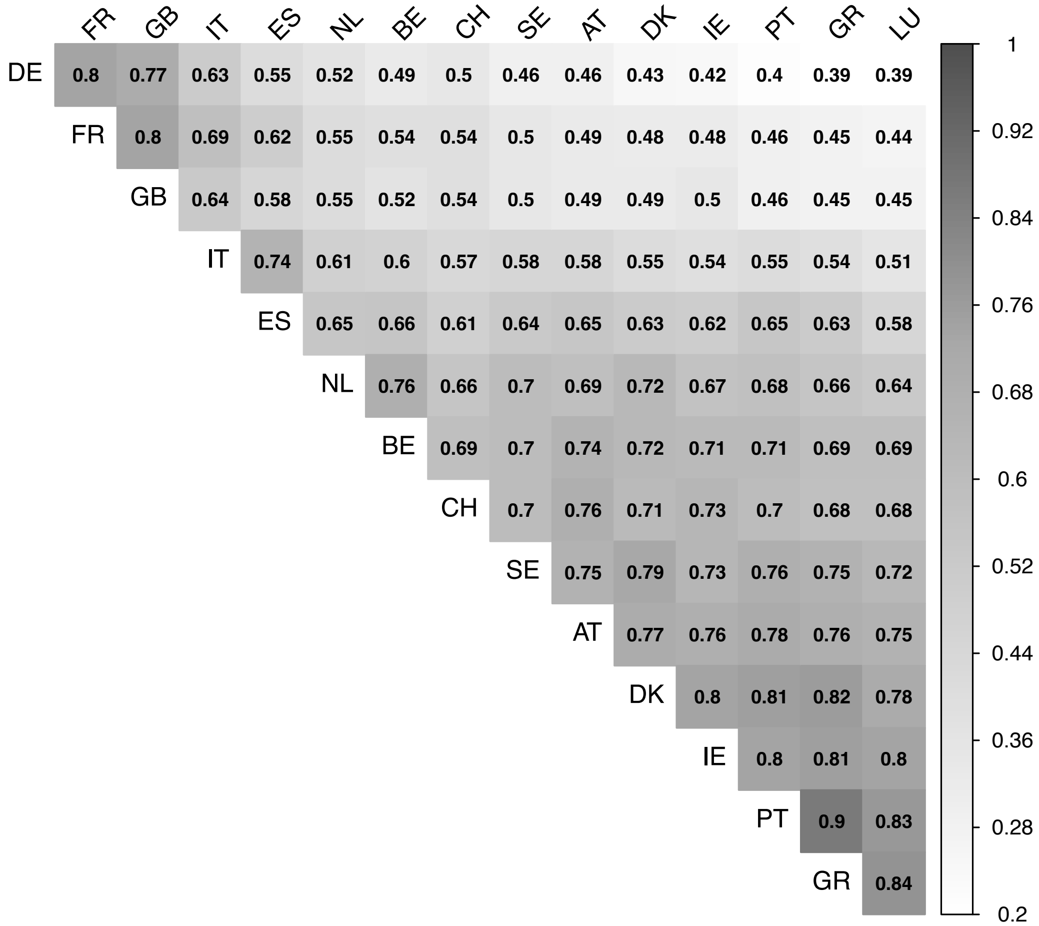


Figure 6: Coefficients for Family Size, Citation 10y, IPC classes, claims and nationality with country interaction

In Figure 7 we show the correlation of returns across countries. Prior work has either assumed that country-specific returns are uncorrelated, or that the correlation is a function of physical distance between the countries (Deng, 2011). We find that correlations are not dictated by distance alone: For example, the correlation between the returns to a given patent in Germany and Spain is higher than the correlation between the returns to the same patent in Germany and neighboring Belgium. All in all, the variation in the correlations is substantial, reaching from a high of 0.9 between Portuguese and Greek returns to a low of 0.4 between German and Luxembourgish returns.



	FR	GB	IT	ES	NL	BE	CH	SE	AT	DK	IE	PT	GR	LU
DE	0.8	0.77	0.63	0.55	0.52	0.49	0.5	0.46	0.46	0.43	0.42	0.4	0.39	0.39
FR		0.8	0.69	0.62	0.55	0.54	0.54	0.5	0.49	0.48	0.48	0.46	0.45	0.44
GB			0.64	0.58	0.55	0.52	0.54	0.5	0.49	0.49	0.5	0.46	0.45	0.45
IT				0.74	0.61	0.6	0.57	0.58	0.58	0.55	0.54	0.55	0.54	0.51
ES					0.65	0.66	0.61	0.64	0.65	0.63	0.62	0.65	0.63	0.58
NL						0.76	0.66	0.7	0.69	0.72	0.67	0.68	0.66	0.64
BE							0.69	0.7	0.74	0.72	0.71	0.71	0.69	0.69
CH								0.7	0.76	0.71	0.73	0.7	0.68	0.68
SE									0.75	0.79	0.73	0.76	0.75	0.72
AT										0.77	0.76	0.78	0.76	0.75
DK											0.8	0.81	0.82	0.78
IE												0.8	0.81	0.8
PT													0.9	0.83
GR														0.84

Figure 7: Correlation in initial value ϵ_{ij}

6 Counterfactual analysis

In this section we first present the formulae for calculating the private value of a patent in the EP and UP regimes. The counterfactual proceeds then in three steps: First, in subsection 6.2 we keep the patent quality constant and study i) what fraction of patent holders would opt for UP instead of EP, had it been available in 2000 and ii) how the gain in value is correlated with the value under EP. In the second step in subsection 6.3, we introduce a model of knowledge production which allows us to interpret the observed patent quality under EP as the outcome of profit maximization. We can then evaluate by how much the quality of the patent would have improved, had the UP regime already been in place at the time the developers of the chemical patents applied for in 2000 made their R&D investments. In subsection 6.4 we decompose the change in value to the effects of i) changed territorial scope of the patent; ii) changed duration of the patent; iii) change in renewal fees; and iv) change in patent quality. In the third step (subsection 6.5), we utilize the fact that we estimate the private value of the monopoly right to utilize the invention underlying the patent. We develop a method that allows us to estimate the consumer surplus of a given patent (in a given country-year-cell) during the period the patent is in force, and after it has been allowed to lapse.

6.1 Private value of EPs and UPs

The discounted private value of invention i under the EP regime is the discounted sum of the country-year-specific returns for all the years in a given country that the EP is renewed:

$$V_i^{EP}(R;\theta) = \sum_{j=1}^{J} \sum_{t=1}^{T_j^*} \quad \beta^{t-1}(\beta\delta_j^{t-1}R_{ij1} - C_{jt}^{EP}) \tag{6}$$

where

$$T_j^* = \max_t \quad \sum_{k=1}^{t} \beta^{k-1}(\beta\delta_j^{k-1}R_{ij1} - C_{jt}^{EP}) \ \ s.t.\ t \leq \bar{T}$$

The discounted private value of an invention i under the UP regime is calculated similarly, but now the patent covers all countries by design, and is renewed for the same number of years in each country:

$$V_i^{UP}(R;\theta) = \sum_{t=1}^{T^*} \quad \beta^{t-1}\Big(\beta\sum_{j=1}^{J}(\delta_j^{t-1}R_{ij1}) - C_t^{UP}\Big) \tag{7}$$

where

$$T^* = \max_t \quad \sum_{k=1}^{t}\beta^{k-1}(\beta\sum_{j=1}^{J}\delta_j^{k-1}R_{ij1} - C_k^{UP}) \;\; s.t.\; t \leq \bar{T}$$

As the UP is an option that the patent holder can exercise, while the EP is the default protection, the private value in the current EP and the new UP regimes are then:

$$V_i^{current}(R;\theta) = V_i^{EP} \tag{8}$$

$$V_i^{new}(R;\theta) = \max\left\{V_i^{UP}, V_i^{EP}\right\} \tag{9}$$

6.2 Private value of patents keeping patent quality constant

Using the parameter estimates, we simulate 100 times each of the 16,492 year 2000 chemical industry patents and compute the net private value under the current and new regimes while keeping patent quality constant. Figure 8 gives the mean values of EP patents by country: German patents (i.e., patents yielding protection in Germany) are the most valuable and more than twice as valuable on average as British and French patents. At the other end of the spectrum, Greek and Luxembourgish patents are on average worth less than €3,000. Using these figures, a patent taken out in all countries and having the mean value of each country would be worth over €200,000.

Figure 9 gives the mean value of EPs by country of applicant. EPs granted to applicants from Ireland, Sweden and Portugal are of higher value on average.

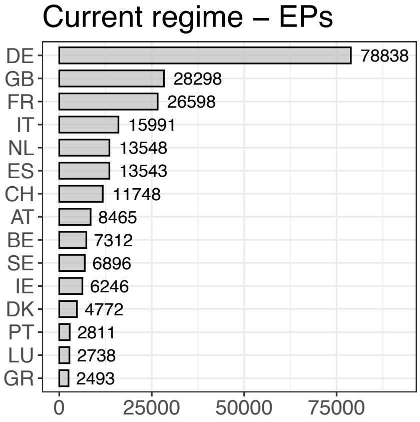


Figure 8: Mean value of EPs by country

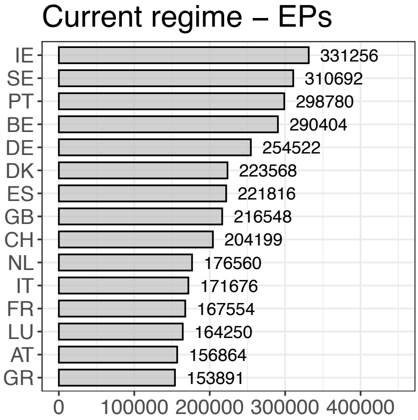


Figure 9: Mean value EPs by country of applicant

Table 3 reports key findings of our first counterfactual exercise. The mean value of a patent increases by €15,656 from the introduction of UP. Further, we see that the distribution of patent value is quite similar under EP and UP. The change in value at the 10th percentile is less than €6,000, while at the 90th percentile it is €27,000. The largest gains happen at the top of the distribution. The UP option turns out to be almost universally valuable even keeping patent quality constant as we find that only 0.1% of patent holders would prefer EP instead of UP.

Table 3: Counterfactual effects on private value of patents, keeping quality constant

Statistics	$\mathbf{V^{current}}$	$\mathbf{V^{new}_{cf1}}$	$\mathbf{V^{new}_{cf1}} - \mathbf{V^{current}}$
Q. 10 %	12,379	19,459	5,841
Q. 25 %	30,518	40,919	9,358
Median	76,900	91,880	14,435
Q. 75%	185,122	205,788	20,864
Q. 90%	407,600	432,808	27,352
Q. 95%	663,300	690,907	31,211
Q. 99%	1,838,672	1,869,236	38,006
Mean	229,659	245,306	15,656
Min	0	0	0
Max	7.2 Bn	7.2 Bn	45,263
N	1,649,200	1,649,200	1,649,200

Figure 10 shows the monetary gains from shifting to the new system given a private value of EP on the x-axis, keeping patent quality constant.

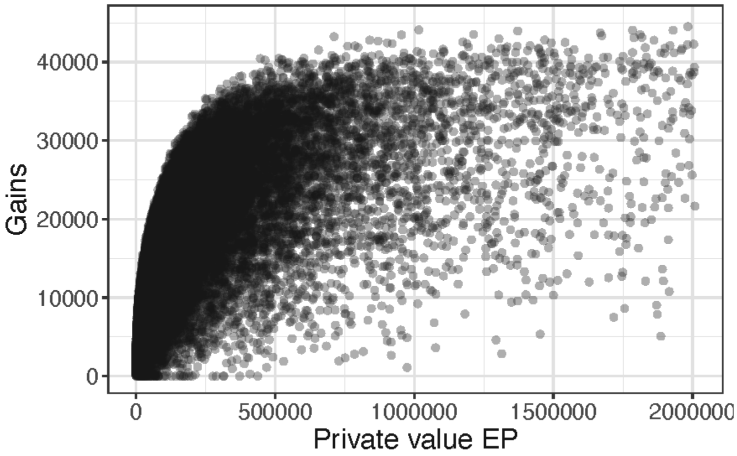


Figure 10: Gains from UP, keeping patent quality constant - Random sample of 50,000 patents

6.3 Private value of patents with endogenous patent quality

6.3.1 Patent production function

A theoretical model of patent production. The renewal decision model presented above allows us to calculate the private value of patent i under both regimes: $V_i^{current}$ and V_i^{new}. Nevertheless, the model does not take into account the effect of the new regime on the incentives to invent. In other words, V_i^{new} is computed under the assumption that the quality of the invention remains constant. To capture the change in patent quality for those patents in our data (the intensive margin), we assume that the profits V from a patent is a function of citations Y (keeping other patent characteristics constant). Each potential inventor is capable of at most one invention, and can affect the value of the invention by investing in R&D (R). The profits for an inventor are:

$$\pi = V(Y(R)) - wR - K, \tag{10}$$

where $V(.)$ is the private value or profit of patenting an invention and relates the quality of the patent Y with the private (expected discounted) value of the patent. $Y(R)$ is the knowledge production function relating a measure of patent quality (number of citations) with the level of R&D investment R, measured by the number of inventors. w is the per-unit cost of R&D and K is a fixed cost.

The first order condition for profit maximization is given by:[14]

$$\frac{\partial \pi}{\partial R} = \frac{\partial V}{\partial Y}\frac{\partial Y}{\partial R} - w = 0$$

We assume that the marginal cost of R&D is not affected by the intellectual property regime. When the inventor faces one or the other IPR regime, only $V(Y)$ changes, meaning that the following holds:

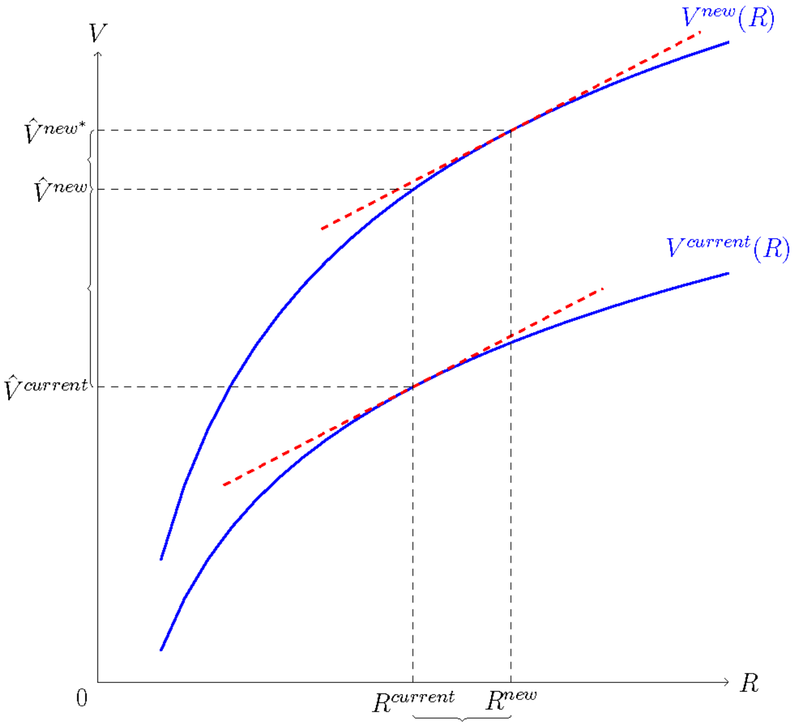
$$w = \frac{\partial V^{current}}{\partial Y}\frac{\partial Y}{\partial R} = \frac{\partial V^{new}}{\partial Y}\frac{\partial Y}{\partial R} \tag{11}$$

Equation (11) shows that at the counterfactual optimum, the inventor will equate the marginal improvement in patent value with its factual value. We depict the situation in Figure 11 where the inventor faces a situation where $V^{new}(R)$ lies everywhere above $V^{current}(R)$, and has a larger derivative w.r.t. R. In such a case, moving from the current

---

[14] The second order condition is $\frac{\partial^2 V}{\partial Y^2}\left(\frac{\partial Y}{\partial R}\right)^2 + \frac{\partial V}{\partial Y}\frac{\partial^2 Y}{\partial R^2} < 0$

to the new regime leads to higher R&D investments, higher quality, and therefore higher private value.



Quality Improvement

Figure 11: Example of quality improvement due to UP

6.3.2 Estimations of $V(Y)$ and $Y(R)$

To operationalize the above model, we project the logarithms of the value of patent i in the two regimes and onto a second order polynomial of the number of 10-year citations. We present the results in Table 4. We find that patent value is convex in the number of citations, and the parameters of the two polynomials are different from each other. This suggests indeed that inventors will adjust their R&D investments to the IPR regime they face. Figures 4 show graphically the results of the linear regressions.

Table 4: Estimation of $V^{EP}(Y)$ and $V^{UP}(Y)$

	Dependent variable:	
	$\log(V^{EP})$	$\log(V^{UP})$
	(1)	(2)
Citations	5.090×10^{-3} ***	4.587×10^{-3} ***
	(1.593×10^{-4})	(1.399×10^{-4})
Citations^2	7.419×10^{-6} ***	7.603×10^{-6} ***
	(3.204×10^{-7})	(2.814×10^{-7})
Constant	11.186***	11.415***
	(1.187×10^{-3})	(1.040×10^{-3})
Observations	1,649,134	1,649,196
R^2	0.004	0.005
Note:		$^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

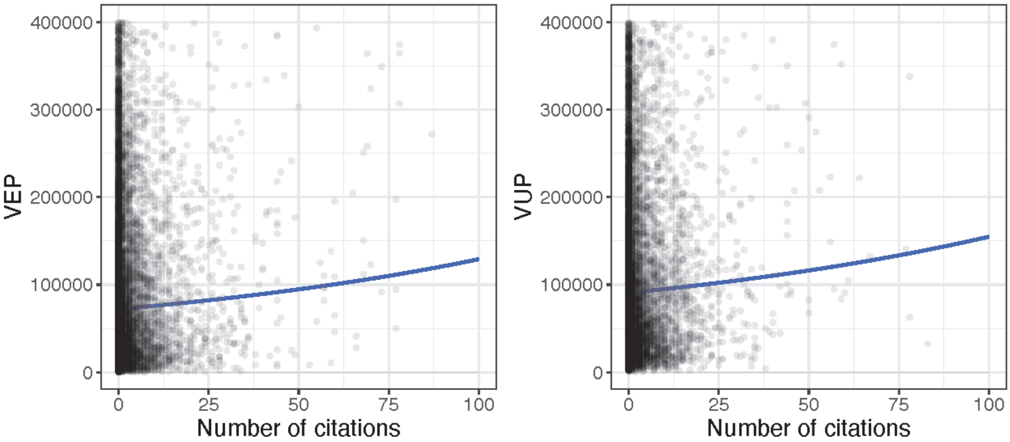


Figure 12: EP and UP private value on citations

Table 5 shows a Poisson regression where the dependent variable is the number of 10-year forward citations and the RHS variables a third order polynomial of the number of inventors. We choose a third order polynomial to ensure that the second order conditions are satisfied.

Table 5: Estimation of $Y(R)$

	Dependent variable:
	Citations
# inventors	-0.007^{***} (0.01)
# inventors^2	0.019^{***} (0.002)
# inventors^3	-0.001^{***} (0.0001)
Constant	0.902^{***} (0.017)
Observations	16,492
Note:	*p<0.1; **p<0.05; ***p<0.01

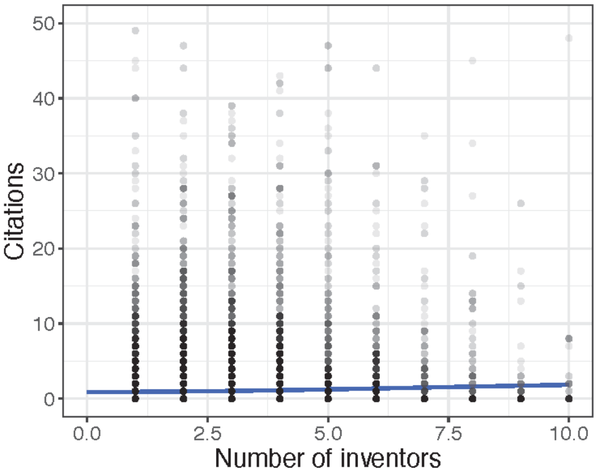


Figure 13: Projecting the number of citations on the number of inventors

Using these estimation results to numerically solve for equation (11) and then recalculating the number of citations we find that 62% of patents have an increase in the level of citations.[15]

In Figure 14 we show how the change in quality is related to the actual number of

---

[15] Our estimates suggest a decrease in patent quality for some of the remaining 38% of patents, but that is due to estimation error. In line with our theoretical model, we round these to zero.

citations (under the EP regime). It is clear that the lower the initial quality, the larger the absolute increase in quality.

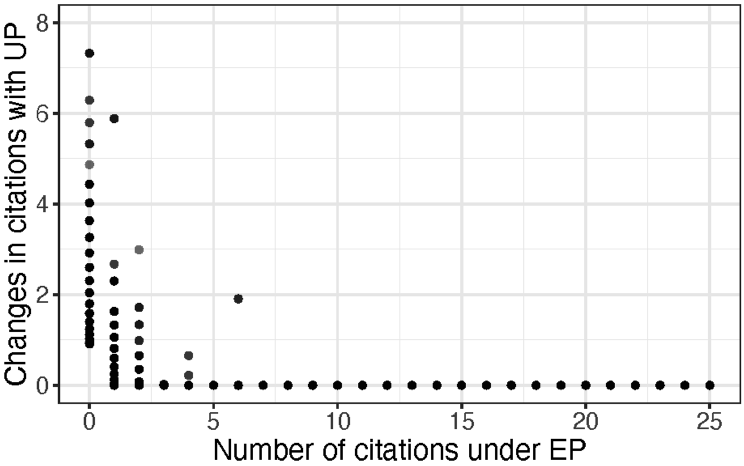


Figure 14: Change in number of citations - Random sample of 50,000 patents

6.4 Decomposition of the change in private value with endogenous quality

The introduction of UP will potentially change the scope of the patent both in terms of the number of countries that the applicant wants to cover, and the optimal length (by country) of patent protection. For some patents, in particular the most valuable ones that are taken out in all countries and renewed to the statutory maximum length, no such changes take place, but the fees needed to obtain the wanted intellectual property protection may change. Finally, as shown above, most patents would have been of higher quality had UP been in place at the time of R&D investment and this, too, will lead to a change both in the optimal patent scope and in the value of the patent. The private gain/cost of moving from EP to UP, allowing for endogenous quality of the invention, is:

$$\Delta PV = V_i^{new,cf2} - V_i^{current} = \underbrace{\sum_{j=1}^{J}\sum_{t=1}^{T_j^*} \beta^{t-1}\, C_{jt}^{EP} - \sum_{t=1}^{T^*}\beta^{t-1} C_t^{UP}}_{\text{Cost effect}} + \underbrace{\sum_{j=1}^{J}\sum_{t=T_j^*|T_j^*\neq 0}^{T^*} \beta^t R_{ij1}\delta_j^{t-1}}_{\text{Length effect}}$$
$$+ \underbrace{\sum_{j=1}^{J}\sum_{t=T_j^*|T_j^*=0}^{T^*} \beta^t R_{ij1}\delta_j^{t-1}}_{\text{Scope effect}} + \underbrace{V_i^{EP2} - V_i^{EP1}}_{\text{intensive margin}}$$

We present the decomposition results in Table 6. The first column gives information on the value of a patent under the current IPR regime, the second under the counterfactual regime where the inventors have the option of taking a UP and investing more in their invention, and the third the difference between these two. As can be seen, at all quantiles the new regime leads to more valuable patents than the old regime. The difference at the first decile is €7,000, at the median €15,000, at the third quartile €21,000 and at the ninth decile €29,000. Most of the change in value comes from savings through renewal fees at the high end of the value distribution and through a change in length at the low end of the value distribution. The effect of changing geographical scope is modest, as is the effect of changing quality.

Figure 15 shows graphically the decomposition of the different effects.

Table 6: Counterfactual effects on private value of patents, endogenous quality

Statistics	$\mathbf{V^{current}}$	$\mathbf{V_{cf2}^{new}}$	$\mathbf{V_{cf2}^{new} - V^{current}}$	**Quality**	**Cost**	**Scope**	**Length**
Q. 10 %	12,379	19,567	6,011	0	718	0	3,661
Q. 25 %	30,518	41,148	9,658	0	2,681	0	5,741
Median	76,900	92,370	14,996	208	5,893	229	7,893
Q. 75%	185,122	206,871	21,983	957	10,738	750	9,531
Q. 90%	407,600	435,120	29,457	2,468	17,606	1,326	10,695
Q. 95%	663,300	694,754	34,411	4,246	22,280	1,641	11,338
Q. 99%	1,838,672	1,880,094	46,283	12,470	31,541	2,177	12,412
Mean	229,659	246,456	16,807	1,112	7,727	452	7,514
Min	0	0	0	0	-8,341	0	-3,177
Max	7.2 Bn	7.2 Bn	2,387,274	2,348,175	45,263	3,883	15,395
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

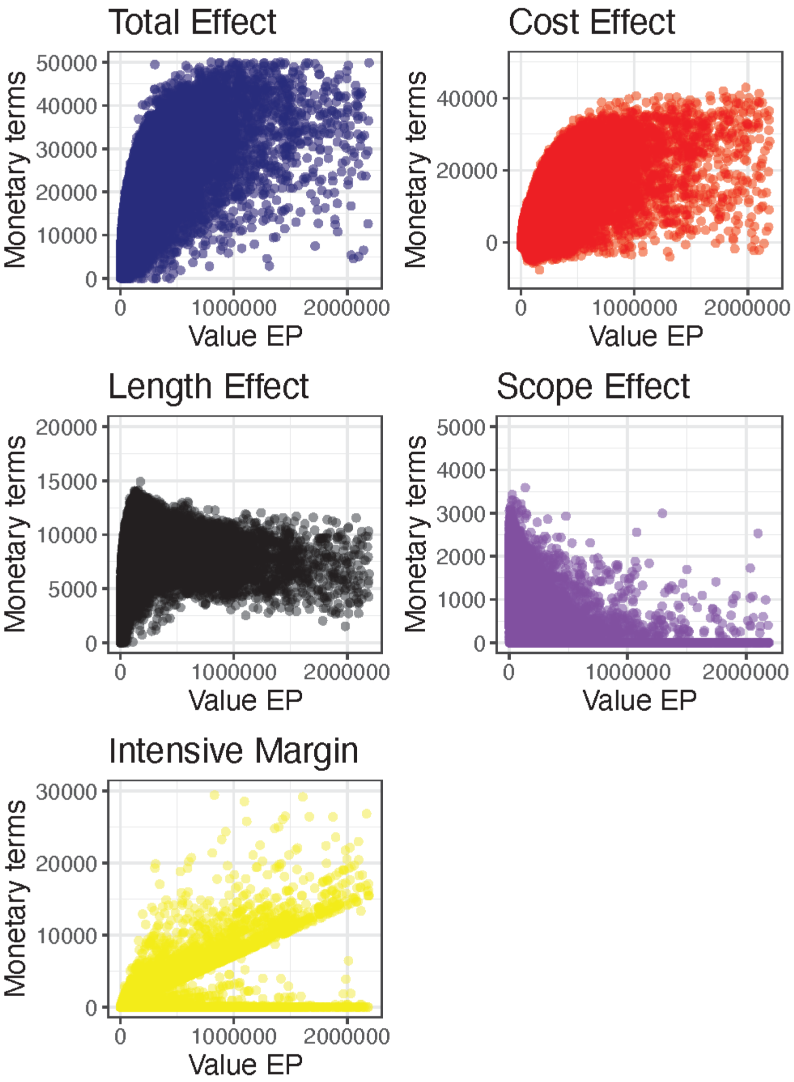


Figure 15: Gains in the second counterfactual with endogenous quality - Random sample of 50,000 patents

Figure 16 shows more specifically the gains and the decomposition of the effects by groups of patents of different value. For EPs of lower value (less than €100,000), most of the gain comes from a length effect (40-50%) and a cost effect (25%-50%). The scope effect is also non-negligible, especially for the lower tail of the distribution. For highly valuable patents, the cost effect is the main driver of the gains (more than 50%) but the quality effect is also an important dimension.

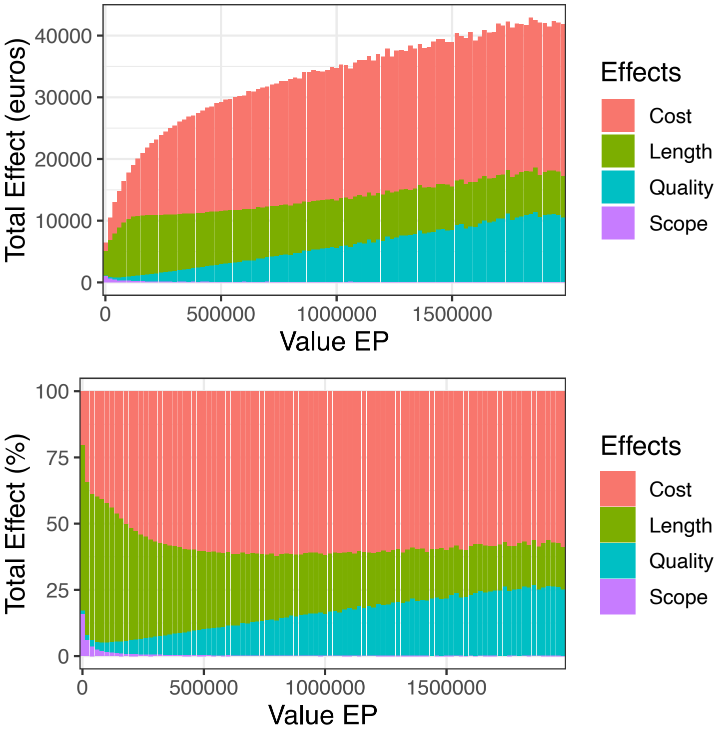


Figure 16: Gains in the second counterfactual with endogenous quality - monetary terms and percentages

6.5 From private value to social value

6.5.1 Mapping between consumer surplus and private rents

The above analysis, and the existing literature using patent renewals to infer their value, concentrate on the private value of patents. This is an obvious first step, as it potentially allows to estimate the incentive effects of a (change in) an intellectual property regime. From the point of view of planning (changes in) such regimes, one would want an estimate of the welfare effects. We now provide a welfare analysis.

Approach. Our approach is the following: Our estimates and counterfactual calculations provide us with an estimate of the (per period) monopoly profits to a given patent both in the EP and in the UP regimes. To arrive at an estimate of welfare, we need a mapping from monopoly profits to consumer surplus under monopoly for each of the periods when the patent is in force. In addition, we need an estimate of the generated welfare in the years after the patent has lapsed.

To produce the required estimates, we lean on results on ρ-linear demand functions (Anderson and Renault, 2003). We restrict our attention to ρ-linear (inverse) demand functions of the form:

$$P(Q) = A - bQ^{\rho},$$

with $\rho \in (-1, 0)$ or $\rho > 0$ (see also Spiegel, 2021). It follows directly from Corollary 1 of Anderson and Renault (2003) (as well as Corollary 1 of Spiegel, 2021) that

$$CS_M = \frac{\Pi_M}{1+\rho}, \tag{12}$$

where Π_M is the monopoly profit and CS_M the consumer surplus under monopoly. Applying Proposition 6 from Anderson and Renault (2003) to a monopoly one can show that

$$TS = \Pi_M (1+\rho)^{(1/\rho)} \tag{13}$$

where TS is total surplus, i.e., welfare under perfect competition. As an example, applying these results to the case of $\rho = 1$, i.e., linear demand, yields the familiar expressions for monopoly profit, consumer surplus under monopoly, and total surplus (with c being the constant marginal cost of production):

$$\Pi_M^{lin} = \frac{(A-c)^2}{4b} \quad ; \qquad CS_M^{lin} = \frac{(A-c)^2}{8b} = \frac{\Pi_M^{lin}}{2} \quad ; \qquad TS^{lin} = \frac{(A-c)^2}{b} = 2\Pi_M^{lin}$$

For the class of demand functions we consider, consumer surplus under monopoly is a decreasing function of ρ (keeping Π_M constant), and so is total surplus. In terms of estimating welfare, it is straight forward to apply equations (12) and (13) once a value for ρ has been determined and one has an estimate of monopoly profits. Regarding the latter, we assume that the computed private value of a patent is a correct proxy for the monopoly profit of a firm: thus the per period monopoly profits in the two regimes for invention i in country j in period t that are relevant for the calculation of consumer surplus are given by $\beta\delta_j^{t-1}R_{ij1}$ (i.e., gross of renewal fees). The patent-holder has a monopoly during the full life of the patent. Once the patent lapses, new firms enter the market and the equilibrium is characterized by perfect competition. We assume that the discount factor for profits and welfare are identical and the same we used in the estimation: $\beta = 0.95$. The consumer surplus for an invention i under EP and UP regimes is given by the following formulae respectively:

$$\begin{aligned} CS_i^{EP} &= \sum_{j=1}^{J}\sum_{t=1}^{T_j^*} \frac{1}{1+\rho}\beta^{t-1}\Pi_{ijt}^{EP} + \sum_{j=1}^{J}\sum_{t=T_j^*+1}^{+\infty} (1+\rho)^{(1/\rho)}\beta^{t-1}\Pi_{ijt}^{EP} \\ CS_i^{UP} &= \sum_{t=1}^{T^*} \frac{1}{1+\rho}\beta^{t-1}\Pi_{it}^{UP} + \sum_{t=T^*+1}^{+\infty} (1+\rho)^{(1/\rho)}\beta^{t-1}\Pi_{it}^{UP} \end{aligned}$$

The change in welfare of the new regime for a given patent i is then:

$$\begin{aligned} \Delta TW_i =& \sum_{j=1}^{J} V_{ji}^{UP} - V_i^{EP} + \sum_{j=1}^{J} CS_{ji}^{UP} - CS_i^{EP} \\ =& \Delta\text{Private Value}_i \ + \Delta\text{Consumer Surplus}_i \end{aligned}$$

To make this approach operational, a value for the demand parameter ρ is needed. As we unfortunately cannot identify it from our data. Also, as far as we know, only few reliable measures of price elasticity of demand are available in the literature for chemical products. Böcker and Finger (2017) in reviewing all works estimating the price elasticity of demand for pesticides in Europe and North America, finds a median of -0.28. Lilien and Yoon (1988) find a price elasticity for acetone between -2.48 and -1.81 during the introduction stage of the life cycle and with two different model specifications. For antibiotics, they find the price elasticity to vary between -1.23 and -0.98. Based on these scarce results, we explore more the cases $\rho = 1$ and $\rho = -1/2$ (in appendix A.5), but in our main analysis, resort to doing our welfare calculations for different values of $\rho \in \{-1/2, 1, 2\}$. $\rho = -1/2$ gives a constant elasticity demand function with a price elasticity of -2. The two other values that we apply yield a linear and a quadratic demand function; both are often used in applied work.

6.5.2 Results

Welfare calculation for different values of ρ. Results in Table 7 are based on simulations of 100 periods (=years). For values of $\rho \in \{-1/2, 1, 2, 3\}$, UP decreases consumer surplus on average by €10,000 to €13,000 per patent which is equivalent to a decrease of 2 to 9% of the consumer surplus. When ρ increases, the price elasticity of demand decreases, implying a smaller consumer surplus under the current regime. Note that the private value is unchanged and does not depend on ρ as it comes from the simulation exercise above. Following the introduction of UP, total welfare increases by €3,500 to €7,000 which is equivalent to 0.4 to 1.9% increase of total welfare.

Table 7: Welfare calculations per patent, by ρ

ρ	PV^{EP}	ΔPV	ΔPV in %	CS^{EP}	ΔCS	ΔCS in %	TW^{EP}	ΔTW	ΔTW in %
$\rho = -1/2$	229,659	16,807	+7.3%	633,499	-13,161	-2.1%	863,149	+3,645	+0.4%
$\rho = 1$	229,659	16,807	+7.3%	193,246	-11,141	-5.8%	422,896	+5,665	+1.3%
$\rho = 2$	229,659	16,807	+7.3%	142,734	-10,558	-7.4%	372,384	+6,248	+1.7%
$\rho = 3$	229,659	16,807	+7.3%	117,106	-10,182	-8.7%	346,756	+6,624	+1.9%

Linear demand case $\rho = 1$. Here we assume $\rho = 1$ (linear demand). Table 8 shows the distributions of private value (V), consumer surplus (CS), total fees collected ($Fees$) and total welfare (TW) for both the current EP regime and the new UP regime. The last column, ΔTW gives the distribution of the total gains per patent from the new system. On average, UP increases total welfare by €5,665 per patent, but reduces total welfare for at least 25% of the patents. Consumer surplus per patent decreases (€193,246 in the current system and €182,104 in the new system) as UP increases the geographical scope and patent length of most patents and thereby the number of country-period-combinations where a monopoly prevails. Interestingly, the fees collected per patent will be significantly reduced with UP. The average renewal fees collected per patent under UP are €9,675, around half the fees collected in the current EP system (€17,358). Note that our calculations do not include the external margin, i.e., new patented inventions due to UP that would generate more renewal fees. These new patented inventions could increase the total income obtained from fees as suggested by Danguy and de la Potterie (2014).[16]

A similar table (Table A.4) for $\rho = -1/2$ can be found in Appendix A.5.

---

[16] Notice though that these marginal new patents would be low value, i.e., they would be renewed for a shorter amount of time than the current least valuable patents. Thus, the extra renewal fee income generated by them is likely to be low.

Table 8: Welfare calculation ($\rho = 1$)

Statistics	$\mathbf{V^{current}}$	$\mathbf{CS^{current}}$	$\mathbf{Fees^{current}}$	$\mathbf{TW^{current}}$	$\mathbf{V^{new}_{cf2}}$	$\mathbf{CS^{new}_{cf2}}$	$\mathbf{Fee^{new}_{cf2}}$	$\mathbf{TW^{new}_{cf2}}$	$\mathbf{\Delta TW}$
	Current system (only EPs)				**New system (UPs option)**				**Difference**
Q. 10 %	12,379	31,086	6,149	43,693	19,567	23,117	4,224	42,845	-1,566
Q. 25 %	30,518	48,498	10,290	79,199	41,148	38,396	7,266	79,825	-208
Median	76,900	83,798	16,051	160,867	92,370	70,739	11,230	163,435	2,443
Q. 75%	185,122	159,989	23,037	345,503	206,871	145,981	12,718	353,191	7,397
Q. 90%	407,600	317,324	30,261	725,672	435,120	305,431	12,718	740,936	16,443
Q. 95%	663,300	502,875	34,941	1,165,461	694,754	492,800	12,718	1,186,715	23,597
Q. 99%	1,838,672	1,386,920	44,207	3,222,940	1,880,094	1,383,328	12,718	3,261,837	43,839
Mean	229,659	193,246	17,358	422,896	246,456	182,104	9,675	428,561	5,665
Min	0	1,503	0	2,552	0	1,504	0	1,514	-10,197
Max	7.2 Bn	6.7 Bn	57,981	13.9 Bn	7.2 Bn	6.7 Bn	12,718	13.9 Bn	4,530,529
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

In Figure 17, we decompose the average effect per patent by country. The upper-left corner shows on the x-axis the discounted sum of renewal fees collected from an average EP in the current regime, decomposed by country where the patent is in force. The y-axis shows the average percentage change in renewal fees collected. To allocate the total renewal fee income received from UPs among national patent offices, we use the assumption of distribution key according to the GDP considered by Danguy and de la Potterie (2014) as the most legitimate and easy to implement. Therefore, the share of UP fees are allocated to the NPOs based on the size of their economy (GDP). It is clear that most patent offices would be worst off as the renewal fee income will decrease. With this key distribution assumption, smaller NPOs (and smaller economies) such as Luxembourg, Denmark or Austria would be strongly affected whereas larger countries such as Italy or France would see an increase or a somewhat smaller decrease in revenues.

The upper-right corner of Figure 17 shows on the x-axis the total private value by nationality of the applicants and the average percentage gain on the y-axis. Applicants from Austria, Luxembourg, France, Italy and the Netherlands will have higher relative gains in terms of private value (around +10%) but also tend to have lower average total private value for their inventions (See also Figure 9). On the other hand, applicants from Ireland, Sweden, Portugal or Belgium who tend to have the highest private value for EP on average will have lower relative gains from the new system (around 6%).

The lower-left corner of Figure 17 shows the effect of UP on the consumer surplus for the countries where the patents are in force. In all countries (except 'other' which is mainly US and Japan, for which there are no effects), consumer surplus decreases. In France, Great Britain and Germany, the effects of the new system on consumer surplus smallest (less than 5%). The reason is that the EPs tend to be validated and renewed for longer periods in these countries and therefore, the UP will affect the renewal and validation decisions in these countries only marginally. On the other side, smaller countries such as Denmark, Greece or Luxembourg will larger consumer surplus decreases (18-24% reduction).

The lower-right corner of Figure 17 shows the total welfare effect (private value and consumer surplus) for all countries; these lie between 1 and 2%.

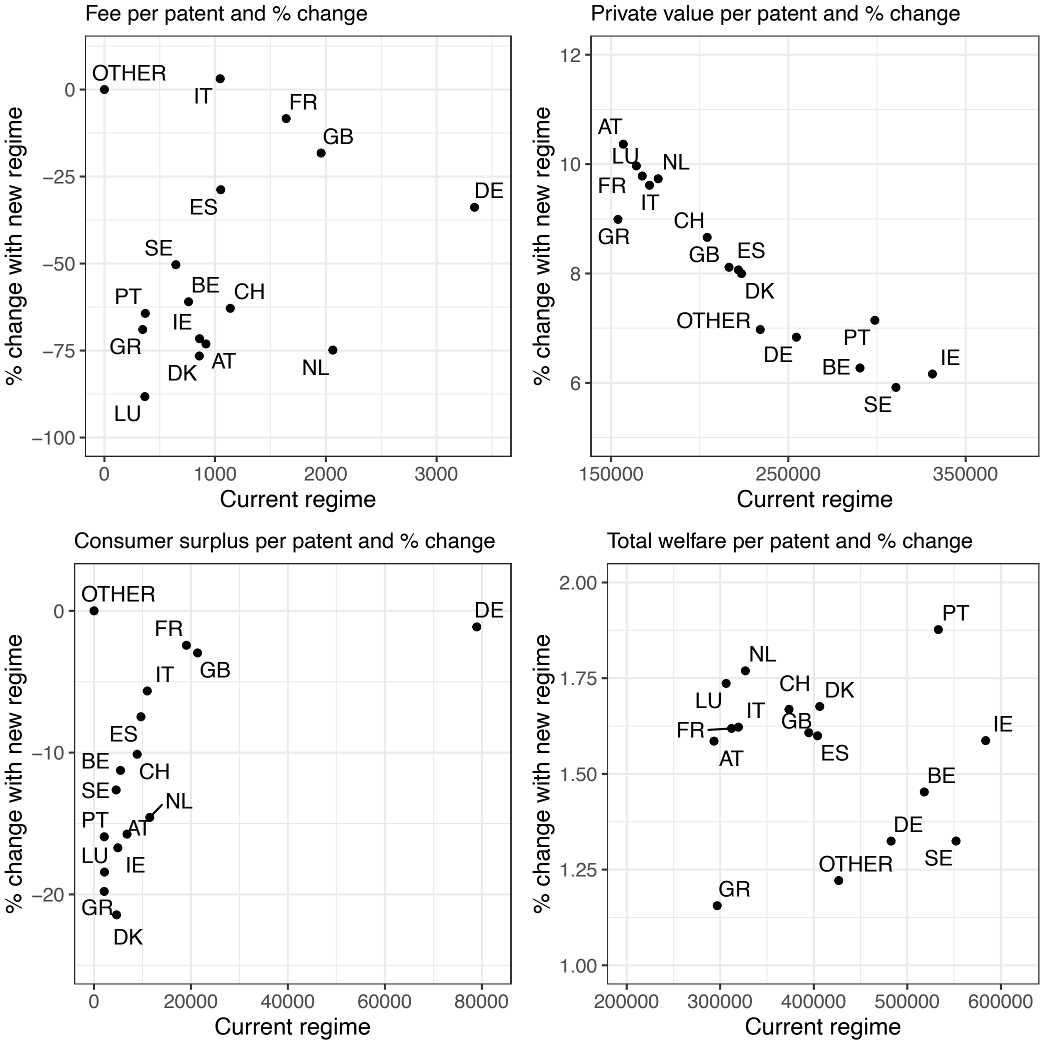


Figure 17: Effects of UP decomposed by country ($\rho = 1$)

Table 9 shows the total welfare in millions and relative to the population in 2000. Change in total welfare varies from €1.2M in Greece to €1,653M in Germany and €3,604M in the group “other countries”. The total welfare change is particularly large for other countries because a significant proportion of patents are applied for by applicants from other countries (mainly the US and Japan, see Figure A.1). Relative to population, the welfare effects are highest in Switzerland, Luxembourg and Germany. The introduction of UP has a marginal effect on welfare per capita.

Table 9: Total welfare in both regimes, in €M and by population

	$TW^{current}$	TW^{new}	$TW^{current}$/pop	TW^{new}/pop
DE	1,653	1,675	20.16	20.43
GB	321	326	5.49	5.58
FR	373	379	6.34	6.44
IT	123	125	2.13	2.17
NL	167	170	10.27	10.45
ES	32	32	0.74	0.75
SE	171	173	18.93	19.18
CH	255	259	35.18	35.77
BE	113	115	10.81	10.97
AT	37	37	4.48	4.55
DK	77	78	14.14	14.38
LU	16	16	34.26	34.85
GR	1.2	1.2	0.11	0.11
PT	3.7	3.8	0.36	0.36
IE	26	26	6.19	6.29
OTHER	3,604	3,649		

7 Conclusion

We provide an ex-ante evaluation of the forthcoming introduction of the so-called unitary patent in Europe. Europe moves a big step towards a truly European patent system with this change. UP offers inventors the option of obtaining a patent which, as long as it is renewed, offers European-wide intellectual property protection. However, the system continues to offer the current possibility of obtaining a collection of national patents (the "European Patent"). These can be individually and separately renewed or allowed to lapse, offering thereby more flexibility to the inventor at the cost of higher renewal fees.

We extend the existing research on the value of European patents by estimating a patent renewal model that allows for free correlation of value across country-pairs. We use the estimated parameters to study whether inventors of chemical patents, applied for in 2000, would have taken up the possibility of a Unitary Patent instead of the then available European Patent. We find that the vast majority would have done so.

We find that the average private value of European Patents, summed up over all countries, is €229,659. The country-specific values are positively correlated, with correlations ranging from a low of 0.3 to a high of 0.8.

We then extend the literature by a adding a patent production function to the renewal model to study how much the quality of the existing EP patents would have increased, had UP been available in 2000. The average private value of these patents would have increased by €16,807. The vast majority of this comes from reduced renewal fees and increased duration of the patent, with increased geographical scope and improved quality both accounting for a small share.

As our final exercise, we study the welfare implications of the introduction of UP and, as a side product, a welfare evaluation of the current EP-based patent protection. We find that the total welfare increases by 0.4 to 1.9% on average which corresponds to €3,645 to €6,624 depending on the assumptions on the demand (ρ). This modest welfare increase hides a transfer of surplus from consumers to the inventors. In relative terms, Austrian, Luxembourgish, Dutch, French and Italian inventors gain the most while Danish, Greek, Irish and Luxembourgish consumers lose the most. Portugal and The Netherlands gain the most overall in relative terms.

References

Anderson, Simon P., and Regis Renault. 2003. “Efficiency and surplus bounds in Cournot competition.” *Journal of Economic Theory*, 113: 253–264.

Baudry, Marc, and Beatrice Dumont. 2006. “Patent renewals as options: improving the mechanism for weeding out lousy patents.” *Review of Industrial Organization*, 28(1): 41–62.

Besag, Julian. 1975. “Statistical analysis of non-lattice data.” *Journal of the Royal Statistical Society: Series D (The Statistician)*, 24(3): 179–195.

Bessen, James. 2008. “The value of US patents by owner and patent characteristics.” *Research Policy*, 37(5): 932–945.

Bessen, James, and Eric Maskin. 2009. “Sequential innovation, patents, and imitation.” *The RAND Journal of Economics*, 40(4): 611–635.

Bessen, James, and Robert M Hunt. 2007. “An empirical look at software patents.” *Journal of Economics & Management Strategy*, 16(1): 157–189.

Bhat, Chandra R, Cristiano Varin, and Nazneen Ferdous. 2010. “A comparison of the maximum simulated likelihood and composite marginal likelihood estimation approaches in the context of the multivariate ordered-response model.” In *Maximum Simulated Likelihood Methods and Applications*. 65–106. Emerald Group Publishing Limited.

Bilir, L Kamran, Petra Moser, and Irina Talis. 2011. “Do treaties encourage technology transfer? Evidence from the Paris convention.” *Wisconsin University Working Papers*, 20(11): 2014.

Böcker, Thomas G, and Robert Finger. 2017. “A meta-analysis on the elasticity of demand for pesticides.” *Journal of Agricultural Economics*, 68(2): 518–533.

Budish, Eric, Ben Roin, and Heidi Williams. 2015. “Do firms underinvest in long-term research? Evidence from cancer clinical trials.” *The American Economic Review*, 105(7): 2044–2485.

Choi, Jay-Pil, and Heiko Gerlach. 2019. “A Theory of Patent Portfolios.” *American Economic Journal: Microeconomics*, 9(1): 315–351.

Cohen, WM, RR Nelson, and PP Walsh. 2000. “Protecting their intellectual assets: Appropriability conditions and why US manufacturing firms patent (or not).” National Bureau of Economic Research 7552.

Cornelli, Fransesca, and Mark Schankerman. 1999. “Patent renewals and R&D incentives.” *The RAND Journal of Economics*, 30(2): 197–213.

Danguy, Jérôme, and Bruno van Pottelsberghe de la Potterie. 2011. “Cost-benefit analysis of the community patent.” *Journal of Benefit-Cost Analysis*, 2(2): 1–43.

Danguy, Jérôme, and Bruno van Pottelsberghe de la Potterie. 2014. “The policy dilemma of the unitary patent.” Bruegel Working Paper.

Deng, Yi. 2007*a*. “The effects of patent regime changes: A case study of the European patent office.” *International Journal of Industrial Organization*, 25(1): 121–138.

Deng, Yi. 2007*b*. “Private value of European patents.” *European Economic Review*, 51(7): 1785–1812.

Deng, Yi. 2011. “A dynamic stochastic analysis of international patent application and renewal processes.” *International Journal of Industrial Organization*, 29(6): 766–777.

De Rassenfosse, Gaetan, and Bruno van Pottelsberghe de la Potterie. 2013. “The role of fees in patent systems: Theory and evidence.” *Journal of Economic Surveys*, 27(4): 696–716.

Galasso, Albert, and Mark Schankerman. 2015. “Patents and cumulative innovation: Causal evidence from the courts.” *Quarterly Journal of Economics*, 130(1): 317–369.

Gambardella, Alfonso, Dietmar Harhoff, and Bart Verspagen. 2008. “The value of European patents.” *European Management Review*, 5(2): 69–84.

Green, Jerry, and Suzanne Scotchmer. 1995. “On the division of profit in sequential innovation.” *The RAND Journal of Economics*, 26(1): 20–33.

Guellec, Dominique, and Bruno Van Pottelsberghe de la Potterie. 2007. *The Economics of the European Patent System: IP Policy for Innovation and Competition.* Oxford University Press on Demand.

Hall, Bronwyn H, and Christian Helmers. 2019. “The impact of international patent systems: Evidence from accession to the European Patent Convention.” *Research Policy*, 48(9): 103810.

Harhoff, Dietmar, Karin Hoisl, Bettina Reichl, and Bruno van Pottelsberghe de la Potterie. 2009. “Patent validation at the country level: The role of fees and translation costs.” *Research Policy*, 38(9): 1423–1437.

Helpman, Elhanan. 1993. “Innovation, Imitation, and Intellectual Property Rights.” *Econometrica*, 61(6): 1247–80.

Hunt, Robert M. 2006. “Economics and the design of patent systems.” *Mich. Telecomm. & Tech. L. Rev.*, 13: 457.

Lai, Edwin L-C, and Larry D Qiu. 2003. “The North’s intellectual property rights standard for the South?” *Journal of International Economics*, 59(1): 183–209.

Lanjouw, Jean O, and Iain M Cockburn. 2001. “New pills for poor people? Empirical evidence after GATT.” *World Development*, 29(2): 265–289.

Lanjouw, Jean O, and Mark Schankerman. 2001. “Characteristics of Patent Litigation: A Window on Competition.” *The RAND Journal of Economics*, 32(1): 129—151.

Lanjouw, Jean O, and Mark Schankerman. 2004. “Patent quality and research productivity: Measuring innovation with multiple indicators.” *The Economic Journal*, 114(495): 441–465.

Lanjouw, Jean Olson. 1998. “Patent protection in the shadow of infringement: Simulation estimations of patent value.” *Review of Economic Studies*, 65(4): 671–710.

Lazaridis, George, and Bruno van Pottelsberghe de la Potterie. 2007. “The rigour of EPO’s patentability criteria: An insight into the induced withdrawals.” *World Patent Information*, 29(4): 317–326.

Lerner, Josh. 2002. “150 years of patent protection.” *The American Economic Review*, 92(2): 221–225.

Lerner, Joshua. 1994. “The importance of patent scope: An empirical analysis.” *The RAND Journal of Economics*, 319–333.

Levin, RC, AK Klevorick, RR Nelson, and SG Winter. 1987. “Appropriating the returns from industrial research and development.” *Brookings Papers on Economic Activity*, 1987(3): 783–831.

Lilien, Gary L, and Eunsang Yoon. 1988. “An exploratory analysis of the dynamic behavior of price elasticity over the product life cycle: An empirical analysis of industrial chemical products.” *Issues in pricing*, 261–87.

Lindsay, Bruce G. 1988. “Composite likelihood methods.” *Contemporary Mathematics*, 80(1): 221–239.

Mansfield, Edwin. 1986. “Patents and innovation: An empirical study.” *Management Science*, 32(2): 173–181.

Marco, Alan C, Joshua D Sarnoff, and AW Charles. 2019. “Patent claims and patent scope.” *Research Policy*, 48(9): 103790.

McCalman, Phillip. 2001. “Reaping what you sow: An empirical analysis of international patent harmonization.” *Journal of International Economics*, 55(1): 161–186.

Moser, Petra. 2005. “How do patent laws influence innovation? Evidence from nineteenth-century world’s fairs.” *The American Economic Review*, 95(4): 1214–1236.

Moser, Petra. 2021. “Pirates and Patents.”

Mullahy, John. 2016. “Estimation of multivariate probit models via bivariate probit.” *The Stata Journal*, 16(1): 37–51.

Og, Joo Young, Krzysztof Pawelec, Byung-Keun Kim, Rafal Paprocki, and EuiSeob Jeong. 2020. “Measuring patent value indicators with patent renewal information.” *Journal of Open Innovation: Technology, Market, and Complexity*, 6(1): 16.

Pakes, Ariel. 1986. “Patents as Options: Some Estimates of the Value of Holding European Patent Stocks.” *Econometrica*, 54(4): 755–784.

Pakes, Ariel, and Mark Schankerman. 1979. “The rate of obsolescence of knowledge, research gestation lags, and the private rate of return to research resources.”

Pakes, Ariel, and Mark Schankerman. 1984. “The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources.” In *R&D, patents, and productivity.* 73–88. University of Chicago Press.

Paleti, Rajesh, and Chandra R Bhat. 2013. “The composite marginal likelihood (CML) estimation of panel ordered-response models.” *Journal of Choice Modelling*, 7: 24–43.

Plomer, Aurora. 2020. “The Unified Patent Court and the Transformation of the European Patent System.” *International Review of Intellectual Property and Competition Law volume.*

Putnam, Jonathan. 1996. “The value of international patent protection.” *Unpublished Ph. D. Dissertation, Yale University.*

Qian, Yi. 2007. “Do national patent laws stimulate domestic innovation in a global patenting environment? A cross-country analysis of pharmaceutical patent protection, 1978–2002.” *Review of Economics and Statistics*, 89(3): 436–453.

Sakakibara, Mariko, and Lee Branstetter. 2001. “Do stronger patents induce more innovation? Evidence from the 1988 Japanese patent law reforms.” *RAND Journal of Economics*, 32(1): 77–100.

Sampat, Bhaven, and Heidi Williams. 2019. “How Do Patents Affect Follow-on Innovation? Evidence from the Human Genome.” *The American Economic Review*, 109(1): 203–236.

Schankerman, Mark. 1998. “How valuable is patent protection? Estimates by technology field.” *The RAND Journal of Economics*, 77–107.

Schankerman, Mark, and Ariel Pakes. 1986*a*. “Estimates of the value of patent rights in European countries during the post-1950.” *Economic Journal*, 96(384).

Schankerman, Mark, and Ariel Pakes. 1986*b*. “Estimates of the value of patent rights in European countries during the post-1950 period.” *Economic Journal*, 96: 1052.

Schmoch, Ulrich. 2008. “Concept of a Technology Classification for Country Comparisons.” World Intellectual Property Organisation (WIPO).

Schuett, Florian, and Mark Schankerman. 2021. “Patent Screening, Innovation, and Welfare.” *Review of Economic Studies*, forthcoming.

Serrano, Carlos J. 2018. “Estimating the gains from trade in the market for patent rights.” *International Economic Review*, 59(4): 1877–1904.

Spiegel, Yossi. 2021. "The Herfindahl-Hirschman Index and the Distribution of Social Surplus." *The Journal of Industrial Economics*, 69(3): 561–594.

Sullivan, Richard J. 1994. "Estimates of the value of patent rights in Great Britain and Ireland, 1852-1876." *Economica*, 37–58.

Todd, Petra, and Kenneth Wolpin. 2006. "Assessing the Impact of a School Subsidy Program in Mexico: Using a Social Experiment to Validate a Dynamic Behavioral Model of Child Schooling and Fertility." *The American Economic Review*, 96(5): 1384–1417.

Trajtenberg, Manuel. 1990. "A penny for your quotes: Patent citations and the value of innovations." *The RAND Journal of Economics*, 172–187.

van Pottelsberghe de la Potterie, Bruno, and Didier François. 2009. "The cost factor in patent systems." *Journal of Industry, Competition and Trade*, 9(4): 329–355.

Varin, Cristiano, Nancy Reid, and David Firth. 2011. "An overview of composite likelihood methods." *Statistica Sinica*, 5–42.

von Graevenitz, Georg, and Antanina Garanasvili. 2018. "The European Patent System: A Descriptive Analysis." *Centre for Globalisation Research.*

Wang, Changtao. 2012. "Estimating the value of patent rights in Australia." *School of Economics, UNSW, SyAustralia.*

Williams, Heidi. 2017. "How Do Patents Affect Research Investments?" *Annual Review of Economics*, 9: 441–469.

A.1 Renewal fees European Patent

All fees are expressed in euros 2010. See Table A.1.

A.2 Renewal and validation rates

Validation and renewal data are available in Table A.2.

---

[16] Note that a 15% reduction in the renewal fees are available for patent holders who file a statement on a licence of right with the EPO

Table A.1: Renewal fees in EUR 2010

Countries/Year	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**13th**	**14th**	**15th**	**16th**	**17th**	**18th**	**19th**	**20th**
Austria (AT)	78	87	113	121	166	209	297	366	445	559	628	698	1021	1283	1396	1746	2095	2095
Belgium (BE)	37	55	74	92	111	135	160	184	209	233	270	307	350	393	436	485	534	584
Denmark (DK)	82	180	204	229	261	294	335	375	416	457	498	539	588	637	686	735	784	833
France (FR)	38	44	61	121	150	180	209	239	270	303	340	380	424	472	523	578	637	699
Germany (DE)	82	82	106	153	211	282	341	411	552	728	893	1069	1245	1445	1657	1868	2068	2279
Greece (GR)	50	64	75	98	117	137	159	187	215	257	299	338	380	450	500	548	601	660
Ireland (IE)	75	112	142	167	187	220	242	275	302	331	356	388	418	444	477	509	547	584
Italy (IT)	39	45	58	84	116	161	193	226	322	451	516	580	709	709	709	709	709	709
Luxembourg (LU)	38	48	61	77	96	116	135	153	169	188	208	227	247	266	286	305	325	351
Netherlands (NL)	269	311	353	392	434	491	547	603	645	687	729	785	897	953	995	1037	1093	1135
Portugal (PT)	43	53	67	75	85	96	107	117	128	142	160	178	196	214	231	255	285	313
Spain (ES)	26	33	63	92	124	153	184	214	259	305	350	395	440	502	561	622	682	742
Sweden (SE)	45	64	77	96	115	134	153	185	217	249	281	313	345	383	421	460	498	536
Switzerland (CH)	75	89	105	119	149	178	208	252	297	343	402	460	521	595	670	744	892	1041
Great Britain (GB)	-	-	101	141	182	222	262	303	343	383	424	464	504	545	605	666	726	807

Table A.2: Survival rates and validation rate in per cent

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Validation (%)
DE	99.9	99.2	97.2	93.9	89.5	84.5	78.5	72.1	65.6	60.1	54.9	49.6	44.4	39.3	34.3	29.7	24.6	89.1
GB	99.7	98.2	94.7	90	84.6	79	72.6	66.1	59.5	53.8	48.7	43.6	38.7	33.9	29.6	25.6	21.3	82.8
FR	99.9	98.4	95	90.2	84.9	79.2	72.8	66.3	60.1	54.5	49.3	44.2	39.1	34.4	29.9	25.9	21.5	82.4
IT	99.3	94.6	87.4	80.5	72.9	66.1	59.6	53.2	46.7	40.8	35.8	31.6	27.6	24	20.7	17.6	14.6	59.9
NL	99.2	94.1	84.3	72.9	62	53	45.6	39.3	34	29.5	25.8	22.5	19.4	16.8	14.5	12.3	10.2	45.1
ES	99.5	94.9	86.3	76	66.6	58.4	51.2	44.8	39.1	34.3	29.8	26.3	23	19.9	17.2	14.6	12.2	52.1
SE	99.1	92.2	80.1	66.7	54.7	45.3	37.9	32	26.9	22.8	19.5	16.6	14.3	12.1	10.4	8.8	7.2	33.5
CH	99.2	93.2	82.2	70	58.9	50.3	43.2	37.4	32.5	28.1	24.5	21.4	18.5	16	13.8	11.8	9.8	42.3
BE	99.3	93.5	83.1	71	59.8	50.8	43.5	37.2	31.7	27.4	23.5	20.3	17.4	15	12.8	10.9	9.1	41.6
AT	99.2	92.5	80.4	67	54.8	45.3	37.8	31.8	26.6	22.6	19.1	16.2	13.8	11.8	10.1	8.5	7	33.5
DK	99	91.1	77.7	63.1	50.6	41	33.8	28.2	23.4	19.7	16.7	14.3	12.2	10.5	9	7.6	6.3	27.9
LU	98.8	89.9	75.2	59.5	46	36	28.8	23.3	18.6	15.2	12.5	10.3	8.7	7.3	6.1	5.1	4.2	20.8
GR	98.8	90.1	75.6	60.1	46.8	37	29.6	24.2	19.5	15.9	13.2	11	9.3	7.9	6.6	5.5	4.5	21.5
PT	98.9	90.5	76.5	61.4	48.4	38.6	31.3	25.7	21	17.4	14.5	12.1	10.3	8.7	7.3	6.1	5.1	23.7
IE	98.9	90.9	77.6	63.3	51.1	41.9	34.8	29.2	24.6	20.7	17.6	15	12.8	11	9.3	7.9	6.6	29.8

A.3 Nationality of applicants

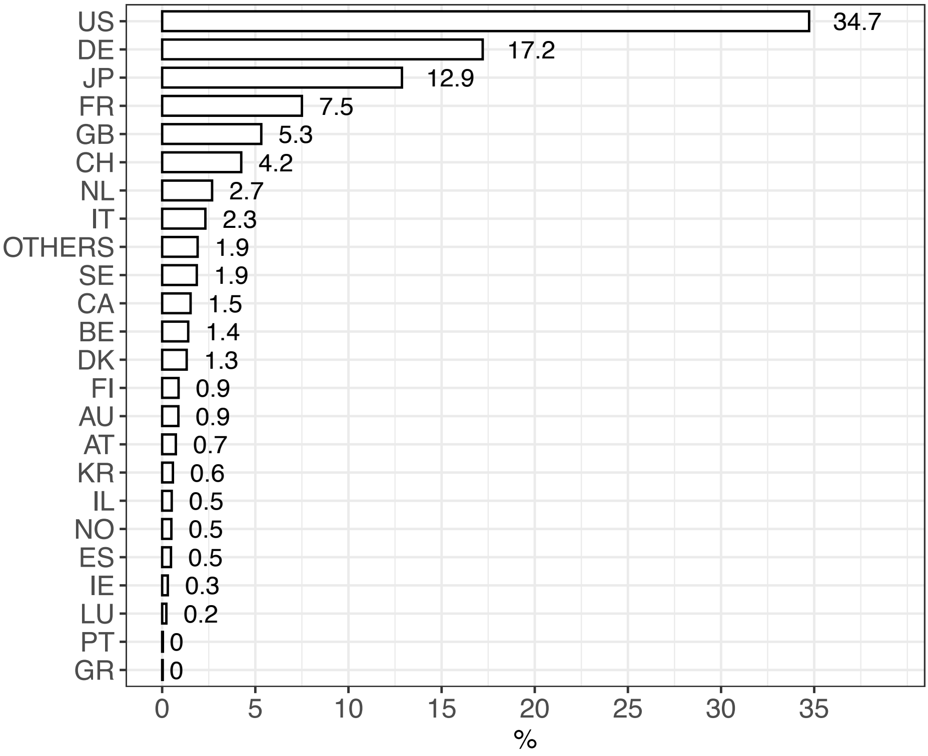


Figure A.1: Nationality of applicants - per cent

A.4 Estimates renewal model

Table A.3: Parameter estimates and standard errors

Param.	Estimates	Param.	Estimates	Param.	Estimates	Param.	Estimates
μ_{DE}	6.5321 (0.0641)	δ_{PT}	0.7644 (0.0009)	$r_{GB/DK}$	0.4900 (0.0855)	$r_{ES/LU}$	0.5840 (0.1235)
μ_{GB}	6.4861 (0.0568)	δ_{IE}	0.7963 (0.0043)	$r_{GB/LU}$	0.4451 (0.0592)	$r_{ES/GR}$	0.6264 (0.1561)
μ_{FR}	6.4411 (0.0280)	$\gamma_{FamSize}$	0.0432 (0.0006)	$r_{GB/GR}$	0.4511 (0.0703)	$r_{ES/PT}$	0.6496 (0.1412)
μ_{IT}	5.9909 (0.0248)	$\gamma_{Citations}$	0.0076 (0.0007)	$r_{GB/PT}$	0.4597 (0.0747)	$r_{ES/IE}$	0.6160 (0.1009)
μ_{NL}	6.4439 (0.0199)	γ_{IPC}	0.0056 (0.0005)	$r_{GB/IE}$	0.5033 (0.0738)	$r_{SE/CH}$	0.6958 (0.1706)
μ_{ES}	5.8848 (0.0298)	γ_{Claims}	-0.0061 (0.0005)	$r_{FR/IT}$	0.6880 (0.1223)	$r_{SE/BE}$	0.6995 (0.1948)
μ_{SE}	5.4954 (0.0417)	γ_{DE}	1.1095 (0.1024)	$r_{FR/NL}$	0.5528 (0.0026)	$r_{SE/AT}$	0.7540 (0.1842)
μ_{CH}	5.8602 (0.0471)	γ_{GB}	0.2573 (0.0638)	$r_{FR/ES}$	0.6153 (0.0532)	$r_{SE/DK}$	0.7889 (0.2011)
μ_{BE}	5.5881 (0.0420)	γ_{FR}	0.465 (0.0485)	$r_{FR/SE}$	0.5037 (0.1413)	$r_{SE/LU}$	0.7236 (0.1339)
μ_{AT}	5.7621 (0.0389)	γ_{IT}	0.2929 (0.0589)	$r_{FR/CH}$	0.5357 (0.0918)	$r_{SE/GR}$	0.7486 (0.2134)
μ_{DK}	5.5757 (0.0209)	γ_{NL}	0.6067 (0.0461)	$r_{FR/BE}$	0.5397 (0.0952)	$r_{SE/PT}$	0.7629 (0.1229)
μ_{LU}	5.0812 (0.0027)	γ_{ES}	0.4285 (0.0790)	$r_{FR/AT}$	0.4904 (0.1003)	$r_{SE/IE}$	0.7304 (0.1483)
μ_{GR}	4.9154 (0.0260)	γ_{SE}	0.6785 (0.0381)	$r_{FR/DK}$	0.4785 (0.0702)	$r_{CH/BE}$	0.6875 (0.1770)
μ_{PT}	5.1781 (0.0009)	γ_{CH}	0.6324 (0.0476)	$r_{FR/LU}$	0.4378 (0.0608)	$r_{CH/AT}$	0.7559 (0.1728)
μ_{IE}	5.8099 (0.0178)	γ_{BE}	0.5697 (0.0702)	$r_{FR/GR}$	0.4477 (0.0656)	$r_{CH/DK}$	0.7113 (0.1923)
σ_{DE}	1.7879 (0.0228)	γ_{AT}	0.8061 (0.0464)	$r_{FR/PT}$	0.4589 (0.0745)	$r_{CH/LU}$	0.6834 (0.1359)
σ_{GB}	1.6026 (0.0272)	γ_{DK}	0.4766 (0.0351)	$r_{FR/IE}$	0.4792 (0.0699)	$r_{CH/GR}$	0.6837 (0.1759)
σ_{FR}	1.6120 (0.0127)	γ_{LU}	-0.0831 (0.0500)	$r_{IT/NL}$	0.6113 (0.0991)	$r_{CH/PT}$	0.6951 (0.1409)
σ_{IT}	1.6444 (0.0493)	γ_{GR}	-0.1243 (0.2448)	$r_{IT/ES}$	0.7432 (0.1497)	$r_{CH/IE}$	0.7281 (0.0941)
σ_{NL}	1.3452 (0.0066)	γ_{PT}	0.2219 (0.2536)	$r_{IT/SE}$	0.5826 (0.1682)	$r_{BE/AT}$	0.7375 (0.1946)
σ_{ES}	1.6284 (0.0084)	γ_{IE}	1.0764 (0.0557)	$r_{IT/CH}$	0.5744 (0.1575)	$r_{BE/DK}$	0.7162 (0.2011)
σ_{SE}	1.5085 (0.0165)	$r_{DE/GB}$	0.7723 (0.0485)	$r_{IT/BE}$	0.6012 (0.1718)	$r_{BE/LU}$	0.6872 (0.1415)
σ_{CH}	1.5820 (0.0149)	$r_{DE/FR}$	0.8041 (0.0712)	$r_{IT/AT}$	0.5815 (0.1664)	$r_{BE/GR}$	0.6894 (0.1840)
σ_{BE}	1.5161 (0.0076)	$r_{DE/IT}$	0.6315 (0.1556)	$r_{IT/DK}$	0.5509 (0.1217)	$r_{BE/PT}$	0.7071 (0.1310)
σ_{AT}	1.5480 (0.0426)	$r_{DE/NL}$	0.5164 (0.2026)	$r_{IT/LU}$	0.5102 (0.1084)	$r_{BE/IE}$	0.7057 (0.1148)
σ_{DK}	1.3047 (0.0093)	$r_{DE/ES}$	0.5486 (0.3125)	$r_{IT/GR}$	0.5375 (0.1070)	$r_{AT/DK}$	0.7652 (0.2174)
σ_{LU}	1.4092 (0.0004)	$r_{DE/SE}$	0.4552 (0.0878)	$r_{IT/PT}$	0.5548 (0.1161)	$r_{AT/LU}$	0.7456 (0.1512)
σ_{GR}	1.3767 (0.0085)	$r_{DE/CH}$	0.4977 (0.1038)	$r_{IT/IE}$	0.5438 (0.0935)	$r_{AT/GR}$	0.7624 (0.2318)
σ_{PT}	1.3396 (0.0007)	$r_{DE/BE}$	0.4935 (0.0804)	$r_{NL/ES}$	0.6533 (0.0691)	$r_{AT/PT}$	0.7808 (0.1456)
σ_{IE}	1.3911 (0.0130)	$r_{DE/AT}$	0.4594 (0.1638)	$r_{NL/SE}$	0.6965 (0.1351)	$r_{AT/IE}$	0.7551 (0.1314)
δ_{DE}	0.9438 (0.0022)	$r_{DE/DK}$	0.4278 (0.0440)	$r_{NL/CH}$	0.6565 (0.1153)	$r_{DK/LU}$	0.7778 (0.1054)
δ_{GB}	0.8926 (0.0020)	$r_{DE/LU}$	0.3858 (0.0628)	$r_{NL/BE}$	0.7618 (0.0415)	$r_{DK/GR}$	0.8184 (0.1693)
δ_{FR}	0.8837 (0.0021)	$r_{DE/GR}$	0.3896 (0.0451)	$r_{NL/AT}$	0.6924 (0.1149)	$r_{DK/PT}$	0.8145 (0.1061)
δ_{IT}	0.8579 (0.0059)	$r_{DE/PT}$	0.4009 (0.0665)	$r_{NL/DK}$	0.7182 (0.1135)	$r_{DK/IE}$	0.7979 (0.1750)
δ_{NL}	0.8514 (0.0015)	$r_{DE/IE}$	0.4225 (0.0537)	$r_{NL/LU}$	0.6371 (0.1298)	$r_{LU/GR}$	0.8449 (0.0936)
δ_{ES}	0.8580 (0.0024)	$r_{GB/FR}$	0.7963 (0.0412)	$r_{NL/GR}$	0.6585 (0.0934)	$r_{LU/PT}$	0.8252 (0.0018)
δ_{SE}	0.8139 (0.0029)	$r_{GB/IT}$	0.6416 (0.0462)	$r_{NL/PT}$	0.6780 (0.1300)	$r_{LU/IE}$	0.7953 (0.0384)
δ_{CH}	0.8570 (0.0022)	$r_{GB/NL}$	0.5499 (0.0190)	$r_{NL/IE}$	0.6677 (0.0505)	$r_{GR/PT}$	0.8973 (0.0736)
δ_{BE}	0.8394 (0.0039)	$r_{GB/ES}$	0.5796 (0.0328)	$r_{ES/SE}$	0.6384 (0.1739)	$r_{GR/IE}$	0.8123 (0.0396)
δ_{AT}	0.8362 (0.0022)	$r_{GB/SE}$	0.5048 (0.1530)	$r_{ES/CH}$	0.6089 (0.1694)	$r_{PT/IE}$	0.8032 (0.0849)
δ_{DK}	0.8415 (0.0027)	$r_{GB/CH}$	0.5363 (0.0823)	$r_{ES/BE}$	0.6639 (0.1615)		
δ_{LU}	0.7659 (0.0006)	$r_{GB/BE}$	0.5209 (0.0907)	$r_{ES/AT}$	0.6475 (0.1903)		
δ_{GR}	0.8001 (0.0034)	$r_{GB/AT}$	0.4859 (0.1007)	$r_{ES/DK}$	0.6285 (0.1517)		

Note: Std. Err in parentheses

A.5 Welfare calculation $\rho = -1/2$

Table A.4: Welfare calculation ($\rho = -0.5$)

Statistics	$\mathbf{V^{current}}$	$\mathbf{CS^{current}}$	$\mathbf{Fees^{current}}$	$\mathbf{TW^{current}}$	$\mathbf{V_{cf2}^{new}}$	$\mathbf{CS_{cf2}^{new}}$	$\mathbf{Fee_{cf2}^{new}}$	$\mathbf{TW_{cf2}^{new}}$	$\mathbf{\Delta TW}$
	Current system (only EPs)				**New system (UPs option)**				**Difference**
Q. 10 %	12,379	81,160	6,149	93,706	19,567	70,630	4,224	90,342	-4,350
Q. 25 %	30,518	138,393	10,290	169,032	41,148	125,376	7,266	166,673	-3,097
Median	76,900	261,728	16,051	338,718	92,370	245,128	11,230	337,681	-964
Q. 75%	185,122	529,291	23,037	714,514	206,871	512,187	12,718	1,494,591	4,116
Q. 90%	407,600	1,071,963	30,261	1,479,960	435,120	1,059,570	12,718	2,386,142	15,357
Q. 95%	663,300	1,699,777	34,941	2,362,558	694,754	1,691,821	12,718	2,386,142	25,385
Q. 99%	1,838,672	4,638,663	44,207	6,481,369	1,880,094	4,653,082	12,718	6,536,392	60,051
Mean	229,659	633,499	17,358	863,149	246,456	620,338	9,675	866,795	3,645
Min	0	3,007	0	3,007	0	3,028	0	3,028	-14,033
Max	7.2 Bn	20.6 Bn	57,981	20.6 Bn	7.2 Bn	20.6 Bn	12,718	27.9 Bn	9,028,926
N	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200	1,649,200

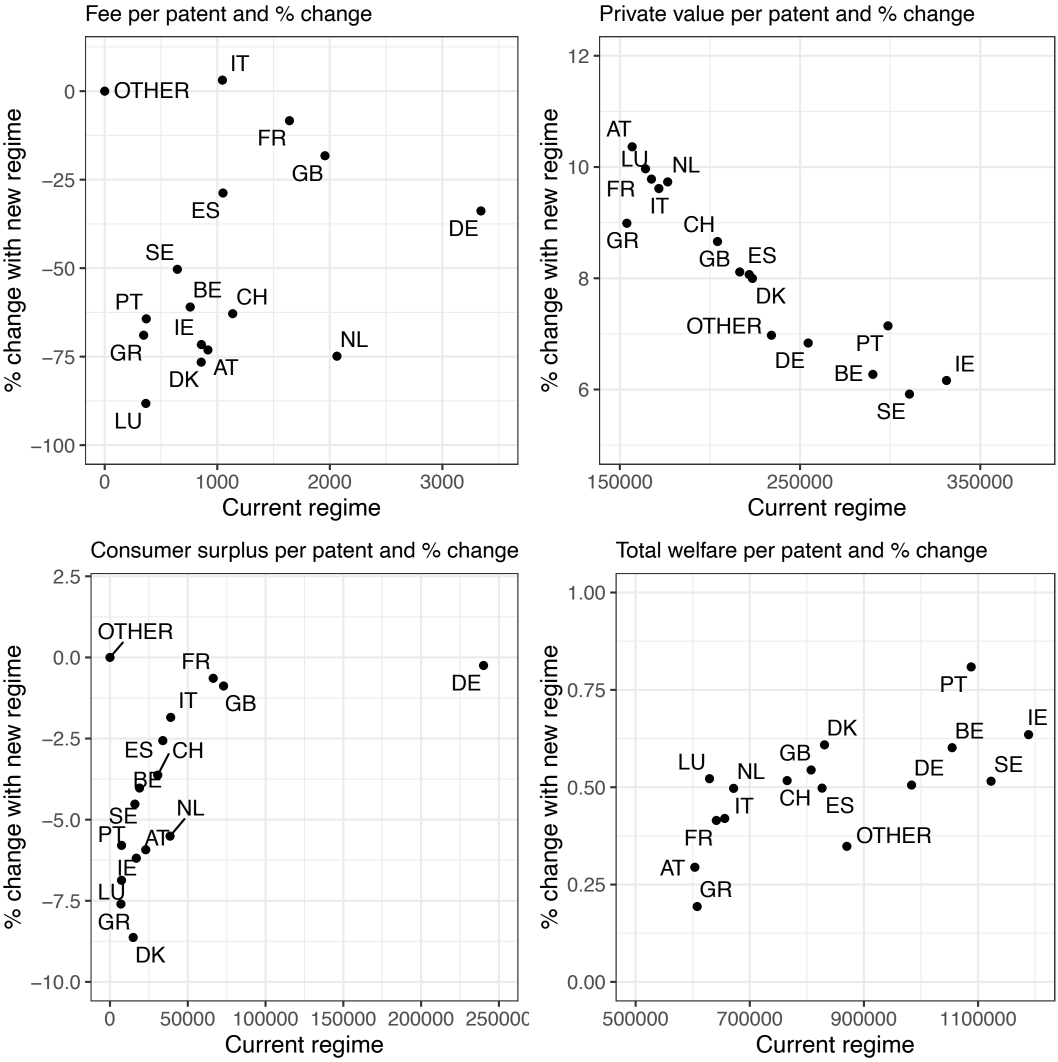


Figure A.2: Effects of the UPs decomposed by country ($\rho = -1/2$)

Table A.5: Total Welfare (in M € and by population) in both regimes ($\rho = -1/2$)

	$TW^{current}$	TW^{new}	$TW^{current}$/pop	TW^{new}/pop
DE	3,369	3,386	41.08	41.29
GB	657	660	11.23	11.29
FR	767	770	13.02	13.07
IT	253	254	4.38	4.40
NL	344	346	21.10	21.20
ES	65	66	1.52	1.52
SE	348	350	38.50	38.70
CH	523	525	72.09	72.46
BE	231	232	22.01	22.14
AT	75	76	9.22	9.24
DK	157	158	28.92	29.09
LU	33	33	70.39	70.76
GR	2.4	2.4	0.22	0.22
PT	7.6	7.7	0.73	0.74
IE	52	53	12.61	12.69
OTHER	7,352	7,377		

Alexis Stevenson

Essays on the Economics of Patent Rights: Measuring the value of patents using renewal information

This dissertation is a collection of three empirical essays in the fields of industrial organization and economics of innovation. The first two essays build on the literature of patent renewal models to develop new methods to estimate the value of patent rights. The third essay provides a counterfactual analysis of an important institutional change in the European patent system, the introduction of the Unitary patent.

The first essay measures the private value of patents granted to companies in Finland between 1990 and 2000 using a dynamic stochastic model of patent renewal decisions. In this model, a patent owner decides to renew a patent for each period as long as the expected returns from the patent exceed the renewal costs. The renewal decisions are then used to infer the distribution of private value of patents. This essay contributes to the existing literature by decomposing the private value of patents by technological field and by providing an estimate of the returns to R&D for Finnish companies.

The second essay provides estimates of the private value of patents granted in Germany in the field of semiconductors. This essay contributes both to the literature on renewal decision models and the link between patent value and citations. Indeed, the model includes the possibility for patent holders to learn about the value of their invention with citations received across time. This extended framework allows the dynamic link between forward patent citations and patent value to be investigated in a counterfactual exercise. Additionally, patent-level predicted grant probabilities are computed, applying machine learning algorithms on the text of patent abstracts in order to model the pre-grant renewal decisions.

The third essay – a joint work with Otto Toivanen and Tuomas Takalo – estimates the private value of European patents in the chemical industry and analyzes the incentive and welfare effects of introducing the Unitary patent. This major institutional change implies that inventors will save on legal and translation costs and will face a single schedule of renewal fees instead of multiple national renewal fee schedules, which is the current situation with European patents. To evaluate the expected effects of the Unitary patent option, we build a three-part model combining: i) A patent renewal model, ii) a patent production function linking the level of R&D to the quality and the private value and (iii) a mapping between private value and consumer surplus. The counterfactual analysis provides key insights on the effect of the Unitary patent on the private value of patents, consumer surplus in Europe as well as on income for national patent offices.

HANKEN SCHOOL OF ECONOMICS

HELSINKI
ARKADIANKATU 22, P.O. BOX 479,
00101 HELSINKI, FINLAND
PHONE: +358 (0)29 431 331

VAASA
KIRJASTONKATU 16, P.O. BOX 287,
65101 VAASA, FINLAND
PHONE: +358 (0)6 3533 700

BIBLIOTEKET@HANKEN.FI
HANKEN.FI/DHANKEN

ISBN 978-952-232-466-5 (PRINTED)
ISBN 978-952-232-467-2 (PDF)
ISSN-L 0424-7256
ISSN 0424-7256 (PRINTED)
ISSN 2242-699X (PDF)

HANSAPRINT OY, TURENKI