PATENT VALUATION, INTERNATIONAL INTELLECTUAL PROPERTY RIGHTS AND INNOVATION

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To my teachers and professors who helped me grow in knowledge.

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ABSTRACT

My research addresses three questions. The first is, does the value of a patent depend on its family size and composition? In the literature on technological change, patents are the most widely used intangible rights to proxy for innovation. However, there is a consensus among innovation economists that the current valuation methods (patent count, citations, renewals, etc.) have limitations. With Walter Park, I create and test the robustness of a patent valuation method, termed "family size and composition patent valuation method," and I hypothesize that the value of patents depends both on the number of the legal jurisdictions where patents are protected and on the market size of the countries that constitute those jurisdictions. We use renewal data, as independent confirmation data, to help demonstrate the predictive accuracy of this method in determining the likelihood of patent renewal and patent survival.

Given these results to the first question, the second question investigates the impact of Intellectual Property Rights (IPR) on the flow of valuable knowledge capital and on technology gaps, using the new “family size and composition patent valuation method.” The chapter develops and estimates a model of international patenting and

Total Factor Productivity (TFP) behavior. I find that IPR protection positively impacts the flow of local innovation and the diffusion of valuable knowledge and TFP. Using the citation method of valuing patents tends to underestimate the impact of IPR on the diffusion of valuable innovation.

The third question focuses on the impact of IPR on innovation and technology transfer in Africa. The study investigates whether stronger patent rights protection pushes out the frontiers of technology by favoring the emergence and flow of valuable innovation. I find that stronger IPR protection favors the generation of important innovation as well as the diffusion of valuable technology. Moreover, the impact of local innovation is larger in magnitude than the impact on technology diffusion. This suggests that previous results were likely driven by proxies used for innovation. Further IPR-related data collection and a cautious strengthening of IPR to foster the generation of valuable knowledge capital in Africa are the implications for policy.

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CHAPTER 1

RATIONALE FOR THE RESEARCH

The Topic and Related Questions

The topic of my research is patent valuation and the impact of IPR on valuable innovation. Three questions constitute the object of my research. First, do family size and composition determine patent value? Technological change is often proxied by patents. However, there is no controversy about the fact that the numerical count of the number of patents is a patent portfolio valuation method that has its limitations. One of the main weaknesses of the alternative, existing methods, such as citations and litigations valuation methods, is that they can largely value patents only ex-post. The new patent valuation method that we[1] are developing addresses those limitations. To show the robustness of our method we check the correlation between patent value as estimated by our method and the probability of patent renewal and patent survival. We show that more valuable patents, according to our new patent valuation method, are more likely to be renewed and survive than patents deemed valuable according to the citation method.

[1] The chapter referred to is chapter II of this dissertation and is a joint work with the chair of my dissertation committee, Professor Walter Park.

The second question stems from the results of the first one. I investigate whether the impact of Intellectual Property Rights (IPR) on the generation and diffusion of *valuable* knowledge capital and on total factor productivity (TFP) is positive. This question addresses an empirical issue along the lines of the study by Xu and Chiang (2005) on international patenting. The point of my study is to check the correlation between IPR and valuable knowledge capital, at the country level, as estimated according to two different patent valuation methods: the family size and composition patent valuation method and the citation method.

The third question asks what the impact of IPR on innovation and technology transfer is, on developing economies, in general, and on Africa, in particular. I investigate whether stronger patent protection favors the generation of valuable technological innovation and whether stronger IPR protection helps African countries attract valuable international technology transfers. The first question of my research on patent valuation is therefore the building block of the second and third questions that investigate the impact of IPR. I am not, indeed, only interested in testing whether stronger IPR increase patenting per se. Beyond the quantitative aspect of its impact on patenting, I am mostly interested in whether stronger IPR favor the emergence and flow of valuable, or marginal, innovation and to what extent IPR drives total factor productivity up.

Rationale for the Research

Why a New Patent Valuation Method?

The literature on innovation and technological transfer often refers to patents as evidence of technological progress and innovation. However, since some innovations are minor while others are major, it is widely admitted that simple counts of patents does not convey the quality of the innovation and technological dynamism of a firm or a nation. This raises the question of how to value a patent.

Since the pioneering work of Pakes (1986), Griliches (1990) and Harhoff et al. (2003), many economists have investigated different ways of valuating patents. Two main ideas have dominated the patent valuation literature so far. The first idea pioneered by Putnam (1996) focused on family size as an indicator of patent value. The second idea posited by Harhoff et al. (2003), Hall et al. (2005) suggests the use of family size, oppositions, and citations as measures of the importance of a firm's patent portfolio. The firm's patent portfolio, in turn, is measured by the stock market valuation of the firm's stocks. Many other important studies looked at patent right renewals as evidence of the importance of a patent. Indeed, the rights to more valuable innovations are renewed regularly until the statutory duration is reached, while the rights to less valuable ones are allowed to lapse.

However, an evaluation of the aforementioned valuation methods shows that such approaches present some limits that our new method addresses. Indeed, given those methods, one can only judge patent values ex-post, and for older technologies, for the simple reason that enough time has to elapse in order to observe citations, opposition and renewal behavior. As for patent counts, it is obvious that some inventions are minor while others are major so that a simple patent count does not convey the proper quality of a firm's or nation's stock of knowledge and innovations.

Thus, an alternative approach that we propose is to examine the size and composition of a patent family. It is costly to patent both at home and abroad, thus, only more valuable innovations tend to be patented in several jurisdictions. Therefore, the expected value of q patentable innovation should be correlated with its family size. Moreover, the composition should matter in terms of whether or not the family includes the U.S., Japan, Europe, and other blocs of countries ranked in term of market size. This is, instead of simply counting the number of countries covered by a patent, weight the countries by their market size.

As mentioned earlier, valuable patents, typically, tend to be renewed and non-valuable patents are likely to expire fast. We therefore use renewal data as an independent criterion to determine if our new method indeed helps discriminate between valuable and marginal innovations. To do so, we check the correlation between patent value, the likelihood of being renewed, and survival rates, according to our new valuation method and according to the citation method.

Why Study the Impact of IPR on Valuable Knowledge Capital and Total Factor Productivity?

Empirical research confirmed the positive correlation between IPR and the generation and accumulation of knowledge both at firm and country level. However, it is reasonable to assume that those results depend largely on the proxies used for innovation. Most research used patent counts as proxy for the value of patent portfolio.

Xu and Chiang (2005) studied the impact of IPR on technology diffusion and find a positive correlation. My study therefore aims at investigating to what extent the estimated impacts of IPR on innovation and technology diffusion are sensitive to the proxy used for innovation and for technology diffusion. I find that the citation method tends to underestimate the impact of IPR on the accumulation and diffusion of valuable knowledge capital, as well as on technology gaps as proxied by levels of TFP.

To estimate the extent to which innovation gaps can be attributed to weak and divergent patent protection levels across countries, two issues need to be addressed: (i) the extent to which patenting activity is sensitive to levels of patent protection; (ii) the extent to which innovation is related to domestic TFP. The underlying assumption is that domestic TFP depends on both domestic and foreign patent knowledge spillovers. The extent to which stronger patent rights stimulate international patenting, coupled with the extent to which patentable ideas contribute to TFP, together determine the effects of patent rights on TFP.

On the Need and Importance to Study the Impact of IPR on Innovation and Technology Diffusion in Africa

Theoretical research on the impact of IPR on innovation in developing countries provide, so far, mixed and conflicting predictions as will be made more explicit below. The real impact of IPR on innovation can therefore be estimated, at least partially, based on empirical findings. Consequently, at least three reasons justify my current study of the impact of IPR on innovation and technology transfer.

(i) First, considering the different and conflicting results mentioned above, empirical studies focused on developing countries in general, and on Africa in particular, would help assess the impact of IPR on innovation and technology transfer in this part of the world. (ii) Second, most studies on the impact of IPR on innovation use either count data method, utilizing patent, trademark, utility model applications, or publications. The results of such studies are likely to be driven by the proxy used for innovation and technology diffusion. (iii) Third, another puzzle justifies the current study. It is often assumed that knowledge is non-rival. If so, why do poor countries not appropriate that publicly available knowledge to boost their growth? This is where theoretical predictions about the impact of IPR on generation of knowledge can be tested by empirical data. The results of my current study suggest that intellectual property protection has a positive impact on both local innovation and technology transfer. Moreover, the impact on the generation of local innovation is stronger in magnitude than the impact on technology transfer. Such results provide relevant policy implication as to how to tailor innovation policies that could help African countries catch up and get closer to the world wide technological frontiers.

To investigate the main questions raised in my dissertation, I conduct my study in three steps that constitute the next three chapters of my dissertation. The second chapter develops and tests a theoretical model for patent valuation based on a classical knowledge production function. Chapter three investigates the impact of IPR on the generation and diffusion of new and valuable knowledge capital and on total factor productivity (TFP). The forth chapter builds on the two previous chapters to test the impact of intellectual property on the generation of valuable innovation and technology transfer, as proxied by patents weighted by their family size and composition. Chapter four provides concluding remarks of the study.

CHAPTER 2

THE FAMILY SIZE AND COMPOSITION PATENT VALUATION METHOD[2]

Patent counts are used as a proxy for innovation in most empirical research on innovation as shown in Griliches' (1990) survey on patent statistics as economic indicators. However, although count data method and citation method are widely used in the literature, there is a consensus that these methods have limitations that will be discussed below. In this chapter, we develop a new patent valuation method, "the family size and composition patent valuation method" which addresses the limitations of previous patent valuation methods, and predicts patent renewal and survival.

The rationale of our method is that it is costly to patent both at home and abroad; thus value should correlate with family size. Moreover, the composition should matter in terms of whether the family of the patent includes large blocs such as the U.S.A., Japan, Europe, and other blocs, ranked in terms of market size and cost of patenting. That is, instead of simply counting the number of countries covered by a patent, we weight the countries by their market size. We take into account not only the size (the number of legal jurisdictions where patents are protected), but also the composition of the patent family (the market size of the countries that constitute these jurisdictions).

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[2] This chapter is a joint work with Walter Park.

The novel valuation approach, that we are developing consists, therefore, in examining the size and composition of a patent family, where a patent family3 is a set of patents, filed in different countries (or patent authorities), to protect the same invention. The European Patent Office (EPO, henceforth) defines patent family as a group of patent filings that claim the priority of a single filing, including the original priority forming filing itself and any subsequent filings made throughout the world. However, in an attempt to consolidate patent documents, the OECD defines it as a set of patents taken out in various countries to protect a single invention (Hingley and Park (2003)).

A priority patent is a document issued by a patent office that gives, an inventor/applicant, the exclusive property right to an invention, and allows him to file other applications, usually within 12 months to protect the invention in other countries. Ownership of patents is based on either first-to-invent or first-to-file criteria. The U.S Patent and Trade Office (USPTO), which had been working on the first-to-invent principle, has just switched, in 2011, to the first-to-file principle. In that regards, the date of application of a patent is of substantial importance.

In this chapter, we review prior attempts to address the issue of patent value in the literature in section 2. In section 3, we highlight the limitations of those attempts. Section 4 is dedicated to the construction of the family size and composition patent valuation method. Section 5 provides empirical support for the new valuation method. More precisely, we use renewal data as benchmark to discuss its robustness as compared to the citation method. Concluding remarks are provided in section 6.

[3] Technical terms and notions are defined the first time they are used. In addition, the appendix, at the end of the chapter, provides a set of definitions of intellectual property related terms.

Literature Review on Patent Valuation

Estimating the value of a patent is a great challenge due to the skewed distribution of observed patent values. Numerous authors including Scherer (1965), Schankerman and Pakes (1985), Pakes (1986), and Griliches (1990) addressed the issue of the distribution of patent value. In particular, Scherer (1997) showed that the top 8.5 % of the patents comprised 80% of total patent value, i.e., little is worth lots and lots is worth little. Although they often overlap, there are many studies that investigated what makes the value of a patent. These studies include research on patent renewal, oppositions, patent families and studies that emphasize patent citations, patent counts, patent scope, licensing, number of priorities, references to patent literature and citations received. Patent renewal is the keeping of a patent in force, by paying the renewal (maintenance) fees at the patent office, so as to prevent the patent from lapsing. A patent citation is a reference made by a patent to another patent that embodies relevant prior art, and which may have contributed to narrowing the claim of the original application. A citation may be made by the inventor or the examiner during the examination process. Technical journals or textbooks, i.e., "non-patent literature" may be cited. The vast literature on patent value could be separated in two parts: the non-citation and citation literature.

The Quest for the "True" Value of a Patent

Prior to discussing how in the literature, research is striving to assess the value of patents, it is worth investigating what the "true" value of a patent should be. First of all, as an intangible asset, whatever the value of a patent is, it depends on the capacity to enforce the rights the patent secures. Second, on the theoretical ground, the "true" value of a patent cannot be easily determined, as one need to wait until the patent expires in order to assess the value of the patent, based on commercial success or failure. Barney (2002), in his study of patent survival rates, provides a comprehensive overview of what the value of a patent could be. The income valuation approach considers that the value of a patent depends on the income streams (licenses, royalties…), received for a patent. The market valuation approach considers the market value of the patent portfolio as reflective of the values of a patent.

Another way to think about the "true value" of the patent is to investigate what an applicant would have earned without the patent, i.e., what is the counterfactual of patenting? Could the opportunity cost of patenting be taken into account, as an "implicit cost" of patenting? We assume that the decision to patent stems from the optimization of the applicant. If an applicant chooses to patent their invention, this reveals that the expected benefit of patenting is higher than the cost of patenting. In that regards, cost of patenting includes, and is not only limited to, the patenting fees. The cost of patenting could be understood as including any implicit, as well as any explicit costs. The explicit cost of patenting would, then, be the patenting fees and the implicit cost comprises any opportunity cost that the applicant is forgoing by patenting. This does not, still, clearly define what the counterfactual is. However, whatever the counterfactual is, the choice of patenting reveals that the applicant considers the expected benefit of patenting to be higher than the benefit of the counterfactual coupled with the patenting fees. Alternatively, a counterfactual could be a trade secret. But even in such a case, saying that the counterfactual is a trade secret does not really give complete satisfaction.

What would the firm have earned without a patent? This question strongly echoes the issue of the "true" value of a patent, and both questions, deserve further investigations. Any attempt to find the "true" value of a patent, as evidenced also in the literature review in the next two subsections, actually provides estimates of the "perceived" or "revealed" value of a patent. The current paper, along the lines of Barny (2002) and Van Zeebroeck (2008), considers patent renewal as a strong piece of evidence of the "revealed" value of a patent. It is costly to renew a patent or to pay maintenance fees. Hence, in a statistical survival analysis, an objective way to investigate the determinants of the "true" value of a patent could consist in studying the determinants of patent renewal and patent survival. The next two subsections discusses the uses of "non-citation" valuation method (such as renewal and opposition), and the use of citations as evidence of patent value.

Literature on the "Non-Citation" Valuation Method

We consider the use of renewal, licensing, litigation… as part of the "non-citation" patent valuation method. The World Intellectual Property Organization (WIPO, henceforth) defines a patent as an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem. Among other conditions, an invention must be of practical use and show some novelty. That means that an invention should be a contribution to the body of existing knowledge in its technical field. To that extent, the WIPO draws the conclusion that patents have been rightly used as evidence of innovation and technical change.

Prior to the ideas about patent valuations, research on innovative output was spearheaded by Scherer (1965), Schmookler (1966) and Griliches (1984) who used patent counts as evidence of technical dynamism. The recognition that innovations vary, according to their technological and economic contribution to prior art, spurred investigations on patent renewal and family size, patent citations and opposition. Griliches, Pakes and Hall (1987) acknowledge the heterogeneity of the values of patents and investigate patent renewal as the main indicator of patent value. Indeed, the rights to more valuable innovations are renewed regularly until the statutory duration is reached, while the rights to less valuable ones are allowed to lapse. Putnam (1996) showed that the number of jurisdictions in which patent protection is sought for a particular invention is likely to be correlated with the value of the invention and thus with the value of any single national patent right. The results of the research of Giummo (2003), on royalties received by the inventor or patent holders at nine major German corporations, under the German Employee Compensation Act of 1957, show also a high correlation between royalties and patent values. Pakes and Schankerman (1984), Pakes (1986) and Schankerman and Pakes (1984) pioneered estimation models in which the observed renewal decisions are used to estimate the distribution of patent values. Along the same lines, Barney (2002) studied the mortality rates of patents and finds that patent renewal is highly correlated with USPTO patent classifications in classes such as equipment, engineering, and computer, etc. But besides renewal and licensing, citation is the most widely used method for patent valuation.

Literature on the Citation Based Valuation Method

As mentioned earlier, many approaches have been used to estimate the value of patents. One of the most widely used methods is the citation valuation method in which a focus could be put on citations received or citations made[4], on patents vs. international patent classification (IPC). The rationale for using forward citations is that they reflect commercial interest and should correlate with patent economic value.

Lerner (1994) uses the market value of biotechnology firms as a measure of the value of the respective patent portfolio and also takes into account the citations made but not received. He argues indeed that patent value is correlated with the number of IPCs referred to in the patent. He posits that such a variable captures the scope of the patented invention and reports a positive and sizable correlation between the firm's market value and the average scope of its patents.

Trajtenberg (1990), and Albert et al. (1991) hypothesize the importance of citations as the means of revealing the value of patents. Jaffe, Trajtenberg and Henderson (1993) put the emphasis on citations not only as evidence of the importance of patents but also as a way to trace technological diffusion. To that extent, patent citations convey information about two major aspects of innovations. The first is linkages between inventions, inventors, and assignees over time and space, and the second is the importance of individual patents.

[4] It seems obvious to consider citation received, more than citation made, as a piece of evidence of patent value. However, it can also be argued that the size of the citation made reflects the extent of prior art on which a new invention is built.

Using citation-weighted patent counts, Trajtenberg (1990) related the various flows of patents in computed tomography (CT) scanners, to the estimated social surplus due to improvements in this technology. His results showed that citation weighted patent counts turn out to be highly correlated, with the estimated surplus value, while simple patent counts are uncorrelated with it.

Using data, with value assessments, coming directly from a survey of patent holders, Harhoff et al. (2002) measure the value of a patent right as the price for which the original inventor would be willing to sell the patent right. They also, however, resort to a broad set of indicators to model respective valuations, including the number of citations received, the number of references to prior patents, the outcome of opposition proceedings, patent family size and the number of different four-digit IPC classifications (which has been made to provide a measure of the scope of the patent). In that respect, the contribution of Harhoff et al. (2002) consisted in weighting in the outcome of opposition cases, as well as jointly including forward and backward citations.

Harhoff et al. (1999) surveyed German patent holders of U.S. patents that were also filed in Germany asking them to estimate the future price of their patents after three years. They found that the estimated value correlated with subsequent citations; and mostly cited patents are highly valuable with a single citation implying an average value of about $1 million.

Lanjouw and Schankerman (2004) argue that citations combined with number of claims, and number of countries in which an invention is patented is a good proxy for patent value. Their analysis showed that a composite measure has significant power in predicting patent renewal, litigation, and the private value of patents. Hall et al. (2005)

explore the usefulness of patent citations as a measure of the importance of a firm's patent portfolio, as indicated by the stock market valuation of the firm's intangible stock of knowledge. Their results show evidence that, in addition to R&D and simple patent counts, patent citations contain significant information on the market value of firms.

Barney (2002) links citations to patent renewal. He finds that fourth year maintenance rate is positively correlated with the number of forward citations that patents receive. Patents that receive no forward citation, in their first four years, have an observed fourth year maintenance rate of 79.3%, compared to 93.5% for patents having fourteen or more citations. Last but not least, Zeebroeck (2008) uses a survival analysis method to investigate patent renewal. He finds that more cited patents and patents with larger family size are more likely to be granted, and tend to be renewed for longer periods.

However, the main patent valuation methods aforementioned (patent count, citation and renewal) have some limitations. Besides the patent count method, whose limitations are obvious, the main weakness of the other two methods (citation and renewal) is that we can only judge values ex-post and for older technologies. Indeed, sufficient amount of time has to pass in order to observe citations and renewal behavior, as we explain below.

Some Limitations of the Previous Valuation Methods

The current literature, which looks at the valuation of patents, focuses on patent family size, patent citations and patent oppositions and renewals. As will be made more explicit, however, these approaches, although very helpful, have important limitations.

Some Limitations of the Patent Counts, Scope, Number of Priorities and Family Size Approach

The approaches of using patent counts, scope and family size have the advantage of giving a good account of the absolute number of patents owned by a country (or a firm) or the absolute number of countries covered by the patents. If patent family is simply defined as a set of patents taken out in various countries, to protect a single invention, then, patent family size also indicates the extent of the coverage of a patent. It is sensible to assume that the more valuable a patent is, the larger its coverage. Harhoff, Scherer and Vopel (2003) used Lerner's (1994) approach and generated a measure of scope computed as the number of different four-digit IPC classification codes in patent application document. Putnam (1996) and Lanjouw, Pakes and Putnam(1998) have indeed shown that patent family size, as a measure of the number of jurisdictions and patent survival span, are positively correlated

However, the approaches of using patent counts, scope and family size have three main weaknesses: it assumes that (i) two different patents have the same value, (ii) two different jurisdictions reflect the same strategic importance for a firm and (iii) patents are always active or working. On the one hand, a patent that is rather close to a utility model or a patent for a minor invention should not be compared to a patent for a major invention. On the other, a patent that protects an invention in the U.S.A might be more valuable than a patent covering all the countries of the African Intellectual Property Organization (OAPI). This could be the case, since OAPI covers mostly the currently poorest countries in Africa (according the UNDP HDI rankings). The salient point, here, is that the potential market value of the jurisdiction covered also matters.

Referring to the patent family classification suggested by Hingley and Park (2003), families can be classified in terms of the bloc of origin of the priority that defines the family, and the set of blocs in which the family is active. The blocs consist of either single countries or groups of countries. Hingley and Park (2003) suggest four blocs: the European Patent Community's (EPC) contracting states, Japan, the USA and the group of all other countries called ROW (Rest of the World). It seems obvious that a patent that protects an invention, in only one of the three main blocs (EPC, Japan and USA), might turn out to be more valuable than another one that protects an invention in several poor countries. Indeed, figures, provided in Hingley and Park (2003), show that 82.52% of the priority filing of patent families originates in the trilateral blocs (EPC, Japan and US). This confirms that even if the size of the patent jurisdiction matters, the market size of jurisdictions covered matters as much, if not more.

Last but not least, not all patents, which are granted, will ever be renewed, licensed, or commercially exploited. Therefore, just counting patents does not take into account the basic fact that a patent might not lapse but still, not be active.

Some Limitations of Patents Citations, Oppositions and Renewal Approach: Skewness and Timing Issue

The WIPO makes it clear that an invention must show some novelty, i.e., the invention should be a contribution to the body of existing knowledge in its technical field. To that extent, it is legitimate for patents to cite prior patents, in order to show what are their contribution and value added. It can, therefore, be assumed that the more a patent is cited, the more valuable it is. As for renewal, given that there is a cost for renewal, only more valuable and probably active patents would be renewed. If a patent is subject to opposition, this is a clear indication that the patent is worth being claimed for. Valuable patent rights are more likely to be attacked during the application process and even after, amounting to a two-tiered selection process with a highly informative outcome (Harhoff, Scherer and Vopel (2003)). To that extent, citations, oppositions and renewal are evidence of the value of a patent (Lanjouw and Schankerman (2004)). However, those three approaches to patent value suffer (i) from the fact that the distribution of citations, renewal and oppositions is skewed and (ii) from the fact that patent values can only be assessed "ex post facto".

In their research on market value and patent citations, Hall, Jaffe and Trajtenberg (2005) recognized that the distribution of patent citations is much skewed, with about one-quarter of all patents getting none and only a few dozen out of millions receiving a hundred citations and more. In addition, they acknowledge the fact that citations unfold over time, so that how the market anticipates these future citations or react to them is unsettled. Time has to pass in order to observe citations, renewals and oppositions.

As far as citations are concerned, literature on patent citations seems to favor citations received instead of citations made. In any event, it is fair to assume that both citations received or citations made have a positive correlation with patent value. However, in an earlier paper on the NBER patent citations data file, Hall, Jaffe and Trajtenberg (2001) thought that, standing by itself, the fact, that a given patent has received 10 or 100 citations, does not tell whether that patent is highly cited. Moreover, intrinsically, information on patent citation is meaningful only when used comparatively. The timing issue raised here, however, is primarily concerned with citations received.

Hall, Jaffe and Trajtenberg (2001) called it the inversion problem, i.e., the fact that the original data on citations come in the form of citations made whereas for many of the uses (certainly for assessing the importance of patents) one needs data on citations received.

Another important issue revolves around self-citations, i.e., citations coming from patents assigned to the same firm that holds the cited patent. Do citations and self-citations have the same values, if we assume that patents, owned by the same right holder, are very likely to show little increments in innovation?

Haroff, Scherer and Vopel (2003) confirm the positive correlation between patent citations and patent values. Moreover, they suggest that measurement of family size and observed outcomes of opposition cases also contribute to an approximation of the patent right's value. In particular, a successful defense against opposition and annulment claims is a particularly strong predictor of patent value. Following Lerner (1994), however, their findings on patent scope, as measured by the four-digit IPC classification, doe not have any explanatory power.

Even if patent citations, oppositions and renewal improve patent valuation approach in general, it remains that as recognized by Hall, Jaffe and Trajtenberg (2005), a substantial time is needed, after a patent is granted, to accumulate significant information about its citation, and this implies that citation-based analysis will never be usable for evaluating current or very recent innovations. Therefore, and ultimately, despite their notable contribution to the literature on patent valuation, the deficiencies of patent citations, oppositions and renewals, as methods, require another approach to patent valuation.

A New Method of Patent Valuation: the Family Size and Composition Adjusted Patent Valuation Method[5]

Against the background of the different pitfalls of prior patent valuation methods, our contribution consists in building on Hingley and Park (2003), by taking into account the size and composition of patent families in the valuation of a patent and a patent portfolio. Indeed, incurring the cost of patenting in many jurisdictions can be perceived as a signal of patent value. However, our contribution consists not only in factoring in the number of countries or jurisdictions, but also, in weighting in the countries' market size, as measured by their GDP. The next subsection shows the construction of our new valuation method, and the next section provides the empirical evidence on the impact of family and citation weighted patents on their rate of renewal and survival.

Theoretical Specification of the Family Size and Composition Valuation Method

A priority patent application under the Paris Convention is an initial patent application that allows an inventor to patent subsequent applications in other countries than the country of the initial application within a year. Define V_j, the value of priority patent j and V^i, the value of patents in a source country i as follows[6]:

$$V^i = \sum_{j=1}^{J} \sum_{n=1}^{N} Y_{n,j} \quad ; n=1,\dots, N \text{ countries and } j=1,\dots,J \text{ patents} \qquad (1)$$

[5] In this chapter, and for practical purposes, we sometimes refer to this method as "the family method".

[6]A source country is a country of origin of a patent applicant while a destination country is the country where a patent has legal protection. Please, see the appendix, for definitions of IP related technical terms.

where Y_n is the total amount of output created in destination country n and N is the number of countries where the $j-th$ patent is filed. Weights are created using GDP[7]. Equation (1) can be decomposed into two parts to facilitate interpretation.

$$V^i = \sum_{j=1}^{J} V_j \quad ; \text{at time } t \qquad (2)$$

with

$$V_j = \sum_{n=1}^{N} Y_n \quad ; \text{at time } t \qquad (3)$$

Equation (3) expresses the fact that for each priority application j, we assume that its value is proportional to the number of jurisdictions n covered (with $n \epsilon [1, N]$); and also proportional to the market values (Y_n) of these jurisdictions. Equation (2) then expresses the value of patent portfolio, V_i, at source country level as the sum of the individual patent values V_j, owned by residents of country i. Value , V_j , (see equation (3)), is therefore the weight assigned to each patent j , in order to estimate its value, according to the family size and composition valuation method. V_i is the weight at source country level (see equations (1) and (2)).

[7] It is possible to use other measures of output such as value added, or private GDP, conditional on data availability. This should not substantially affect the conclusions of the study. In a prior version of this work, we used private GDP. However, using GDP seems more consistent, since the potential market of some patents may depend on government expenses.

Ranking of Patents According to the Two Patent Valuation Methods

Before using parametric probit and discrete time survival analysis to investigate the impact of innovation on patent renewal and survival, we perform a horse race between the family and citation method. To do so, we rank patents in descending order of values $p_1 < p_2 < ....p_J$. We then group priorities in four categories defined as follows:

(i) Very low: This category gathers patents whose values are below the 25th percentile, in the distribution of the values of patents. These patents are considered of very low value. If patents deemed of very low value, according to a patent valuation method, and are actually renewed, it casts doubt on the accuracy of the corresponding patent valuation method, and commits a type I error. Consider the null hypothesis to be:

$$H_0 = P_{VeryHigh} \tag{4}$$

Equation (4) is stating that the value of Patent P is very high, since the patent has been renewed. Yet, the valuation method classifies patent P as very low, i.e., the valuation method rejects a true null hypothesis, which is a type I error. A good patent valuation method should have a low number and share of patents that are , both, deemed of very low value and actually renewed. The same type of analysis prevails for the next three categories, mutatis mutandis.

(ii) Low: patents whose values are comprised between the 25th and the 50th percentile, in the distribution of the values of patents.

(iii) High: patents whose values are comprised between the 50th and the 75th percentile, in the distribution of the values of patents.

(iv) Very high: patents whose values are comprised between the 75th and the 100th percentile, in the distribution of the values of patents. Patents in this category are expected to have a very high likelihood of renewal. A good patent valuation method should have a high number and share of patents that are, both, considered of very high value and renewed.

We plot the number of renewed patents in each category. However, we are not only interested in knowing whether patents are renewed or not, we also want to know whether priorities deemed valuable are, de facto, renewed or whether they lapse. In that respect, we also plot the share of renewed patents in each category. If a valuation method captures patent value very well, the share of renewed priorities should be an increasing function of categories. For instance, assume that s1 is the share of renewed patents for the category "very low", and s2 is the share of renewed patents for the category "low". It should be the case that s2>s1, if the valuation method considered is good and consistent

Empirical Specification for Parametric
Analysis

As mentioned earlier, the underlying assumption of the study is that patent value, V_j , is a function of potential market size M and of the number of countries covered N.

Define,

$$V_j = V(M,N) \tag{5}$$

where V_j is a vector of the values of patent i according to either the family or citation valuation method. Consider ΔV_j the change in value of patent j , as a result of renewal, with V_j^R the value of patent j when it is renewed, and V_j^{NR} the value of patent j when it is not renewed, and c is the cost of renewal.

$$\Delta V_j = V_j^R - V_j^{NR} \geq c \qquad with \; V_j^{NR} = 0 \qquad (6)$$

Equation (6) states that when a patent is renewed, the change in the value of patent j, resulting from renewal, is greater than the cost of renewal, and equal to the difference between V_j^R and V_j^{NR}, as defined above in equation (6). When a patent is not renewed, it's perceived value for its previous owner must be inferior to the cost of renewal, i.e., $\Delta V_j^{NR} < c$

The Probit Regression for Renewal Analysis

Define R_j, the legal status of patent j. Consider $prob(R_j)$, an indicator variable taking value 1 if patent i is renewed, 0 otherwise with[8]:

$$\Pr ob(R_j) = \{^{1 \text{ if } E(\Delta V_j) \geq c}_{0 \text{ otherwise}} \qquad (7)$$

We are interested in the following two probabilities:

$$\Pr ob(R_j = 1 | x) = F(x, \beta) \text{ and } \Pr ob(R_j = 0 | x) = 1 - F(x, \beta) \qquad (8)$$

[8] Notation for renewal probability, as well as for the discrete time survival analysis is built on Greene (2008).

where x is a vector of variables, including value V_j and other characteristics such as year and country. We want, therefore, to explain renewal R_j, as a function of x, as given in structural equation (9) below:

$$R_j = x'\beta + \epsilon_j \tag{9}$$

where ϵ_j is an error term. For regression analysis, we would be interested in the vector of coefficients β that gives the change in the probability of being renewed, induced by a change in 1% in the value of patent i, where patent value is measured according to the family and citation method.

Discrete Time Survival Analysis

Besides the binary question, "is a patent renewed or not", we are also concerned with the length of time that elapses from the time of a patent application until the patent expires. This raises a duration analysis issue. Therefore, we build on the treatment of Greene (2008), in his chapter on “Models for Event Counts and Duration”. The process being observed, lapse of patents, starts at different points in calendar time for the different individuals in the sample. Using Greene's notation, assume that, validity is represented by the random variable $T.$ Conditional on x that has remain fixed from $T = 0$ to $T = t,$ and t has a normal distribution. Further, suppose that the random variable T has a continuous probability distribution, $f(t)$, where t is a realization of $T.$ The cumulative probability is:

$$F(t) = \int_0^t f(s)ds = \Pr ob(T \leq t) \tag{10}$$

As mentioned earlier, we are interested in the probability that the period, during which a patent is in force, is at least of length t, which is given by the survival function,

$$S(t) = 1 - F(t) = \Pr ob(T \geq t) \tag{11}$$

Another way of considering the issue, at hand, is to ask the question: given that the period of "in-force" has lasted until time t, what is the probability that it will end in the next short interval of time, say, Δt? To answer this question, we need to check the duration hazard rate. Investigating the survival function will suffice to answer our question, on the length of time that elapses from the time of application until a patent expires and on the likelihood of expiry in the next interval of time. To do so, we assume that the process is not "memoryless", i.e., the conditional probability of "lapse" in a given short interval depends on when the observation is made. The probability of renewal (or lapse) of a patent probably depends on the number of years the patent has been in force, because technologies become obsolete or replaced by better innovation. This boils down to assuming a non-constant hazard function $\lambda(t)$.

We assume that $\lambda(t)$ follows a logistic distribution with mean $-\ln(\lambda)$ and variance $\pi^2/(3p^2)$, where p is a scale parameter and λ a location parameter. It could be argued that the distribution of the hazard function slopes upward (positive duration dependence) or downward (negative duration dependence). As a matter of fact, the likelihood of lapsing at time t, conditional upon duration up to time t, could be considered either increasing or decreasing. However, we do not make any explicit assumption about that. Instead, we rather follow established tradition on unemployment spells and use logistic hazard function to analyze survival.

Survival function $S(t)$ can be expressed as:

$$S(t) = \Pr ob(T \geq t) = 1/(1+\lambda(t)^p) \text{ with } \lambda_i = e^{-x_i'\beta} \tag{12}$$

Where x_i is a vector of a constant term, and of a set of variables that are assumed not to change from $T = 0$ to $T = t$. x_i comprises all the exogenous variables such as the cost of patenting, the number of years in force, the renewal categories (that will be explained below), the country and year dummies.

Robustness of the Family Size and Composition
Valuation Method

We use two different, but complementary methods, to test the robustness of the family size and composition patent valuation method against the citation method.

(i) First, we perform a horse race between the two methods to investigate how accurately each of the valuation methods predicts renewal. To do so, we run a Probit regression of the estimated value of patents on their likelihood of being renewed. Renewal information is, therefore, used as independent confirmation data. The marginal effects provide the impact of a one percentage change in patent estimated value, on the likelihood of renewal. Before the discussion of the results of the Probit regression, descriptive tables and figures provide an overview of the data and unravel the patterns of the data, at hand.

A first description consists in ranking the priority applications, according to the values assigned to them, by the two valuation methods, and in checking their legal status. In order, to facilitate description of the data, we gather patents in four cohorts. Patents are gathered, according to the number of years they have been in force, as follows: at least 4 years, between 5 and 8, between 9 and 12 years, and more than 12 years. This corresponds to the schedule of patent renewal at the USPTO where patents are renewed on their 4^{th}, 8^{th} and 12^{th} year. We also rank patents in ascending order of their estimated values, and group them in four categories (very high, high, low, very low), as explained, above, at subsection 4.2. Cross checking the two different groups (across years in force and the categories of patent value) allows a comparison between the two methods. For instance, such an exercise provides information on the number and share of patents, of age more than 8, that have been renewed according to each method. A good patent valuation method is expected to have a high share of renewed patents in the categories of high and very high valued patents. A second descriptive exercise consists in ranking the 16 countries, of the origin of primary inventors, according to the two methods. This exercise provides an assessment of the correlation of the two methods at country level.

(ii) Second, we use a parametric discrete time logistic regression model to perform the survival analysis at patent level. The first method of investigation, based on summary statistics and a Probit regression, is static. This second method, however, is more dynamic as we take, explicitly, into account, the duration until a patent dies. Furthermore, the choice of a discrete time survival analysis model, stems from the fact that summary statistics provided below show that the data is of a high variance distribution, in addition to the fact that the duration analyzed, i.e., the time before a patent lapses, is a discrete type variable. For the duration model, the question addressed is the likelihood that a patent lapses by a certain time t. More precisely, we investigate the impact on the likelihood that a patent lapses when the value of a patent is incremented by 1%.

There is a fundamental difference between the renewal and survival approach that makes the two approaches very complementary to each other. With the Probit (renewal) regressions, we are looking at the likelihood that a patent is renewed, conditional on its estimated value, as measured by the family or citation method. In the survival analysis, we are investigating the likelihood that a patent lapses, conditional on the estimated value but, also, given that the patent has been in force for, let's say, t years. In that regards, it can be considered that, in survival analysis, duration is more explicitly taken into account. Another dimension of duration, that is more clearly expressed in a survival analysis than in a probit regression, relates to the truncation of the number of years for renewal information. If a patent is renewed after 4 years, the information, actually available, is that the patent is in force for "at least" 4 years. The patent might, however, end up being in force for a longer period of time (9 or 15 years). Therefore, in order to focus on duration, we need to use survival analysis, because, when a patent lapses after 11 years, it is known, for certain, that the patent is in the public domain from that time onwards. In that regards, the survival analysis complements the renewal analysis that is performed using a probit regression. In short, when we analyze the impact of valuable innovation on the likelihood of renewal, a probit regression does not explicitly takes into account the overall life span of a patent. This can only be done using a survival analysis.

By characterizing the distribution of patent values, we further contribute to the international debate on patent systems. We carry out the empirical part of our study using, mostly, the April 2011 4.21 edition of PatStat (the World Wide Patent Statistical data base) as well as the April 2011 edition of PRS-INPADOC, the data set on patents in force, that provides the legal status of some patents covered by PatStat[9].

The Data

General Overview and Methodology

Three datasets are used for the current study: (i) PatStat 4.21[10] April 2011 version and PRS legal status data, (ii) Global IP estimator data on cost of patent application and (iii) GDP is taken from the World Bank World Development Indicators (WDI, henceforth).

PatStat is a database gathered by the European Patent Office (EPO), on behalf of the OECD Taskforce on Patent Statistics, and designed to assist in statistical research into patent information. The database is distributed from the Vienna sub-office of the European Patent Office by the publication department. PatStat is supplied as-is, i.e., the EPO puts together, without editing it, the patent information it receives from national patent offices. In that regard, PatStat is a snapshot of the source databases at a single

[9] Please, see next section and appendix for description of the data.

[10] I am very grateful to the Institute for Humane Studies at George Mason University from whom I received a grant for the academic year 2010-2011 to buy PatStat, the World Wide Patent Statistical database, and INPADOC/PRS, the patent in force data, to complete my dissertation.

point in time. However, the database covers a very long period from the early 20th century to 2011, for the latest edition. The source databases include information from around 160 countries in the world and dozens of millions of observations. Besides national patent offices, information is also gathered from regional patent offices such as ARIPO, OAPI, EPO… For the purpose of this study, and because of lags in the process of patent publications and citations received, we use a sample covering the period 1980 to 2011. Application period ranges from 1980 to 2009. Publication years and years of renewal, however, range, respectively, from 1980 to 2010 and from 1983 to 2011.

Table 1: Original Files of Patstat 4.21 Used in this Study[a]

File Name	# of files /variables/ Observations	Name	Description of variables
1.tls201[b]	4/10 68,481,300	Application	Appln_id, appln_auth, appln_nr, appln_kind, appln_filing_date, ipr_type, appln_title_lg, appln_abstract_lg, internat_appln_id
2.tls204	1/3 29,706,641	Applicant-Application	Appln_id, prior_appln_id, prior_appln_seq_nr,
3.tls206	5/2 38,418,130	Technical relation	Person_id, person_ctry_code, doc_std_name_id, person_name, person_address
4.tls207	5/3 138,684,682	Inventor-application	Person_id, appln_id, applt_seq_nr, invt_seq_nr
5.tls211	3/5 76,668,550	Patent publication citation	Pat_publn_id, publn_auth, publn_nr, publn_kind, appln_id, publn_date, publn_lg, publn_first_grant
6.tls212	6/9 104,598,819	Application- IPC classification	Pat_publn_id, citn_id, cited_pat_publn_id, npl_publn_id, pat_citn_seq_nr, npl_citn_seq_nr, citn_origin
7.PRS tls221	17/4+	INPADOC[c] Worldwide legal status	Appln_id, prs_event_seq_nr, prs_gazette_date, prs_code, L501EP-L527EP

Note: Codes of abbreviation of variables'name: Appln=application; id=id, auth=authority; nr=number, kind=king; lg=language; internat=international; prior=priority; ctry=country; doc=document; std=standard; seq=sequence; invt=inventor; pat=patent; publn=publication; citn=citation; npl=non patent literature.

[a]PatStat 4.21 as well as the INPADOC-PRS legal status data is provided in double-layer DVD as raw data. The zipped data is about 14.5 GB and 81 GB if unzipped. For the

current study, 7 out of the 19 “tables”[11] are used. Each table contains on average 4 to 5 files except for “table 4” (table for priority applications), that contains only one file, and the PRS legal status data that holds 17 different files. Each file contains millions of rows with primary keys, that allow the different files and “tables” to be merged together. In order to get the data set used for the empirical part of this study, “tables” on applications (Tls201), on applicants and inventors (Tls206 & Tls207), on patent publication (Tls211), on citations (Tls212), on priority filings (Tls204) as well as Tls221 (that is the PRS legal Status data) are used[12]. Since the legal status of patents is needed for the study, only patents whose status is available in the PRS data are used. Table 2.1 displays the different variables, available in PatStat 4.21 and Table 2.2 shows the logical diagram used to merge the data. Each file contains a key variable, or a set of variables, that uniquely identify observations so as to allow for merging.

[b]TLS stands for Transfer Layer Security. It is an encryption communication protocol that provides security over the Internet. PATSTAT data is available to clients over the internet through the Structrure Query Language (SWL)

[c]INPADOC stands for International Patent Documentation Center. It was founded by WIPO in 1972. The INPADOC data base is produced and maintained by the EPO and contains patent families and legal status information.

A first merge consists in merging the PRS legal status data with the priority table in order to retain patent priorities that have renewal status, so as to know the extent of their families. Any other variable is added, by merging the set of priority applications with the “table”[13] that contains the needed variable. However, not all variables that are needed are available. The need to retrieve citations received puts further constraints on the patent families that can qualify for the study as explained below. The raw data provides citations made, when a patent cites another patent but not citations received. Citations received are therefore computed when the publication identification of the

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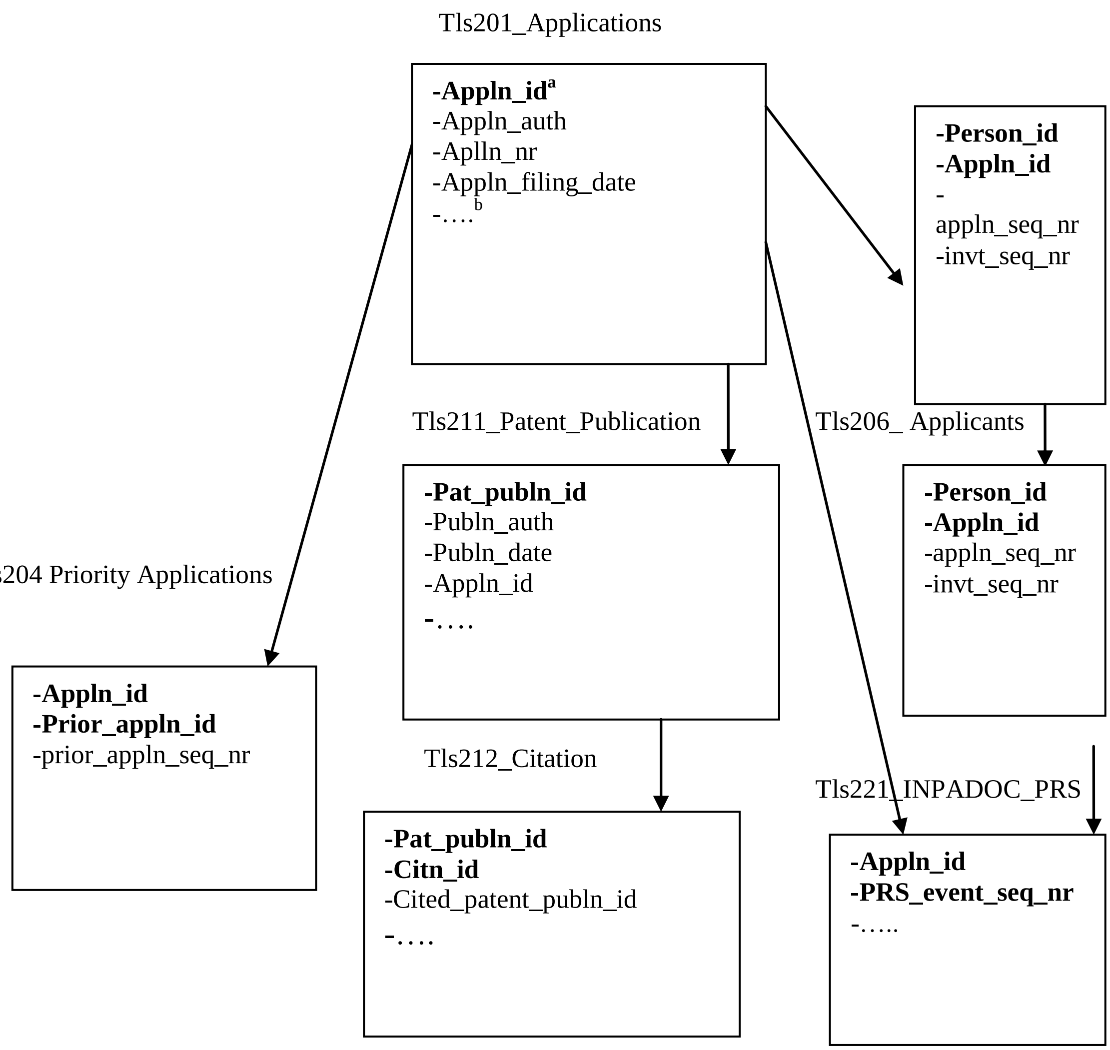
[11] “Table” in this context is equivalent to a large file that is divided into many sub-files. This implies that the sub-files all have the same variables and characteristics.

[12] The SAS codes used for merging the data is available upon request.

[13] The official documentation of PATSTAT used the term “table” to refer to large files that, on average, contain many sub-files. The term “table”, is commonly used in Structured Query Language (SQL) and in the software ACCESS.

citation made is available. Table 1 lists the “tables” used for this study and table 2 shows the logical diagram that is used to merge the data.

Table 2: Relational (Logical) Diagram Used in this Study



Notes: This table is based on the diagram provided by the documentation of PatStat 4.21 April 2011 edition (p.137)

[a]Variables in bold are variables that are “keys”. They uniquely identify observations and are used to merge the different data sets.

[b]See Table 2.1 for a complete listing of the variables contained in each file and also the codes (for the abbreviations used).

Construction of the Variables

Table 3: Original PRS Codes for Legal Status from the Destination Countries Studied

Country	Legal Event	
	Positive legal events	Negative legal event
1.Australia AU	+ND: Application of extension of term accepted +NDA: extension of term for standard patent accepted (sect. 70) +NDB: extension of term for standard patent accepted (sect. 76) +NDF extension of term for petty patent accepted (sect. 69)	-CLAC Lapsed continuation fee- opposition proceedings -MK14: Patent Ceased section 143(A) (Annual fees not paid) or expired -MK22: : Patent Ceased section 143A(D), or expired, non payment of renewal fee or expiry
2.Belgium BE	+CCHV: Grant of complementary protection certificate for herbicides +CCPV: Grant of a complementary protection certificate	-E20: Patent expired -RE: lapsed -RE20: Patent Expired
3.Switzerland CH	+NE: Patent not ceased +SPCH: Reinstatement of a SPC	-PL: Patent ceased -PLZ: Patent of addition ceased
4.Germany DE	+EB: Duration of protection prolongated +V457: SPC Granted	-EHJ: Ceased/Non-payment of annual fee -EHZ: Patent of addition ceased/non-payment of annual fee -8339: Ceased/non-payment of the annual fee
5.Denmark DK	+BP: Correction of lapse of patent +CTFG: Supplementary protection certificate issued	-EBP: Patent lapsed -EDV: Patent ceased -EUP: Patent expired -PBP: Patent lapsed -PDV: Patent ceased
6.France FR	+CT: Granted supplementary certificate of protection for medicine (EEC regulation of 18 June 1992) +CY: supplementary certificate of protection Granted (EEC regulation of 18 June 1992)	-BD: lapse confirmed - ST: Lapsed
7.U.K. GB	+EPF: Patent extended in pursuance of application of extension of term and in force +PCPE: Delete ‘Patent ceased’ from Journal	-PE16: Patent expired after termination of 16 years -PE20: Patent expired after termination of 20 years
8.Israel IL	+KB: patent renewed +KB20 Patent renewed for 20 years	-MM9K: Patent not in force due to non-payment of renewal fees
9.Italy IT	+FITD: SPC for herbicidal products: granted +FITP: SPC for pharmaceutical products: granted	-FITG: SPC for herbicidal products: definitive refusal

Table 3 continued

10.U.S.A. US	+PEL: Patent term extension +PRDP: Patent reinstated du e to the acceptance of a late maintenance fee +REIN: Reinstatement after maintenance fee payment confirmed. +355 Patent term extension under 35 U.S.C 155 until/for +355A: Patent term extension or patent term restoration according to 35 U.S.C. 155, 155A or 156 +946 Patent term extension private law 98-46 until/for	-FP: Expired due to failure to pay maintenance fee -LAPS: lapse for failure to pay maintenance fee

Four main variables, 4 renewal categories or dummies (never renewed (first dummy), renewed once (second dummy), twice (third dummy) or three times (fourth dummy)), 30 time dummies (years of application) and 16 country dummies (country of primary inventors) are used in the renewal and survival regressions.

(i) Renewal status: the dependent variable is a categorical variable that tells us whether a patent has been renewed at the appropriate date of renewal. Table 3 lists the set of the PRS legal status events used as the "in force" variable. Assume that the records for legal status events of four different U.S patents (D1, D2, D3, D4) are the following: D1= "Reissue application filed", D2="Change of address", D3="Patent term extension" and D4="Expired due to failure to pay maintenance fee". The first two events (from table 4), are not related to the renewal of patents. The two last legal events, however, imply that patent D3 is still in force, while patent D4 has lapsed. Hence, only the two last patents can be included in the current study as there is no information about the "in force" or legal renewal status of patent D1 and D2. Therefore, patent D3 takes value 1 for "renewal status" and D4 takes value 0 (see table 3, column 2). Variable "renewal status", in this context encompasses any legal event that shows that an applicant has taken action to keep their patent in force. Stating that a patent is “in force”, means that the patent was not abandoned. However, being in force could imply that the patent was renewed once, twice or even three times. The variable “renewal status” does not convey all that information. The renewal dummies, as explained below, address the issues of whether a patent was renewed and how many times it was renewed.

It occurs that, for a few observations, the same priority patent has different patents, with, at least, one of them in force and, at least, one of them not “in force”. Given the scarcity of “in force” patents, such a patent is considered in force. We, therefore, apply, what Van Zeebroeck (2008) termed the “Single Renewal Approach”, SAR. The alternative approach is the “Complete Renewal Approach”, CRA, that consists in observing the shortest common renewal over a set of countries. There are, however, few such cases in the data.

Table 4: Sample of PRS Legal Data

Patent ID	PRS Event Code*	PRS event Year	PRS Event Meaning	In force Status
D1	RF	1995	Reissue application filed	-
D2	AS21	1994	Change of address	-
D3	PEL	1998	Patent term extension	1
D4	FP	2005	Expired due to failure to pay maintenance fee	0

Note: These are examples of real PRS codes available in the 2011 PRS legal status data for the U.S.A.

(ii) Weighted innovation (log(family) and log(citations)[14]): The main independent variable of interest is the estimated value of innovation embedded in patents. This value is computed, as either the log of the sum of the citations received by a patent, during its first 5 years, or, as the family size and composition of the patent family. As for the family method, GDP, in 2000 constant dollars, is used as a proxy for potential market[15].

In order to give a head start to the citation method; and also for purposes of robustness, two measures are taken. In the data available in PatStat 4.21, citations received drop substantially 5 years after publication. So the first corrective measure taken consists in counting only citations received during the first five years of the patent publication. Bottazzi and Peri (2007) take three years average μ_3 and compute their weight as $(1+\mu_3)$. The second measure is that we study patents with strictly positive citations, i.e., we study, also, only patents that have received at least one citation during their first 5 years, as reported by our data. These two measures (only five years citations and patents that received at least 1 citation during their early 5 years) provide two samples for our study. The first sample includes all the patents available for the study, i.e, 1,017,374 patents. The second sample contains 611,425 patents that received at least one citation during their early 5 years of life. In both samples, the citation weight is the log of the number of citations received during the first 5 years.

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[14] In order to keep observations that has 0 citations, in the data, we actually take ln(1+x), if x is the number of citations.

[15] See note 7 for the rationale for using GDP (vs. private GDP). An additional sensitivity test could also use current GDP vs. GDP in constant dollars.

The number of citations received is not provided, readily, in PatStat. Citations made, however, as well as the publication identification of the citing and cited patents are provided. Given a set A of patents that cited patents, in set B, it is possible to reverse count how many citations each patent in set B received from patents, in set A. This is, however, possible only when the publication identification of the cited patents, as well as other important information in set B are provided. For instance, in order to count only citations received during the first 5 years, the year the citation was made (proxied by the year of publication of the citing patent) and the year of publication of the cited patent application are necessary. Citations, in PatStat, include citations from both patent and non-patent literature, such as journals or scientific reviews. However, for this study, only citations received from other patents are taken into account.

(iii) Patenting Cost: This is computed as the log of the total cost of application and maintenance fees. The cost variable, for application countries, is the log of the total cost that an applicant contemplates, when he/she plans to keep a patent until full term, i.e., 20 years. Given our interest on renewal, as benchmark for patent value, taking into account the total cost incurred by applicants is justified. The rationale, for using renewal as a piece of evidence for patent value, is indeed that it is costly to maintain patents in force, so that only largely valued patents are renewed. Costs are expressed in 2000 constant U.S. dollars. Costs of patenting include costs of filing, examination, prosecution, granting and maintenance, for a full term of 20 years. Data is provided by Global IP estimator, in 2000 constant U.S. dollars, for the years 2006 and 2010. We, then, compute values for the rest of the years, using the inflation rate implied by the costs in 2006 and 2010[16].

(iv) Number of years in force: The number of years a patent is in force is the difference between the year of application and the year when a patent lapses or is renewed. Assume, for example, that application for a patent is filed in 1991 and the patent is renewed in 1999. The number of years of “in force” of the patent is 8 years (i.e.1999-1991). For the variable “renewal status”, such a patent takes value 1. Number of years in force takes a value in the interval [0-20], as the maximum full term for a patent is 20 years.

(v) Renewal Categories: as discussed above, the fact that a patent is in force does not provide the information about whether the patent has ever been renewed once, twice or three times. To take that into account, 4 dummies are created. Renewal category 1 takes value 1, if a patent has been in force for at most 4 years, 0 otherwise. Renewal category 1 separates patents that have been renewed at least once from patents that never made it to their first renewal. Patents are renewed indeed at their fourth year. Therefore, a patent that have been in force for at most 4 years should have not been renewed even once, at their 4th year. Renewal category 2 takes value 1 if a patent has been in force for years in the interval [5-8], and 0 otherwise. This corresponds to patents that have been renewed once. Renewal category 3: takes value 1 if a patent has been in force for years in the interval [9-12], and 0 otherwise. This corresponds to patents that have been renewed

[16] Another option would be to use independent information on inflation. However, we assume that, besides inflation, other factors might affect the change in patenting costs (innovation or R&D policies, structural adjustments…). In that regards, the implied change in prices that is derived given the two data points (2006 and 2010) is more reliable than just using inflation rate.

for a second time, at their 8th year. Renewal category 4 takes value 1 if a patent has been in force for more than 12 years. This corresponds to patents that have been renewed for the third time, in their 12th year. Such patents might have enjoyed their full term of 20 years. However, there are obviously very few patents in that last category.

(vi) Year dummies: there are 30 year dummies covering the period of applications from 1980 to 2009, to account for year specific characteristics.

(vii) Country dummies: 16 dummies for the countries, listed as sources countries in table 2.1, account for country specific characteristics. These countries are the countries of origin of the primary inventors.

Summary Statistics and Description

The correlation table 5 shows that weighted innovation evaluated according to the family and citation method correlate positively. Cost of patenting is negatively correlated with patent value, i.e., with the citation weighted and family weighted innovation. Family weighted innovation correlates more strongly with patent renewal than citation weighted innovation. However, the magnitude of the correlation is not very high (see table 5). Although most patents are at least protected in the U.S. (87.65% of the patents), only 61.37% of them belong to U.S primary inventors and 21% of them to German inventors[17].

Table 5: Correlation Table

	Renewal Status	Log (Family)	Log (Citation)	Log (Cost)	Years in Force

[17] Some patents have several inventors, but in this study, and without loss of generality, with respect to the conclusions of the study, we use only primary inventors.

Table 5 continued

Renewal Status	1.000				
Log(Family)	0.070	1.000			
Log(Citation)	0.036	0.197	1.000		
Log(Cost)	0.028	-0.173	0.307	1.000	
Years in Force	-0.025	-0.081	0.105	-0.246	1.000

Note: Family weighted innovation (log(Family)) and citation weighted innovation (log(Citation)) are positively correlated. 1,017,644 patent applications are used.

Figure 1 shows that the renewal category, that has the largest number of patents, is the category of patents that have been in force for 9 to 12 years. Patents, in this class of [9-12] years constitute the mode of the distribution.

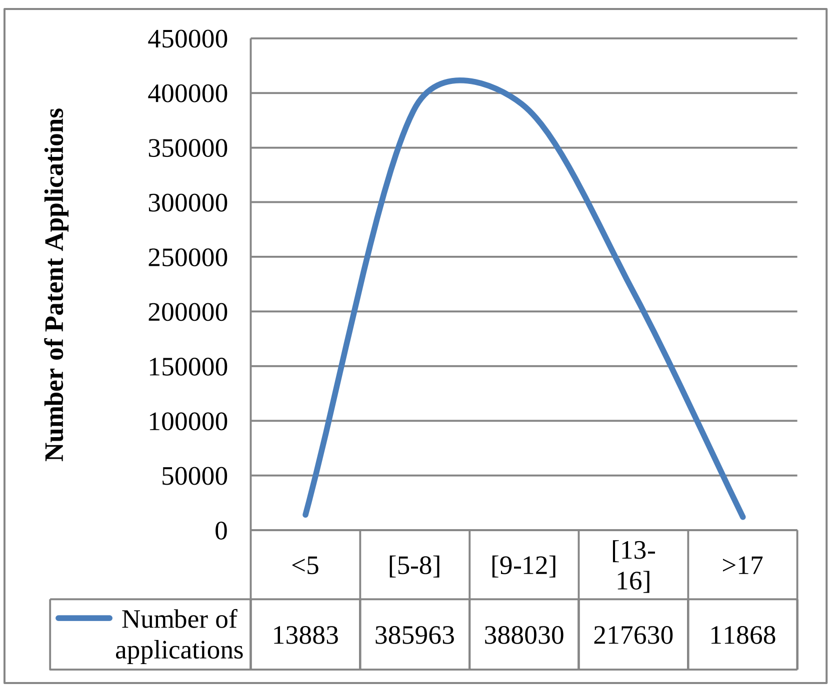


Figure 1: Number of Patent Applications per Years in Force

Note: X-axis = years a patent is in force, aggregated in five cohorts: [0-4], [5-8], [9-12], [13-16], [17-20]. The distributions of patent applications, as shown above, looks like a normal distribution (see the almost bell shape). 388,030 patents in the total sample lived between 9 and 12 years.

However, figure 2 provides evidence that more patents in the cohort of [5-8] years are renewed than in any other cohort. Since comparing patent values across the two valuations methods is more appropriate for patents of the same age, and that the older a patent the more likely it has value, a ranking horse race is performed using the cohort of patents aged more than 8 years[18].

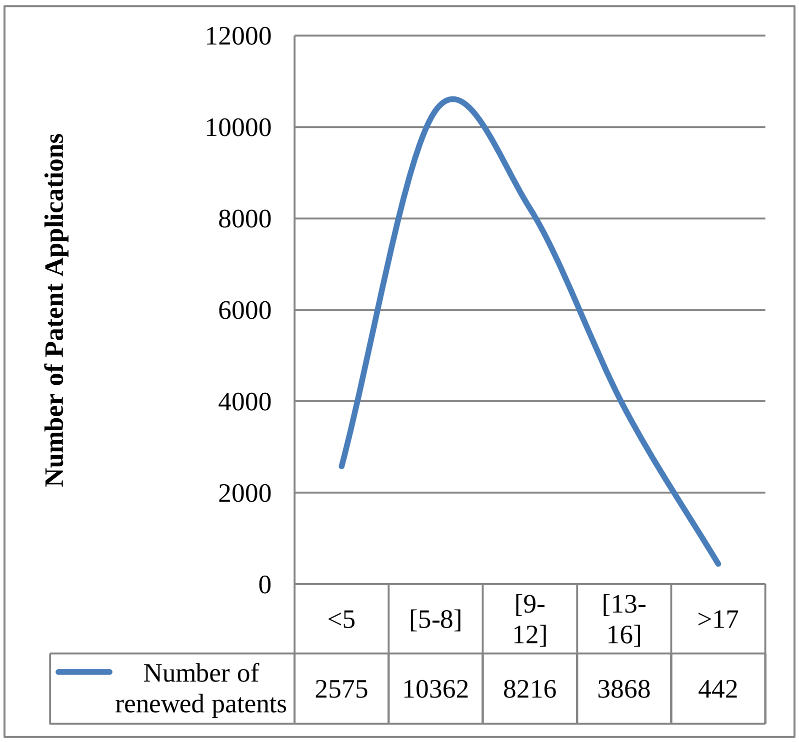
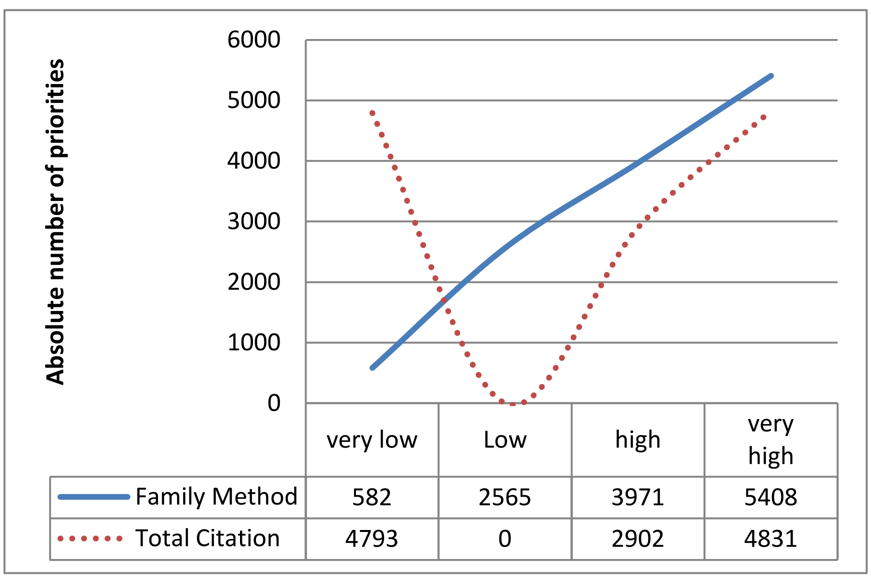


Figure 2: Number of Renewed Patent Applications per Years in Force

Note: - X-axis = years a patent is in force, aggregated in five cohorts: [0-4], [5-8], [9-12], [13-16], [17-20]. The distributions of renewed patents, as shown above, is close to a lognormal distribution. 10,362 patents have been renewed at least once, since they lived between [5-8] years.

[18] There is no substantial difference when performing the exercise with different cohorts.

Figures 3 and 4 show the results of the ranking of the patents, according to their estimated values, using either the family or the citation method. Figure 3 shows the absolute number of patents that have been renewed. However, absolute numbers are not good enough information, if we also want to know whether high valued patents are renewed, and whether low valued patents are not renewed. Figure 4, thus, provides the share or renewed patents in each category of patent value. As explained earlier, we want to observe which method accurately predicts renewal status for high valued patents, and which method wrongly attributes low value to actually renewed patents. The latter case could be termed "type I error", in the sense that the valuation method rejects a true null hypothesis[19].



	very low	Low	high	very high
Family Method	582	2565	3971	5408
Total Citation	4793	0	2902	4831

Figure 3: Number of Renewals in Each Category for more than 8 Year Old Patents

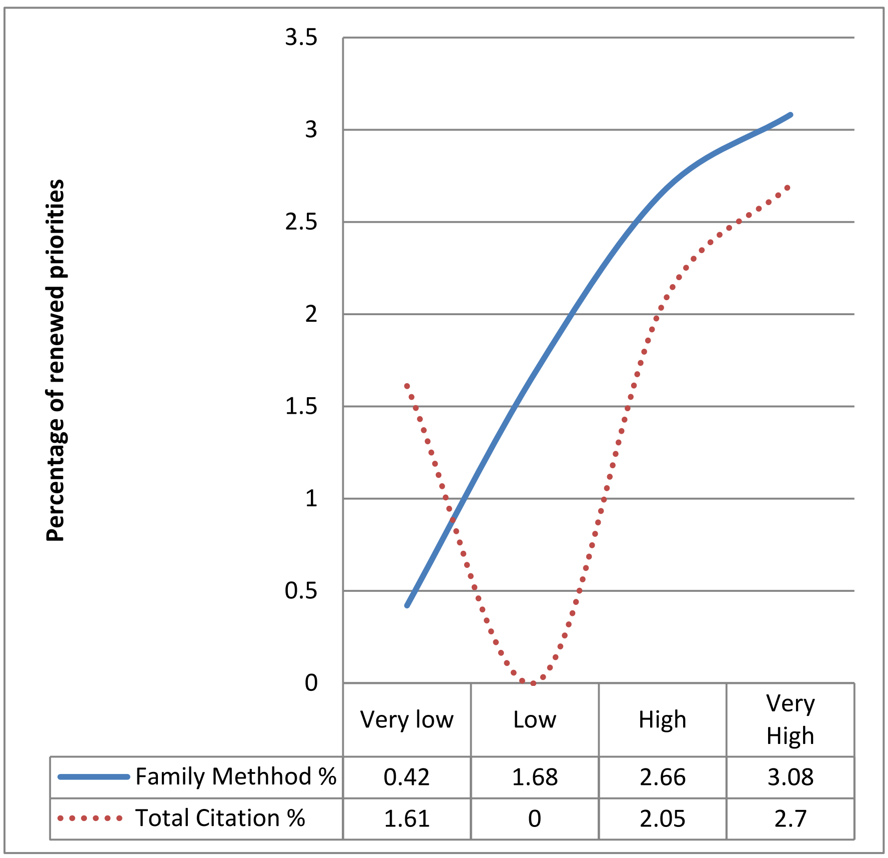
[19] The null hypothesis, here, is that the patent is of high value, since the patent has been renewed. Consider patent P that has been renewed. If a patent valuation method rather classifies patent P as a patent of very low value, the valuation method is wrongly rejecting the fact that patent P is actually of high value, since patent P has been renewed, it must have been classified as high value patent.

Note: - Information on this figure answers the following question: consider patents aged more than 8 years, and which are renewed. How many of them belong to each category (very low, low, high and very high), as measured by each valuation method?
- From all the patents that are more than 8 years old, and that are renewed, only 4.65% (=582/12526) of them are of very low value, according to the family method. However, from all the patents that are more than 8 years old, and that are renewed, up to 38.26% (=4723/12526) of them are of very low value according to the citation method. This gives the extent, or size, of the type I error that each method is subject to (i.e., type I error, defined as rejection of a true null hypothesis. The null hypothesis, here, is that the patent is of high value since the patent was renewed).

Figure 3 shows that up to 38.26% of patents, that are renewed, are deemed of very low value, according to the citation method. Only 3.38% of the renewed patents are deemed of very low value according to the family method. This provides information on the extent to which each method is subject to type I error. Using the family method, 43.17% of renewed patents are considered of very high value. 38.57% of renewed patents are considered of very high value according to the citation method.

Per figures, 3 and 4, the shape of the distribution of patent applications, and renewed patents according to the citation method, suggest that there is a truncation issue with citation data, as suggested by previous studies (Jaffe and Trajtenberg, (2002). As a matter of fact, many patents receive 0 citation. Using five years citations addresses a truncation issue mostly related to the age of patents, but does not address the very issue that citation, as a valuation method, seems to be more relevant only for patents that received positive citations. This issue is addressed in the sampling strategy for parametric analysis, below using sample II.

Sample II, in the parametric renewal and survival analysis, holds patents that have received at least one citation during their early 5 years of life. The intuition, here, is to control for the fact that, if a patent has received 0 citation, during its first 5 years, it is not due, for example, to the fact that the patent is inaccessible in some ways to other inventors. That way, we are ranking patents that all had the opportunity of being known. In our data, 52.89% of patents received 0 citation, during their first 5 years of life. In his data on computer tomography, Trajtenberg (2002) finds that 47.1% of patents receive 0 citations.



	Very low	Low	High	Very High
Family Methhod %	0.42	1.68	2.66	3.08
Total Citation %	1.61	0	2.05	2.7

Figure 4: Share of Renewals in Each Category for more than 8 Year Old Patents

Note: -Information on this figure answers the following question: consider patents aged more than 8 years, which are ranked as very low, low, high and very high value, by each valuation method. How much percent in each category are actually renewed?
- Positive slope tells that the more valuable a patent is, the higher its likelihood of renewal.

- Overall, 2.04% of patents are renewed in the reference population (that is composed of patents aged more than 8 years).
-3.02% of patents of very high value in the family method are renewed. Only 2.71% of very high-value patents are renewed in the citation method.

For descriptive purposes, we also use the product limit estimator proposed by Kaplan-Meier (1958), in order to picture the data, at hand, without imposing any restriction with regards to distributional form (see figure 5). Assume that priority applications are sorted in ascending order, so that $t_1 \leq t_2$ and so on; and no observation is censored. Suppose that there are K distinct survival times in the data, denoted T_K . In the data, $K = 20 \neq n$. K, the maximum full term years for patents, is different from n, the total number of applications; because there are ties as survival time of patents varies from 0 to 20, as shown in figure 5.

Figure 5 provides a non-parametric survival estimation of the life of patents. A good share of patents is "at risk" after 4 years, i.e., they survive or have not yet lapsed during the first 5 years. The share of surviving patents decreases over time with large drops after 5 and 10 years. Most surviving applications (95%) are very likely to survive until age 5 (in years). Afterwards, only half of surviving patents would reach 10 years and 5% of them would last 15 years.

Scherer (1997) found that 8.5% of the patents comprise 80% of patent value which confirm that distribution of patent value is very skewed. The share of priorities that survive more than 20 years is asymptotically close to 0. The results of the Probit renewal analysis and of the discrete time survival analysis support the patterns, unraveled above, on patent renewal and patent survival.

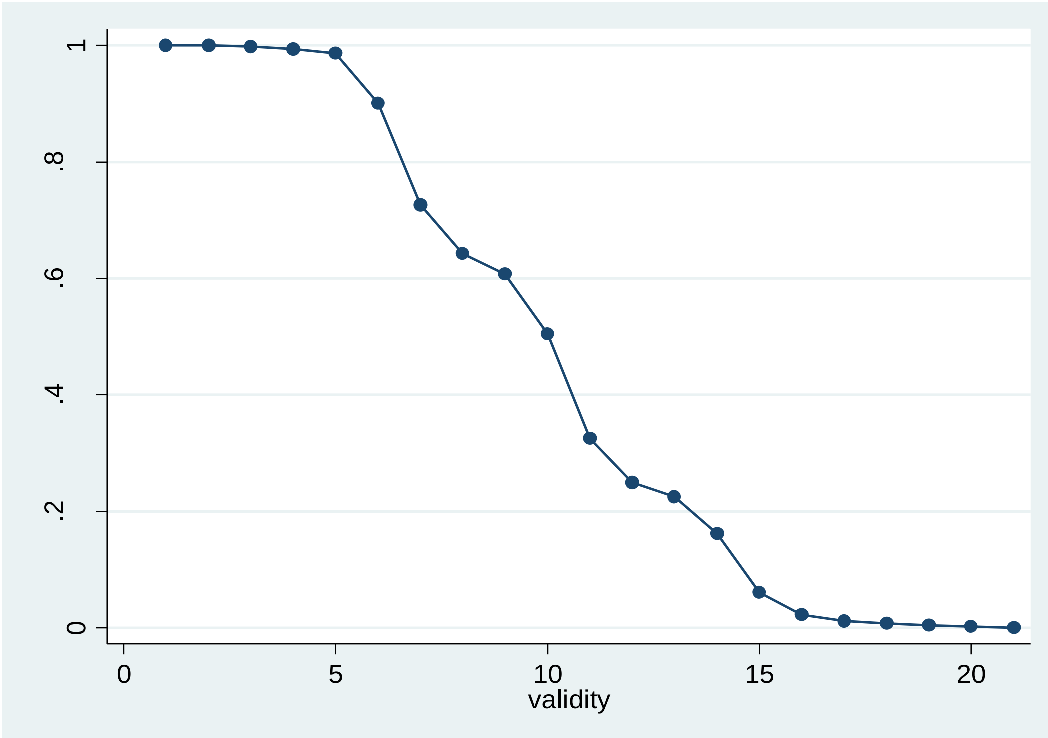


Figure 5: Survival Rate of Patent Applications (1980-2011)

Note: -Patents tend to survive the first 4 years.
-50% of patents are likely to survive at least 10 years.
-5% survive up to 15 years.
-Survival rate is asymptotically close to 0 after 16 years

Given that correlation between the citation and family method is not very strong at patent level, we also rank countries, according to their flows of innovation, where the flow is the logarithm of the mean of innovation, over the 30 years period, from 1980 to 2009. Table 6 gives an overall picture of the means and standard deviation values of flows of innovation, as measured by the family and citation methods. It also ranks the countries of origin, of the primary inventors, according to the two valuation methods. Innovation at country level is computed as the simple mean of the values of patents, whose inventors belong to the country considered. The result of the country ranking is the same according to the two methods and suggests that, at country level, the two methods correlate more strongly.[20]

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Table 6: Innovation Flow from 1980-2010 in the 16 Source Countries

	Mean flow of Innovation		Country Ranking	
Country of Primary Inventor	Log (Mean Family Innovation) (Standard dev.)	Log(Mean number of citation received (Standard dev.)	Family Method	Citation Method
U.S.A[a]	39.61 (39.16)	10.25 (10.06)	1st	1st
Germany[a]	38.10 (37.58)	8.35 (8.09)	2nd	2nd
U.K. [a]	36.86 (36.23)	7.28 (7.00)	3rd	3rd
France[a]	36.78 (36.33)	7.1 (6.92)	4th	4th
Canada	36.43	6.89	5th	5th

[20] The current study is a thorough study at patent level. But ranking of countries according to the two methods should be investigated further, as it is not the main focus of the current study.

[21] The current study is a thorough study at patent level. But ranking of countries according to the two methods could be investigated further.

	(35.98)	(6.67)		

Table 6 continued

Switzerland[a]	36.03 (35.54)	6.38 (6.23)	6th	6th
Italy	35.98 (35.29)	6.25 (5.96)	7th	7th
Sweden	35.55 (34.93)	5.79 (5.51)	8th	8th
Australia[a]	35.32 (34.60)	5.68 (5.34)	9th	9th
Israel	34.98 (34.54)	5.38 (5.11)	10th	10th
Belgium[a]	34.87 (34.59)	5.07 (4.85)	11th	11th
Austria	34.81 (34.30)	5.04 (4.84)	12th	12th
Finland	34.70 (34.08)	4.79 (4.44)	13th	13th
Denmark[a]	34.58 (34.11)	4.69 (4.37)	14th	14th
Ireland	33.14 (32.57)	3.43 (3.19)	15th	15th
Brazil	32.92 (32.41)	2.81 (2.71)	16th	16th

Note: -Family data (2nd column)= log of the mean of innovation flow over the period (1980-2009).
-Citation data (3rd column)= mean of the number of citations received per source country over the same period.
-The two different valuation methods provide the same ranking at country level.

[a]Indicates a destination countries (=countries where patents have legal protection)

Results and Limitations of the New Family Size and Composition Patent Valuation Method

The Results of the Probit and Discrete Time Survival Analysis

Table 7 displays the marginal effects of weighted innovation on the probability of patent renewal. Both types of weighted innovation (family weight and citation weight) have a positive impact on the likelihood of patent renewal. Doubling family weighted innovation results in an increase by 1.34% in the likelihood of patent renewal. The marginal impact is only 0.6% when innovation is citation weighted. As expected, cost of patenting has a negative impact on patenting. Overall, the information from the table 7 provides evidence that both patent valuation methods are able to predict renewal. However, the marginal impact for the family weighted innovation is, at least, twice the marginal impact of the citation weighted innovation (1.34% versus 0.6% for citation method). When only patents that received at least one citation are used in the regressions, the magnitude of the marginal impact of citation weighted innovation increases by 50%, from 0.006% to 0.009%. This suggests that there is a truncation issue for citations, not only in terms of time, i.e., young vs. old patents, but also between patents that have 0 citations vs. patents with at least one citation.

Table 7: Probit Renewal Analysis
Marginal Effects of a change in weighted innovation on the probability of renewal of a patent

Renewal status	Sample I Family Weighted	Sample I Citation Weighted	Sample II Positive Citation Weighted
Log(Family Innovation)	0.013***	-	-
	(0.0003)		
Log(citation Innovation)	-	0.006***	0.009***
		(0.0001)	(0.0008)
Log(Cost)	-0.054***	-0.045***	-0.0776***
	(0.0009)	(0.0010)	(0.0058)
Years in Force	0.007***	0.008***	0.0000
	(0.0001)	(0.0000)	(0.0000)
Renewal Category 2	-0.102***	-0.084***	-0.117***
	(0.001)	(0.0010)	(0.002)
Renewal Category 3	-0.201***	-0.167***	-0.348***
	(0.003)	(0.0023)	(0.006)
Renewal Category 4	-0.120***	-0.103***	-0.266***
	(0.001)	(0.0015)	(0.005)
Year dummies	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes
Observations	1,017,374	1,017,374	460,994
Pseudo-Likelihood	-101,347.36	-102,039.75	-52,153.374
Pseudo-R2	0.1486	0.1428	0.1435

Note: t robust standard errors in parentheses

-Both, the family and citation weighted innovation have a positive impact on patent renewal.
-The magnitude of the marginal impact for family weighted innovation is twice the magnitude of the marginal impact of the citation weighted innovation.
-When only patents that received positive citations are used, the marginal impact increases by 50% (from 0.006% to 0.009%).

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8 shows the hazard rates[22] of the survival analysis using discrete time survival logistic regression. It provides effects of a change in the weighted innovation on the probability of lapsing after a certain time t. Consider a priority patent that survived until time t. The hazard rates help answer the question: how does a change in patent value impact the likelihood for a patent to lapse? In other terms, given that the patent was in force until time t, how does a change in patent value impact the likelihood that the patent will lapse in the next short interval of time, say, Δt?

Table 8: Logistic Survival Analysis
Hazard rates of a change in weighted innovation on the probability of lapse of a patent

Lapse	Sample I Family Weighted	Sample I Citation Weighted	Sample II Positive Citation Weighted
Log(Family Innovation)	-0.237***		
	(0.004)		
Log(citation Innovation)		-0.051***	-0.027***
		(0.002)	(0.005)
Log(Cost)	0.300***	0.947***	1.595***
	(0.017)	(0.014)	(0.048)
Years in Force	-1.247***	-1.244***	-1.310***
	(0.001)	(0.001)	(0.002)
Renewal Category 2	6.100***	6.040***	7.149***
	(0.011)	(0.011)	(0.031)
Renewal Category 3	11.047***	10.975***	12.372***
	(0.014)	(0.013)	(0.014)
Renewal Category 4	15.322***	15.243***	16.792***
	(0.017)	(0.017)	(0.008)

[22] Odd ratios can be computed by taking the exponential of the hazard rates.

Table 8 continued

Year dummies	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes
Observations	9,591,558	9,591,558	4,503,984
Log-Likelihood	-1,505,441.9	-1,507,138	-661,049.61
Pseudo-R2	0.5280	0.5275	0.5466

Note: t standard errors in parentheses
-Both the family and citation weighted innovation have a negative impact on the likelihood that a patent lapses.
-The impact of family weighted innovation is almost 5 times the magnitude of the impact of the citation weighted innovation
-The number of observations is larger than with the Probit regression on table 7. This stems from expanding the data into data suitable for discrete time survival analysis. Ex: assume a patent expired after 10 years. For survival analysis, the same patent will be expended into 10 observations, i.e., the same patent is observed each year until the last year when the patent expires. In that case, categorical variable "lapse" takes value 0 for the first 9 observations, when the patent has not lapsed, but takes value 1 for the last observation when the patent has expired.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Three main points emerge from table 8. First, patents deemed valuable according to the citation and family methods are more likely to survive or not to lapse. As a matter of fact, doubling the value of a priority decreases its likelihood of lapse by 23.7%, for the family valued patents, and by 5.05%, for citation valued patents. Second, the results imply that the impact of family weighted innovation is almost 5 times larger, in magnitude, than the impact of citation weighted innovation. That means that innovation deemed more valuable by the citation is less likely to lapse than citation deemed valuable by the citation method. Third, the fact of using only patents that received at least one citation during their first 5 year does not improve results of the survival analysis, as it is the case for renewal analysis.

Cost of applications increases the likelihood of patent lapse, as expected. The renewal categories have a decreasing impact on patent survival over time. The first renewal impacts more strongly the likelihood of patent death than the second and the third renewal. That shows intuitively that for high value patents, their likelihood of lapsing is lower in magnitude around the time of their first renewal than at the time of their second or third renewal.

The Results of Some Post-Estimation Tests

Post-estimation tests are also used to check the accuracy, goodness of fit, sensitivity and specificity of the regression model (see table 9). Assume a cutoff point of 0.5. That is, a predicted probability p equals 1 if $p \geq 0.5$ and equals 0 otherwise. For example, if a patent has lapsed and the model predicts that such a patent lapses with probability $p \geq 0.5$, then the model correctly predicted the lapse of the patent. This being the case, when the threshold (or cutoff) is 0.95, post-estimation statistics show that in 89.66% of the cases, the model correctly classifies survival, i.e., the model accurately predicts renewal or lapse correctly in 90% of the cases. Furthermore, in order to verify that such a high accuracy of prediction does not depend on the threshold (or cutoff point), a sensitivity test is performed by graphing the ROC curve. The ROC (Receiver Operating Characteristic) curve represents the sensitivity of a binary classifier system when the threshold (or cutoff) is varied. The area under the ROC curve is 95.13% for both family and citation regressions. Last but not least, the goodness of fit test, that reports the Pearson Chi-Square statistics, shows that, we cannot reject the hypothesis that both models are good models. Post-estimation methods, therefore, confirm that both valuations methods are valid patent valuation methods.

At least four conclusions stem from the results mentioned above. First, family size and composition valuation method, as well as citation methods, are consistent and reliable patent valuation methods. Second, the family size and composition valuation method, however, captures patent value, at least, as well as the citation method, as it predicts patent renewal and patent survival more accurately. Another advantage of the family method is that it is an ex-ante patent valuation method. One does not need to wait for time to elapse, in order to be able to infer patent value from the citations. This makes the family method more appropriate for investment decision making. Investors or stakeholders interested in the value of the knowledge portfolio of a firm can have an estimated value of the portfolio. Third, although at patent level, the family method is a strong predictor of renewal, at a country level, the ranking of countries according to the two methods show that the two patent valuations methods are more correlated. Fourth, cost of patenting negatively impacts patent renewal and survival.

Table 9: Post-Estimation Tests for Logistic Survival Analysis of Patent Lapse

Lapse	Family Weighted	Citation Weighted
Classification Test	correctly classified	correctly classified
(cut off: 0.95)	89.66%	89.66%
Table 9 continued		
Pearson Chi2	815839.94	923,300.47
Prob>chi2	0.0000	0.0000
Sensitivity Test	Area under the curve	Area under the curve
(Roc curve)	0.9513	0.9513

Note: Post-estimation tests confirm that both patent valuation methods are strong methods at predicting patent renewal and patent survival. The ROC analysis might not the most relevant. The analysis should be completed by computing the likelihood that the patent is renewed based on coefficient estimates

Limitations of the Family Size and Composition Valuation Method

Despite the strengths of the new family size and composition patent valuation method evidenced by its ability to predict patent renewal and patent survival, some limitations still need to be mentioned.

The first limitation is that being an “ex-ante” patent valuation method is a double-sword as it has both advantages and disadvantages. One of the main limitations is that the family method estimates the value of a patent, before the life of the patent is over. To that extent, the question discussed in the first subsection of section 2 about the “true” value of a patent is very crucial. Obviously, the “true” value of a patent has to be “ex-post”, or “after the fact”, i.e., after the patent has died. However, for decision making purposes, investors and innovators need to anticipate. That justifies why the family size and composition method could be a good tool for decision making.

The second limitation concerns the proxy used for potential market, in order to construct the weight of patents. Ranking of patents could be affected by the proxy used (GDP, Private GDP or value added). However, changes in ranking will be only in absolute terms, but not in relative terms. This means that for two given patents, Y and Z, if patent Y is deemed more valuable than patent Z, when GDP is used as a proxy for potential market, it should always be the case that Y is more valuable than Z, whatever the proxy used. However, the absolute value of patents Y and Z may vary depending on the proxy. In this study, we used GDP as explained in note 7.

The third limitation relates to measurement errors. Whatever the proxy for potential market is, estimation, using the family size and composition valuation method, relies on the quality of data from national accounts, such as GDP, private GDP or value added. To that extent, this limitation, although worth being mentioned, is not intrinsic to the method per se.

A fourth limitation, pertains less to the method, per se, than to the data used for this study, as we use fixed, instead of, real time GDP to proxy for potential market. The use of fixed GDP, however, does not affect the results of our study. In order to provide real time value of patents, we would need to take into account the change over time of the size of the potential market, whatever the proxy for that potential market is (GDP, private GDP, value added…). The use of real time proxies would be very recommended for a comparison of patent portfolios, for instance, across firms, for the purpose of investment.

Despite these three limitations, the family size and valuation method provides a very practical, *ex-ante* decision making tool for investors and stake holders in knowledge portfolios. For instance, the search for the right proxy suggests that proxies could be tailored to the type of innovation or sector investigated (for instance, value added in computer, equipment, pharmaceutical industry could be used…). If the patents studied are mostly produced and marketed in the private sector, using private GDP as proxy for potential market will be more relevant.

Conclusion

In this study, we have developed a new method of patent valuation, termed, "the family size and composition patent valuation method", that is an *ex-ante* patent valuation method. In comparison to the citation or renewal methods of patent valuation, the advantage of the family size and composition method is that it does not estimate values only for older technology. The new method does not also suffer from a truncation bias, as discussed above. The empirical part of our study uses PatStat 4.21 April 2011 edition from the European Patent Office, as well as data from Global IP estimator, and the World Development Indicators. We use quartile rankings to capture renewal rates across a quality ladder according to the two valuation methods. We find that the family size and composition valuation method and the citation method, both, predict patent renewal reliably. Our study builds on prior literature (Schankerman (1984), Schankerman and Pakes (1984), Pakes (1986), etc.) that already provide evidence that renewal of patents constitutes evidence of high patent value. This being the case, the findings of the current study confirm prior research (Trajtenberg (1990), Albert et al. (1991), Hall et al. (2005), etc.) on the importance of citations as a proxy for patent value.

Furthermore, family size and composition method strongly predicts patent renewal and survival. Patents deemed valuable according to the family size and composition method are more likely to be renewed. They are also more likely to survive, or less likely to lapse, than citation valued patents, across different specifications, that are designed to give a head start to the citation method. In that regards, our findings builds on, and extends, the insights of the followings researchers, who posit that the number of jurisdictions, where patents are protected, is correlated with patent value: Putnam (1996), Barney (2002), Hingley and Park (2003), Lanjouw and Schankerman (2004), and Van Zeebroeck (2008). Moreover, our findings extend theirs, by providing empirical evidence that the number of jurisdictions and the market size of these jurisdictions are strongly correlated with patent value, when patent renewal is used as a benchmark. The fact that a small share of patents, in the data, are renewed confirm also the findings of Scherer

(1997), who showed that, as far as the distribution of patent value is concerned, little is worth lots, and lots is worth little. In addition, when innovation is aggregated at country level, the two methods provide the same ranking for countries. That suggests that the two valuation methods correlate strongly at country level. As mentioned above, results also provide evidence that patenting cost negatively impacts renewal.

This study makes three important contributions to the patent literature. First, it confirms that the citation valuation method is a good valuation method as suggested by Trajtenberg (1990), Albert et al. (1991) and Hall (2005). Second, it shows that when using citation as a valuation method, the truncation issue does not arise only with respect to time (old versus new patents) but also with respect to whether or not a patent receives citation (i.e., patents with 0 versus patents with at least 1 citation). The citation method is a better fit, mostly, to rank patents that have received a strictly positive number of citations, during the first 5 years of their life. Third, and most importantly, this study provides a new patent valuation method that predicts patent renewal, at least, as well as the citation method. The new *ex-ante* family method would be of substantial help to investors in intangible capital, as well as to researchers working on patent portfolios, in order to estimate the value of their patent portfolios.

The results of our study are robust to different sampling and refinement to give a head start to the citation method. However, there is convergence between the two methods when innovation is aggregated at country level. Further studies could build on the current one to use this novel valuation method to investigate and characterize levels of innovation, not only in developed, but also in developing countries. In particular, regional studies (on Africa, South East Asia, Latin America, Central Eastern Europe, OECD…) as well as sectoral studies (across firms and industries…), using family weighted innovation, would complement the present study.

CHAPTER 3

IMPACT OF INTELLECTUAL PROPERTY RIGHTS ON INNOVATION, TECHNOLOGY DIFFUSION AND TECHNOLOGY GAPS

The aim of this chapter is to study the impact of Intellectual Property Rights (IPR) on the flows of innovation, technology diffusion, and Total Factor Productivity (TFP), controlling for other factors. The study investigates the impact of IPR, using the novel patent valuation method[23], termed, "the family size and composition patent valuation method", developed in chapter II, as well as the citation method. In the family size and composition valuation method, patents are weighted by the potential market of the countries where they have legal protection. In the citation method, patents are weighted by the number of citations that they receive during the first 5 years, after publication. Local[24] innovation is measured as the flow of innovation originating from resident inventors and technology diffusion is the flow of innovation originating from non-resident inventors. The technology gaps between countries are proxied by their levels of TFP.

[23] In another chapter (chapter II of this dissertation), Walter Park and I, provide details on the construction of the family size and composition patent valuation method.

[24] In this chapter, the terms, local, national, domestic and resident describe the same reality when applied to innovation or knowledge capital. The counterparts of these terms are international, foreign, non-domestic and non-resident.

Many studies have already investigated the impact of IPR on innovation, technology diffusion and technology gaps. However, these studies tend to use simple patent count as a proxy for innovation and technology diffusion. As discussed previously[25], using simple patent counts data has limitations. When innovation and technology diffusion are proxied by simple patent count, coefficients can be interpreted, at best, as the impact of IPR on the number of patents or on the propensity to patent. When innovation and technology diffusion are proxied by the family size and composition valuation method, coefficients are interpreted as the impact of IPR on the generation or diffusion of valuable technology.

The main contribution of this chapter is, therefore, to revisit prior findings on IPR, as a determinant of innovation and technology diffusion. In an open economy setting, Xu and Chiang (2005) study also the determinants of foreign patent inflow. They find that the number of foreign patents, per thousand workers, depends on the level of IPR protection, and on the volume of foreign trade and the technology level relative to the United States. In that regard, my approach builds on Xu and Chiang (2005), but differs from theirs not only in terms of methodology but also in terms of the scope of the study. First, in my study, innovation is evaluated according to a novel patent valuation method. Second, I study both the impact of IPR on local innovation, technology diffusion and technology gaps for a longer period of time from 1980 to 2005.

Furman et al. (2002), investigate the determinants of national innovative capacity and find that differences in the level of inputs devoted to R&D productivity, such as IPR

[25] Please see chapter II of this dissertation.

protection, plays an extremely important role. They introduce a novel framework based on the concept of national innovative capacity. Empirically, they examine the relationship between international patenting (patenting by foreign countries in the U.S.A) and variables associated with the national innovative capacity framework. With respect to the scope of my study, international patenting is analyzed for 10 countries, and for patents originating in 24 countries.

Fagerberg (1994) points out that global technology gaps can arise because countries do not share the same pool of knowledge. International patenting flows tend to be concentrated among developed economies. In that regard, weak patent protection acts as a barrier to technology diffusion that could reduce international technology gaps since weak patent protection inhibits patenting.

My study, thus, contributes to the literature in two respects. First, it shows whether the use of an alternative patent valuation method affects predictions, on the impact of IPR on the generation of valuable knowledge and the diffusion of valuable technology. Second, my study investigates heterogeneity of impact of IRP on local innovation and technology diffusion across levels of technology, i.e., whether the impact of IPR reduces technology gaps.

The second and third sections of this chapter present the theoretical and empirical framework. Section four discusses the data used and the results of the study. Part five provides concluding remarks.

Theoretical Framework[26]

International Patenting Behavior

Assume an N country world. The objective here is to determine the flow of knowledge produced by inventors in country j. Assume for now that the flow of knowledge is proportional to some extent to the quantity of patents that will be filed by inventors of country j in some country n. The case where $j = n$ refers to domestic or resident patent applications, and $j \neq n$ to foreign patent applications. The country from which patents originate is the source country, and the country in which patents are filed is the destination country.

Assume that in the j^{th} source country there are Q_j patentable inventions. Let $q_j = 1, 2, \ldots Q_j$ denote the quality of these inventions in ascending order; that is, invention 1 is of a lower quality than invention 2, which in turn is of a lower quality than invention 3, and so forth. Some, all, or none of these Q_j inventions may be patented at home or abroad. The variations in international patenting depend on three kinds of heterogeneity: (i) market heterogeneities (some destinations are more attractive than others); (ii) invention heterogeneities (some inventions are more valuable than others); (iii) heterogeneity between source countries (some source countries are more inventive than others).

To determine the extent of patenting between a given pair of source and destination countries, the focus will be on the first two kinds of heterogeneity. To begin,

[26] This theoretical part is based on Park (2009).

note that an inventor will seek patent protection if the net benefit of patenting exceeds the cost of filing for protection - say,

$$\Delta V = V^{PAT} - V^{NOPAT} \geq c \tag{1}$$

where V^{PAT} and V^{NOPAT} denote the value of a firm with and without patent protection respectively, and c the cost of filing a patent. The underlying logic is that inventors have means other than patent protection to appropriate the rewards from their innovation (such as lead times, reputation, and secrecy). Thus the value of a patent is the incremental return an inventor can get above and beyond that which can be realized by alternative (non-patenting) means.

To be more concrete, let $\pi_n(q_j)$ be the instantaneous flow of profits to the q^{th} invention from country j that is exploited in market n (again, if $j = n$, the invention is being exploited in the home market). The profits are a function of invention quality, which in turn depends on where the invention is from (hence the reason q is indexed by j). For simplicity, assume that this function is linear; that is, $\pi_n(q_j) = q_j\bar{\pi}_n$, where $\bar{\pi}_n$ is some base level of profits (depending on market size). Each firm also faces hazards of imitation in market n. Assume that imitation acts like a tax on profits, and denote by h the rate at which profits are appropriated by imitation. Thus net instantaneous profits are:

$$\pi_n(q_j) = q_j\bar{\pi}_n(1 - h(\theta_n)), 0 \leq h \leq 1 \tag{2}$$

where h is a function of θ_n, an index of the strength of patent protection in market n (with derivative $h'(\theta_n) < 0$). Assume that $\theta_n \in [0, \theta_{\max}]$, where $\theta_n = 0$ corresponds to the case of no patent laws and $\theta_n = \theta_{\max}$ to that where patent laws are as strong as possible (corresponding to say some international standard). Note that $h(\theta_{\max})$ need not equal 0 nor $h(0)$ equal 1; that is, patent protection and imitation may both be imperfect. Assume that if patent protection is not obtained in market n, the benchmark imitation rate is $h = \bar{h}_n$.

The value of invention q_j with a patent in market n is the present discounted value of the future stream of profits:

$$V_n(q_j) = \int_0^{\infty} e^{-rt}\pi_n(q_j)'dt = \frac{q_j\pi_n(1 - h(\theta_n))}{r} \tag{3}$$

where r is the real interest rate. Without a patent, the value of invention q_j is the above expression with $h(\theta_n)$ replaced by $\bar{h}_n$. That is, a patent in market n enables the patentee to `purchase' a reduction in the incidence of imitation, the benefit from which is reflected in an increase in firm value:

$$\Delta V_n(q_j) = V_n(q_j)^{PAT} - V_n(q_j)^{NOPAT} = \frac{q_j\pi_n(h_n - h(\theta_n))}{r} \tag{5}$$

Given the cost of obtaining a patent in market n (denoted by c_n), the q_{th} inventor from source country j will patent in market n if $\Delta V_n(q_j) \geq c_n$. Thus equation (5) helps identify factors which matter to the patenting decision; namely, market size (as reflected in the basic level of profits) $\bar{\pi}_n$), level of patent rights θ_n , cost of patenting c_n , invention quality q_j , and imitative capacity of local agents, as reflected in $\bar{h}_n$. The greater their imitative capacity, the greater is the incentive of the inventor to patent and prevent the misappropriation of profits.

The critical quality level for country j's inventions in market n is

$$q_{jn}^{*} = \frac{rc_n}{[\bar{\pi}_n(h_n - h(\theta_n))]} \qquad (6)$$

obtained by equating $\Delta V_n(q_j)$ and c_n . Only inventions whose quality levels exceed this critical level are patented in market n . The higher the cost of patenting, the higher the critical cutoff quality q_{jn}^{*} ; in other words, fewer (and higher quality) inventions are worth patenting. The stronger the level of patent protection or the larger the market size, the lower the critical cutoff is Thus, the critical quality level q_{jn}^{*} is a function of market n s characteristics - that is, $q_{jn}^{*} = q_{jn}^{*}(x_n)$, where x_n is some weighted aggregate of market fundamentals (such as market size, patent protection level, imitative capacity, and patent filing costs).

Given q_{jn}^{*} , the quantity of patent applications from country j in country n - denoted by P_{jn} - can be predicted. All $q_j \in [q_{jn}^{*}, Q_j]$ are patented in market n and $q_j \in [1, q_{jn}^{*})$ are not. That is,

$$P_{jn} = Q_j - q^*_{jn} = Q_j - q^*_{jn}(x_n) \tag{7}$$

Finally, controlling for x_n, there are also variations in P_{jn} due to a third type of heterogeneity - namely differences in inventiveness between source countries-. Inventiveness can refer to the overall quantity and/or quality of patentable inventions produced. Let ι_j be the level of inventiveness of the j^{th} source country. As a variant on Eaton and Kortum (1996), it is assumed that $\iota_j = \iota S_j^{\gamma} L_j^{1-\gamma}$, where S denotes scientists and engineers, L total labor, and γ and ι are parameters. The idea is that `inventiveness per worker is related to the fraction of workers engaged in research and inventive activity (i.e. S_j/L_j). The ι_j variable is used to help control for differences in the quantity and quality of inventions between source countries[27].

In particular, the source country's level of inventiveness is assumed to affect the total quantity of patentable inventions as well as the critical quality level. Hence:

$$P_{jn} = Q_j(\iota_j) - q^*_{jn}(x_n, \iota_j) = P_{jn}(\iota_j, x_n) \tag{8}$$

where the greater the ι_j, the greater the number of patentable inventions (i.e. $\frac{dQ_j}{d\iota_j} > 0$) and/or the lower the critical `cutoff' quality (i.e. $\frac{\partial q_n}{\partial \iota_j} < 0$). In summary, patent flows

[27]Of course the productivity of scientists and engineers can vary across countries as well so that inventors in some country could produce more patent-worthy inventions than those in other countries (holding other factors constant). That kind of heterogeneity is more difficult to capture and is not attempted here.

from country j to country n have been derived as a function of both source and destination attributes.

Total Factor Productivity

Consider the following aggregate production function (which is a variant of that from Rivera-Batiz and Romer (1991)):

$$Y = L^{1-\beta}[\int_0^A x_i^a d_i][\int_0^{A^*} x_{i^*}^{*a^*} d_{i^*}] \tag{9}$$

where Y denotes output, L labor, x domestic intermediate capital goods, x^* imported intermediate capital goods, A an index of the most recently invented domestic good, and A^* an index of the most recently invented foreign good. The stock of national physical capital is:

$$K = \int_0^A x_i d_i + \int_0^{A^*} x_{i^*}^* d_{i^*} \tag{10}$$

To simplify this further, assume $x_i = \bar{x}$ and $x_{i^*}^* = \bar{x}^*$ for all i, i^* respectively (so that $K = A\bar{x} + A^*\bar{x}^*$). Let η be the share of domestic intermediate capital goods in the stock of national capital; that is, $A\bar{x} = \eta K$ and $A^*\bar{x}^* = (1-\eta)K$. Substituting these relationships into equation (10) yields:

$$Y = L^{1-\beta}[\Lambda K^{\alpha+\alpha^*} A^{1-\alpha} A^{*1-\alpha^*}] \text{ where } \Lambda = \eta^{\alpha}(1-\eta)^{\alpha^*} > 0 \tag{11}$$

letting $\beta = \alpha + \alpha^*$ gives:

$$Y = (TFP)K^{\beta}L^{(1-\beta)}, \text{ where } TFP = \Lambda A^{1-\alpha}A^{*1-\alpha^*} \tag{12}$$

In the Empirical part, below (see section 3) I use flows instead of stocks. Hence, TFP is a function of the flows of both domestic knowledge (A) and foreign knowledge (A^*):

$$TFP = TFP(A, A^*) \tag{13}$$

As discussed later, the flows of domestic and foreign patents is used as measures of A and A^* , respectively. A rationale for this is that patents embody particular pieces of novel scientific and technological knowledge[28]. In the current study, where the focus is the impact of IPR on innovation, TFP is assumed to depend IPR, on innovation, technology diffusion and other variables.

Empirical Model: Construction of Variables and Measurement Issues

In order to test the impact of IPR on the generation of valuable innovation and the effect of innovation on TFP, as suggested by equation (8) and (13) above, I estimate the

[28]Note, however, the assumption in (11) that domestic and foreign patentable knowledge are not perfect substitutes. Patentees may have tailored inventions to national or local markets. There might also be important quality differences. Given the generally higher cost of filing patents abroad, patentees may file patents abroad only for inventions of rather high quality or high value.

equations (14), (17) and (18) below, using panel data, time series cross sectional autoregressive AR(1) Feasible Generalized Least Squares with heteroskedastic panels.

For the purpose of the empirical investigation, equation (8) is simplified to take, mostly, into account the characteristics of the destination country, as the focus of my study is on the impact of the IPR protection in the destination country. The implicit equation (8) can therefore be rewritten as follows:

$$\ln(P_{i,t}) = \alpha + \beta \ln(IPR_{i,t}) + \lambda \sum_{n=1}^{10} \ln(X^{n}{}_{i,t}) + \varphi_i + \phi_t + s_{i,t} \tag{14}$$

In equation (14), $i = 1,2,3..10$ represents countries and $t \in [1980, \quad 2005]$, the year of patent publication. Equation (14) means that the flows of innovation and technology diffusion depend on the level of IPR protection and on a vector, $X_{i,t}$, of control variables that will be discussed in section 4, below. The dependent variable, $\ln(P_{i,t})$, is considered, here, as a proxy for the flow of local innovation when it represents the value of knowledge available in country i and originating from the resident inventors in country i. $\ln(P_{i,t})$ is a proxy for technology diffusion when it represents the value of knowledge available in country i but originating from the inventors in country j, with $i \neq j$. In the regression analysis, the dependent variable is computed in two different ways. For the first one, the dependent variable is computed as the family size and composition value of the patent portfolios at country level per year. For the second one, the dependent variable is the flow of citations received by patents protected in country *i*. Only citations received in the first 5 years[29] are counted.

In equation (14), φ_i and ϕ_t are respectively country and year dummies that capture country and year specific characteristics. As such, they are correlated with the regressors. $s_{i,t}$ .are random disturbances.

The imitative capacity of a country is defined as the convex combination of the two characteristics that are considered in the literature as indicators of the technological capacity of a country, namely, S&E, the number of researchers per million inhabitants and, RDY, the expenditure in R&D as a share of GDP. Patentees may perceive the hazard of imitation to be high in countries where innovative capacity is high.

The index of imitative capacity is given by:

$$IMIT = \theta_s(S\,\&\,E) + \theta r(RDY) \tag{15}$$

where

$$\theta_s = \frac{(var(S\&E)^{-1})}{(var(S\&E)^{-1}) + (var(RDY)^{-1})} < 1 \tag{16}$$

Equation (16) means that the weights are based on the relative precisions (or the inverse of the variances) of S&E and RDY in the sample.

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[29] Bottazi and Peri (2005) use the average number of citations received other the first 3 years. Whatever the number of years used, the point is that a truncation issue arises with respect to new technology that does not have time to receive enough citations. For more discussion about this, please refer to the second chapter of this dissertation.

Trade inters equation (14) as the sum of imports and exports, the rational being that imports could be used as intermediary goods for production, so that both imports and exports reflect the innovative capacities of a country. The other variables include patenting cost, the percentage of tertiary education, labor, the share of high technology in exports, economic freedom and population.

The implicit equation (13), for TFP, can be rewritten as follows by taking the log of the equation:

$$\ln(TFP_{i,t}) = \tau \ln(A_{i,t}) + \vartheta \ln(A^{*}{}_{i,t}) + \varepsilon_{i,t} \tag{17}$$

Where $\tau + \vartheta = 1$, assuming constant returns.

$A_{i,t}$ ($A^{*}{}_{i,t}$) represents the flow of local (international) knowledge capital, created at country level, where patent portfolios are evaluated according to two measures of the flow of innovation and technology diffusion. The first measure is innovation and technology diffusion evaluated according to the family size and composition patent valuation method. With respect to the second measure, patent portfolio is evaluated according to the citation method. In order to test the direct impact of IPR on technology gap, I control for IPR and other control variables in (17), as follows:

$$\ln(TFP_{i,t}) = \tau \ln(A_{i,t}) + \vartheta \ln(A^{*}{}_{i,t}) + \eta \ln(IPR_{i,t}) + \rho \sum_{n=1}^{8} \ln(Z^{n}_{i,t}) + \varepsilon_{i,t} \tag{18}$$

Equations (18) implies that TFP is a function of domestic innovation ($A_{i,t}$), foreign innovation ($A^{*}{}_{i,t}$), the level of IPR and a vector, $Z_{i,t}$, of other independent variables that are mostly taken from the set of variables used also in equation (14) above. I consider that IPR impacts TFP, indirectly, through domestic innovation and foreign technology diffusion (see equation (14)) and directly, as indicated by equation (18)). Thus, I check to which extent the level of valuable innovation and IPR affect the productivity gaps between countries, where productivity gaps are proxied by levels of TFP.

FGLS is used in the regression analysis of equations (14) and (18). GLS takes heteroskedasticity into account and Feasible GLS estimates the heteroskedasticity before performing GLS. The 10 destination countries studied, here, are heterogeneous in terms of their innovative capacity, level of IPR protection, potential market for innovation, etc. It is, therefore, reasonable to assume that the variance of the error terms could change (increase of decrease), over time and across countries, given that the data is a panel data. This results in heteroskedastic variance of the error term across countries. In addition to not having homoskedastic variances, error terms are likely to be correlated within panels. This justifies the use of AR1 panel specific autocorrelation. When using FGLS, the dependent variable is the log of innovation estimated, according to the family size and composition patent valuation method. I also build on Park and Lippoldt (2008), in their study of technology transfer and the implications of the strengthening of IPR in developing countries, to use FGLS for the current study.

The Data and the Analysis of the Results

The Data

I use five main sources of data. The first data set is PatStat, the World Wide Patent Statistical database gathered by the European Patent Office (EPO). The second data set is the 6.3 version of Penn World Table from the State University of Pennsylvania (PWT 6.3

henceforth). The third data set are taken from the World Development Indicators (WDI henceforth) from the World Bank and the fourth is patenting cost data, from Global IP estimator. The fifth data include institution variables, taken from the Frazer Institute, on economic freedom.

A sub-sample of PatStat is used for our study in chapter II and, section III, of the same chapter, provides a detailed description of PatStat. PatStat is a snapshot of the source databases at a single point in time and covers a very long period from the early 20th century to the 2011 edition, used for this study. The source databases include information from around 160 countries in the world and millions of observations that characterize patents. Besides national patent offices, regional patent offices, such as ARIPO, OAPI, EPO, etc., also provide patent information used in PatStat.

For the purpose of this study and because of lags in the process of patent publications and citations received, I use an unbalanced sample panel data covering the period 1980 to 2005, for 24 sources countries and 10 destination countries. A list of these countries is provided in table 10 of the appendix. The sample studied contains 2,302,307 patents among which 1,068,236 are first filings and 1,234,071 are patent priorities[30]. The total sample is collapsed into 196 observations of local innovation and technology diffusion flows for the 10 destination countries. The unit of analysis is country-year. That means that not all destination countries have data covering the whole period of 26 years from 1980 to 2005. It is not surprising that not all variables are available for that length of time. As a matter of fact, variables such as labor and capital per worker gathered from

[30] Please, refer to the appendix of chapter II, of this dissertation, for definitions of IPR related technical terms.

version 6.3 of Penn World Table are only available from 1980 at the earliest, and better from the late 1990s. TFP data is derived from capital per worker and GDP per worker according to equation (19) below. Gross expenditure in R&D, as well as GDP, are taken from the WDI.

There are 6 main groups of variables of interest in my study. Summary statistics of the variables used are provided in table 11 and the correlation matrix in table 12. The correlation matrix shows (table 12) that family weighted innovation and citation weighted innovation are positively correlated (0.21 for resident or location innovation and 0.08 for technology diffusion), at country level. Innovation valued according to the two methods is also positively correlated with TFP (with a correlation of 50% for the family method).

Table 10: Sample of 24 Source Countries and 10 Destination Countries

Australia[a]	Denmark	India	Mexico	Sweden
Austria	Finland	Ireland	Netherlands[a]	Switzerland[a]
Belgium[a]	France[a]	Italy	Norway	Turkey
Brazil	Germany[a]	Japan[a]	Spain[a]	United Kingdom[a]
Canada	Hungary	Korea	South Africa	United States[a]

Note: A destination country is the country where a patent has legal protection; A source country is the country of origin of a patent applicant.

[a]The Ten destination countries. Belgium is only a destination country (but not a source country).

Table 11: Table of Summary Statistics (Average over the Period 1980 to 2005)

	Log(F. Res)	Log(F. N.Res)	Log(C. Res)	Log(C. N. Res)	Log(IPR)	Log(Imitation)	Log(Cost)	Log(FTP)	Log(Trade)	Log(Labor)	Log(Hitech)	Log(Stock.Market)	Education	Freedom	Log(Population)
Australia	14.78	31.64	0.93	3.90	1.35	1.16	0.34	7.03	25.47	15.99	19.42	23.38	3.94	8.36	16.69
Belgium	-	27.13	-	1.07	1.49	4.28	072	-	6.57	-	7.20	23.66	3.00	7.85	16.13
Germany	35.74	35.62	7.85	7.62	1.39	3.09	0.60	7.23	27.46	17.47	17.21	18.78	1.00	8.23	18.20
France	34.76	35.04	7.02	7.09	1.41	3.07	0.62	6.96	26.97	17.05	16.92	18.35	3.56	7.35	17.86
Japan	29.36	29.96	2.23	3.27	1.33	1.50	1.24	7.29	27.37	17.96	16.26	18.10	2.84	7.68	18.63
Netherlands	25.55	20.60	2.15	1.40	1.45	3.40	0.60	6.10	26.60	15.81	18.78	20.33	3.75	8.61	16.55
Spain	31.62	30.84	4.45	3.02	1.42	5.78	0.83	7.25	26.37	16.69	22.58	26.59	4.00	7.06	17.51
Switzerland	27.90	12.62	1.40	0.40	1.40	1.08	0.72	7.32	25.86	15.18	23.00	21.03	3.21	8.67	15.76
U.K	30.80	33.64	5.39	5.72	1.45	3.45	0.33	7.51	27.22	17.17	19.29	21.54	3.64	8.00	17.88
U.S.A	39.95	39.93	11.74	11.56	1.55	2.60	0.69	7.56	28.10	18.70	16.78	20.56	4.07	8.38	19.37

Note: -Log(Patent Cost)=log(1+x) with x=(cost in country i)/(US cost)
-U.K.: United Kingdom, -U.S.A.: United States of America
-p.c.: per capita
-F. Res: resident innovation flow evaluated according to the family method.
-F. N.Res: non-resident technology transfer evaluated according to the family method.
-C. Res: resident innovation flow evaluated according to the citation method.
-C. N.Res: non-resident innovation flow evaluated according to the citation method.
-Notice that The U.S.A, Germany and France are the top technology leaders both according to the family and citation methods. This shows, to some extent, that the two valuation methods are positively correlated.

Table 12: Correlation Matrix Between the Main Variables

	Log(F. Res)	Log(F. N.Res)	Log(C. Res)	Log(C. N. Res)	Log(IPR)	Log(Imitation)	Log(Cost)	Log(TFP)	Log(Trade)	Log(Labor)	Log(Hitech)	Log(Stock. Market)	Education	Freedom	Log(Population)
Log(F. Res)	1.000														
Log(F. N.Res)	0.841	1.000													
Log(C. Res)	0.210	0.391	1.000												
Log(C.N. Res)	0.228	0.076	0.017	1.000											
Log(IPR)	0.463	0.174	0.124	0.176	1.000										
Log(Imitation)	0.136	-0.097	-0.018	-0.052	0.606	1.000									
Log(Cost)	-0.131	-0.271	-0.274	-0.106	-0.082	0.031	1.000								
Log(TFP)	0.493	0.380	0.273	0.362	0.568	0.205	-0.705	1.000							
Log(Trade)	0.685	0.533	0.114	0.048	0.514	0.290	0.243	0.198	1.000						
Log(Labor)	0.677	0.672	0.179	-0.078	0.285	0.065	0.282	-0.012	0.875	1.000					
Log(Hitech)	0.105	-0.125	-0.135	0.079	0.498	0.439	0.003	0.177	0.058	-0106	1.000				
Log(S.Market)	0.157	-0.040	-0.080	-0.001	0.546	0.459	-0.004	0.173	0.114	-0.016	0.941	1.000			
Education	-0.033	-0.041	0.036	0.031	0.264	0.039	-0.091	0.169	-0.121	-0.078	0.186	0.210	1.000		
Freedom	0.054	-0.120	0.079	0.258	0.470	0.267	-0.167	0.313	0.076	-0144	0.365	0.347	0.068	1.000	
Log(Pop)	0.683	0.687	0.184	-0.102	0.266	0.063	0.269	-0.014	0.866	0.998	-0.124	-0.030	-0.079	-0.180	1.000

Note: -F. Res: resident innovation flow evaluated according to the family method.
-F. N.Res: non-resident technology transfer evaluated according to the family method.
-C. Res: resident innovation flow evaluated according to the citation method.
-C. N.Res: non-resident innovation flow evaluated according to the citation method.
-Log(Pop)=Log(Population), Log(S.Market)=Log(Stock market as a share of GDP), p.c.: per capita
-Resident and local innovation flows are more correlated across the two patent valuation methods than non-resident or foreign innovation.

(i) Innovation, technology diffusion and TFP: the first dependent variable is the logarithm of the flows of knowledge evaluated according to either the citation method or the family size and composition valuation method. An innovation flow of country i, according to the family method, equals a weighted sum of the number of patents owned by residents of country i, where the weight is computed as the sum of the potential market of the countries where patents are protected (see chapter II for a detailed presentation of the family size and composition patent valuation method). As for the citation method, weight is computed as the sum of citations received during the first 5 years.

The second dependent variable of interest is TFP. As mentioned earlier, in regressions on TFP, innovation and technology diffusion inter regressions as independent variables according to the empirical model specified in equation (18) above.

In order to evaluate the impact of IPR on TFP, TFP is derived as follows:

$$\log(TFP) = \log(Y/L) - \beta \log(K/L) \tag{19}$$

Where Y is GDP, K is physical capital, L is labor and $\beta = 0.3$

Data on GDP per worker, as well as capital stocks and labor are taken from Penn State World Tables.

(ii) Patent Rights: The main independent variable of interest, in equations (14) and (18), is the IPR index, constructed by Juan Ginarte and Walter Park (1997), using a coding scheme applied to national patent laws. Five categories of the patent laws were examined: (1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection. The index is the unweighted sum of those categories which were, each, scored on a scale of 0 to 1. The index itself, therefore, ranges from 0 to 5, and higher numerical values indicate stronger levels of patent protection.

(iii) Patent filing cost: data on cost of patenting in the 10 destination countries is available from Global IP estimator. It provides overall costs in 2000 constant dollars. The cost includes the official costs, the cost of the legal agent and translation cost if required[31].

(iv) Variables on the market and the capacity of innovation of the destination countries: Market size is measured by trade in 2000 constant dollars taken from the World Bank WDI, where trade is the sum of imports and exports. The amount of stocks traded as a share of GDP is also controlled for. The capacity to imitate is given by a convex combination of the number of researcher per million inhabitants and the expenditure in R&D as a share of GDP. Other variables that reflect the capacity of a country to innovate include labor, the share of high technology in total trade and population.

(v) Institution variables: two measures of economic freedom, from the Fraser Institute, are used. The first one if the overall freedom index included in the regression for TFP (equation (18)); and the second one is a component of the overall index that focuses on the legal structure and security of property rights. This latter index is used in

[31] An inventor does not incur translation cost when both the source and destination countries share the same language. For instance a South African inventor who patents in the U.S.A does not pay translation costs. However, he would pay translation costs should he also want to protect his invention in Korea.

the regressions on the impact of IPR on innovation and technology diffusion[32], i.e, equation (14). I also include the share of tertiary education as part of the variables related to institutions.

(vi) Country and year dummies: The structural equation (8) can be considered as a knowledge production function. Effects of the main independent variables of interest (IPR) might be influenced by country and year-specific effects. To estimate the impact of IPR, I therefore use time series cross sectional AR(1) Feasible Generalized Least Squares, and I control for country and year-specific characteristics. Results from the regressions of the empirical equations (14) and (17) and (18) are discussed in the next sub-section.

Table 13: Impact of IPR on Innovation and Technology Diffusion

Dependent variable	Innovation		Technology Diffusion	
Log(Y/Z)	Family	Citation	Family	Citation
	(1)	(2)	(3)	(4)
Log(IPR Index)	12.07***	12.58**	5.00*	3.590
	(2.21)	(5.97)	(2.73)	(6.11)
Log(Imitation)	-2.462***	-1.522	-2.128**	-3.518**
	(069)	(2.19)	(0.77)	(1.66)
Log(Cost)	-4.113***	-3.554**	-5.708***	0.208
	(0.60)	(1.46)	(0.67)	(2.28)
Log(Imitation)xLog(IPR)	1.617***	1.021	1.389**	2.304**
	(0.45)	(1.43)	(0.52)	(1.09)
Log(Trade)	1.020*	-3.011**	0.555	1.770
	(0.54)	(1.26)	(0.84)	(1.45)
Log(Labor)	5.938	3.866	-3.677	11.82
	(3.22)	(10.20)	(4.26)	(10.63)
Log(Share Hi-tech)	0.019	-0.050	0.004	-0.026
	(0.03)	(0.09)	(0.03)	(0.05)
Log(Stock Market)	0.015	0.031	0.048**	-0.189
	(0.03)	(0.09)	(0.02)	(0.14)
Tertiary Education	0.163**	0.126	0.129	0.239
	(0.08)	(0.24)	(0.09)	(0.18)

[32] Details of the freedom index and their components are provided at http://www.freetheworld.com/2011/reports/world/EFW2011_appendix.pdf

Table 13 continued

Econ Freedom	1.012***	0.467	0.290	0.274
	(0.20)	(0.52)	(0.25)	(0.58)
Log(Population)	-4.207	-1.357	6.067	-12.05
	(3.36)	(10.56)	(4.41)	(10.96)
Constant	-76.723***	4.554	-63.63***	-56.09**
	(9.98)	(20.19)	(14.78)	(29.06)
Year Dummies	Yes	Yes	Yes	Yes
Country Dummies	Yes	Yes	Yes	Yes
Observations	183	183	183	183
chi2	522.1	1009.4	98.70	122.7

Note: The dependent variables are deflated by GDP, i.e., log(Dependent/GDP), for the family method and by labor for the citation method, i.e., log(Dependent/Labor).
-The two valuation methods provide similar IPR elasticities for local innovation but the citation method underestimates the IPR elasticity of technology diffusion.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Standard errors in parentheses

Analysis of the Results

Tables 13 and 14 show the AR(1) FGLS results of the estimation obtained through the empirical equations (14), (17) and (18) on the impact of IPR on the flow of innovation, technology diffusion and TFP. In each table, columns (1) and (2) on one hand and columns (3) and (4) on the other hand help compare results between the family size and composition patent valuation method, and the citation method.

Table 14: Impact of IPR on the Expected TFP

Dependent variable:	Family Flows		Citation Flows	
Log(TFP)	With Trade (1)	Without Trade (2)	With Trade (3)	Without Trade (4)
Log(IPR Index)[a]	0.623**	1.030***	0.076	0.928***
	(0.21)	(0.19)	(0.10)	(0.11)
Log(Res. Innovation)	0.0114*	0.016**	0.0001	-0.0002
	(0.01)	(0.06)	(0.00)	(0.00)
Log(NRes. Innovation)	0.009*	0.004	-0.0001	0.0006
	(0.01)	(0.01)	(-0.00)	(0.00)
Log(Trade)	0.139***	-	0.197***	-
	(0.03)	-	(0.01)	-
Log(Imitation)	-0.037	-0.119**	-0.002	-0.061**
	(0.06)	(0.05)	(0.02)	(0.03)
Log(Imitation)xLog(IPR)	0.0231	0.075**	0.001	0.039*
	(0.04)	(0.04)	(0.01)	(0.02)

Table 14 continued

Log(GRD)	0.001	0.004	-0.0001	0.002
	(0.00)	(0.00)	(0.00)	(0.00)
Log(Labor)	-0.059**	0.002	0.004	0.096***
	(0.03)	(0.02)	(0.01)	(0.01)
Log(Share Hi-tech)	0.0009	0.003	0.0003	0.002
	(0.00)	(0.00)	(0.00)	(0.00)
Log(Stock Market)	-0.001	-0.0003	-0.001	-0.0008
	(0.00)	(0.00)	(0.00)	(0.00)
Econ Freedom	0.074**	0.083**	0.007	0.029*
	(0.04)	(0.04)	(0.01)	(0.02)
Constant	3.083***	5.143***	1.729***	4.080***
	(0.64)	(0.35)	(0.22)	(0.21)
Year Dummies	183	183	183	183
Country Dummies	743.0	659.0	2566.4	1188.4

Note: -Standard errors in parentheses;

[a]The impact of IPR on TFP is positive and statistically significant, when the family method is used and when trade is controlled or not controlled for.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;

The IPR Elasticity of Innovation, Technology Diffusion and TFP

The main results of the regressions (see table 13) using cross-sectional time series AR(1) FGLS regressions with heteroskedastic panels confirm that IPR positively impact innovation and technology transfer. This result holds whether innovation is measured by citation or family size and composition weighted patents.

In table 13, the elasticity of local innovation with respect to IPR is almost the same in magnitude between the family and citation method (see columns (1) and (2)). The elasticity of technology diffusion with respect to IPR is higher with the family method than with the citation method (see column (3) and (4)). A one percent increase in the IPR index results in a 12.07% increase in the flow of local valuable innovation, when the family method is used. The increase is by 12.58% with the citation method, when it comes to technology diffusion. For technology diffusion, an increase in the IPR index by

1% induces a 5% increase in the flow of technology with the family method versus 3.6% for the citation method. This suggests that the elasticity of the family method is 40% [=(5-3.6)\3.6] larger than the elasticity of the citation method. In their study of international technology diffusion, Xu and Chiang (2005) find that an increase, in the IPR index, by one unit is associated with a 1.42% in the number of international patent inflow. Results obtained, when using the family or the citation method, clearly suggest that the impact of IPR is larger on innovation and technology diffusion than suggested by estimates using patent counts.

The results suggest that if Australia increases its IPR level (3.87) by 1% to reach the level of protection in Germany (4.07), this will result in a 12.07% increase in the flow of local innovation in Australia and in a 5% increase in technology diffusion towards Australia.

The direct impact of IPR on TFP is positive and statistically significant (see table 14), when using the family method. The results show that the elasticity of TFP with respect to the IPR index is 0.62%. Surprisingly, although positive, the impacts of local innovation and technology diffusion do not strongly drive TFP up. Notice, however, that when using the family method, the direct impact of local innovation on TFP is relatively strong in comparison to the impact of technology diffusion on TFP. In addition to IPR, trade is one of the key drivers of TFP, so as a sensitivity test, columns (2) and (4) show the elasticity of TFP with respect to IPR, when trade is not accounted for. It clearly confirms that, in addition to IPR, trade has a significant positive impact on TFP besides IPR. This result on trade supports the findings by Xu and Chiang(2005) about the positive impact of trade on innovation and technology diffusion.

When trade is controlled for, IPR does not longer impact TFP significantly when the citation method is used (see table 14 column 3). Although positive, the impacts of local innovation and technology diffusion are not very strong. This is unexpected with respect to predictions from theory (see equation 14). There are two possible explanations. The first one is that there are measurement errors on the TFP values used for the study. As a matter of fact, the summary statistics in table 11 suggest that there is not enough variation on the TFP across the 10 destination countries. The second reason could be that knowledge capital is not the key driver of TFP. The two reasons do not exclude each other. The results suggest that innovation and technology diffusion positively impact TFP and that IPR is one of the main key drivers of TFP, in addition to trade. However, the magnitudes of the impact suggest that further investigation could help reveal the extent of the contribution of knowledge capital on TFP.

Discriminating Between the Family and Citation Methods

At least three major conclusions can be drawn from the summary statistics, the correlation matrix, and the regression results discussed above.

The first conclusion is that IPR protection has a positive impact on valuable innovation and technology diffusion. The impact of IPR on valuable knowledge, estimated according to the family method, is larger in magnitude than the impact when estimation is done using the citation method. Second, the direct impact of IPR on innovation and technology diffusion is positive. In addition, resident valuable innovation and technology diffusion (i.e., foreign innovation) both positively impact TFP. Trade is also one of the main drivers of TFP, in addition to IPR. When trade is controlled for, the impact of IPR reduces significantly and only local innovation, estimated according to the family method, still statistically and significantly impacts TFP. The third conclusion follows from the first two and from the summary statistics and the correlation tables (11 and 12): the direction and magnitude of the elasticities suggest that estimates from the citation method, tend to underestimate the impact of IPR on technology diffusion and the impact of valuable technology on TFP. The IPR elasticities of local innovation are similar in magnitude for both the family and citation method. That suggests that both methods have the same valuation of local innovation. However, for technology diffusion, the citation method underestimates the impact of IPR. A possible reason might be a negative bias of the citation method toward foreign patents, as inventors could be prone to citing mostly domestic patents.

Concluding Remarks

This chapter studies the impact of IPR on innovation, technology diffusion and TFP using time series cross sectional Auto-regressive (AR(1)) Feasible Generalized Least Squares regressions.

First, our results show that IPR positively impacts valuable innovation and technology diffusion, which in turn, positively impact TFP. Second, results confirm that the family size and composition patent valuation method and the citation method, both, capture the generation and diffusion of valuable knowledge at country level. However, the citation method underestimates the impact of IPR on valuable technology diffusion. IPR also has a direct positive, and statistically significant, effect on TFP. My findings confirm Xu and Chiang (2005) that IPR and trade are positively correlated with innovation and technology diffusion. My results, using the family and citation method confirms that IPR and trade are positively correlated with *valuable*[33] innovation and technology diffusion. In particular, for developed countries, the impact is stronger on local innovation than on technology transfer. On the other hand, the strong impact of trade confirms, to some extent, Coe and Helpman (1995) that trade could be considered as a carrier of foreign R&D. My findings also support Furman et al. (2002) that IPR protection play an extremely important role both in international patenting and in R&D productivity, namely on TFP.

The main policy implication of this study is that a cautious strengthening of IPR, in developed countries, would result in the generation of more valuable local innovation and make those countries more attractive to valuable international technology. The theoretical contribution to the literature is that the family size and composition valuation method is a strong and reliable method to capture the real impact of IPR both on valuable innovation, technology diffusion and TFP. In that regards, further studies could look at the mechanism of the impact of IPR on valuable technology and TFP. The current study also calls for more investigation on the extent of the contribution of knowledge capital to TFP.

[33] As mentioned earlier, when simple patent count is used, the IPR elasticity of innovation and technology diffusion could be interpreted as the impact of IPR on the number of patents or on the propensity to patent. When patents are weighted (using either the family or the citation method), the IPR elasticity is interpreted as the impact of IPR on *valuable* innovation and on *valuable* technology diffusion.

CHAPTER 4

IMPACT OF INTELLECTUAL PROPERTY RIGHTS ON INNOVATION AND TECHNOLOGY DIFFUSION IN AFRICA

This chapter investigates the impact of IPR (IPR, henceforth) on valuable innovation in Africa. It also studies the diffusion of valuable technology among 8 African countries, and from the top 11 countries, that are world leaders in innovation, to the 8 African countries. Innovation is simply defined here as the technology originating from resident inventors, and technology diffusion refers to technological change created by non-resident inventors but available to resident inventors. I evaluate the empirical evidence of the importance of IPR on the creation of valuable innovation and the diffusion of technology, by resident and non-resident patent applicants, in Africa from 1970 to 2005.

In their evaluation of the sources of differences among countries in the production of visible innovative output, Furman et al. (2002) acknowledge that the variation among advanced economies in their ability to innovate at the global frontier raises an empirical puzzle. If inventors draw on technological and scientific insights from throughout the world, why does the intensity of innovation depend on location? The question, raised by Furman et al. (2002), suggests, at least, three reasons that motivate my current study on the impact of IPR on valuable innovation and technology diffusion in Africa.

(i) First, there are few studies that have investigated the impact of IPR on innovation and technology diffusion, for a diverse range of African countries. Indeed, besides the common characteristics that African countries have, as developing countries, they share together a common political and socio-cultural background that provides ground for studying them together, as an economic entity. This common political and socio-cultural background includes, but is not limited to, colonial rule, strong and centralized governments, a weak rule of the law, weak economic freedom, and dictatorship.

(ii) Second, another puzzle justifies the current study. It is often assumed that knowledge is non-rival. If so, why do African countries not appropriate that publicly available knowledge to boost their innovation and technology? If the relevant knowledge is not non-rival but produced by R&D, then African countries can put in place the appropriate institutions, such as property rights, to favor the creation of local innovation and the inflow of technology. This is where theoretical predictions about the impact of IPR on innovation and the diffusion of technology can be tested by empirical data.

(iii) The third reason, why this study is long overdue, is that African countries are lagging behind, with respect to technological development. Countries, such as Korea, India or Taiwan, that had similar level of technological development with some African countries in the 1960s, have, decades later, outpaced African countries in technology. It is, therefore, worth investigating the extent to which the contribution of IPR matters for innovation and technology diffusion in, and towards, Africa.

The rest of the paper is organized as follows: section 2 provides an overview of the literature on IPR and technology diffusion. Section 3 presents the theoretical and empirical framework. Data and results are analyzed in section 4, and section 5 concludes the study.

Literature Review

Theoretical research, on the impact of IPR on innovation and on technology diffusion in developing countries, provides, so far, mixed and conflicting predictions as will be made explicit below. The real impact of IPR on technology diffusion requires supplementary investigation, based on more empirical research. In the literature, below, IPR impact innovation and technology diffusion, as part of the institutions that determine technological change. The literature shows also that the impact of IPR is heterogeneous across levels of development within developing countries. The use of the family size and composition patent valuation method allows us to revisit prior empirical findings and fill the gap, as far as evidence of the impact of IPR in Africa is concerned.

Literature on IPR as an Enabling Institution for Technological Change

The World Intellectual Property Organization (WIPO) defines intellectual property as creation of the mind, such as inventions, literary and artistic works, and symbols, names, images, and designs used in commerce. Out of the two usual categories of intellectual property, the current study does not focus on copyrights, but, rather, on industrial property that includes inventions (patents), trademarks, industrial designs, and geographic indications of source. The vast literature on technological change recognizes the importance of IPR as an institution for innovation and technology diffusion. Acemoglu and al. (2005) define institutions as a fundamental cause of long-run growth. In that respect, economic institutions, encouraging technological change, emerge when political institutions allocate power to groups with interests in broad-based property rights enforcement. In that regards, IPR are the mechanism that ensures the protection of an individual’s rights to recoup their initial investment in R&D and also allow producers to price their products above marginal cost to make a profit. With respect to innovation and the diffusion of technology, IPR are, hence, recognition of the importance of incentives to drive people's behavior.

Literature on IPR in Developing Countries

There is more literature on the impact of IPR on technology diffusion in developed economies[34] than in developing countries, and there is hardly literature on the impact of IPR on innovation and technology transfer in Africa. Therefore, this subsection reviews studies that focus on the impact of IPR, on various proxies of innovation and technology diffusion, in the context of developing countries.

As far as developing countries are concerned, two conflicting approaches to strengthening IPR dominate the literature. One approach emphasizes the potential negative effect of IPR and the other, the positive effect. Falvey et al. (2006), proponents of the first approach, argue that strong IPR could have a negative impact on developing countries as the low level of innovative capabilities in developing countries requires that imitation be a more important source of technological progress. This implies that, in

[34] Furman and al. (2002) investigate the determinants of country-level production of international patents across advanced economies. They find that besides the level of inputs devoted to innovation (R&D manpower and spending), productivity factors in R&D play a key role. Those factors include four policy choices, among which is the extent of IP protection and openness to international trade. The three other factors are (i) the share of research performed by the academic sector and funded by the private sector and (ii) the degree of technological specialization, as well as, (iii) country-level stock of knowledge and education.

those countries, firms should first innovate by imitating, before they can innovate by creating or inventing. Along the same lines, La Croix and Konan (2006), find that middle income countries should benefit more from IPR, as they can efficiently absorb innovation more than low income countries.

The proponents of the second approach show more caution. On the one hand, the market expansion effects of strong IPR, implies that IPR allow rights holders to exclude imitators. On the other hand, the market power effects of IPR could enable rights holders to increase the rents earned on their technology by restricting the quantity supplied (Park and Lippoldt (2008)). Horii and Iwaisako (2007), indeed, show that strong IPR provide patent owners with long monopoly periods and that tends to increase the share of monopolists within the economy as a whole[35]. Consequently, the overall net effect of IPR depends on the relative magnitude of the negative impact (reduction of number of competitors) with respect to the positive impacts (increase in expected return in R&D and in the number of R&D researchers).

My current study is in line with the second approach, which shows more caution about the possible heterogeneous impact of IPR, i.e., IPR might have a positive or negative impact on the generation of innovation and on technology diffusion. In the literature on innovation and technology diffusion, R&D data, such as employment or expenses, are often considered as the input for R&D, and patents are considered as the output. In that regards, Park and Ginarte (1997) study the impact of IPR for 60 countries

[35] Horri and Iwaisako (2007) demonstrate that IPR affect technological change through at least three main channels: (i) IPR raise the expected return from R&D, (ii) IPR progressively reduce the number of competitive sectors, and (iii) lower the market wage and therefore increase the number of R&D researchers employed in each competitive sector.

and find a significant impact of IPR on R&D activities in developed countries but not in developing countries. Falvey et al. (2006) examine the impact of IPR, on three categories of countries, and concluded that IPR matter more for low and high income countries, but not for middle income countries. If this is the case, then, we could expect a significant negative impact of IPR in Africa, since most African countries are part of low income countries, with low levels of innovative capacities.

Awokuse and Yin (2009) assume that there is a positive correlation between IPR and international patenting in their study on China. They show that stronger IP protection results in significant increase in inward FDI (Foreign Direct Investment), in a developing country such as China. In their study, they use the IPR index created by Ginarte and Park (1997). The growing number of patents filed by foreign firms is considered an indicator of a growing confidence of firms in the IP protection of China.

The correlation between IPR and international patenting is, precisely, the assumption that I am investigating in the context of Africa. Does strengthening of IPR, in African countries, induce more patenting? If so, do the patents filed reflect the generation of valuable innovation and the diffusion of valuable technology? In a more recent paper, Awokuse and Yin (2010) show that stronger IP protection positively impacts the bilateral trade flows of China. Trade is controlled for in this study, all the more since Coe and Helpman (1995) consider trade as the carrier of foreign R&D. Park (2011) investigates the impact of IPR on Foreign Direct Investment (FDI) in Central America. He posits that the strength of IPR in the host country can affect not only the volume or form of technology, but also the mode of entry (FDI, licensing…). In this study, the form of technology diffusion, that I am investigating, is international patenting towards African countries. Considering the different and conflicting theoretical and empirical results on the impact of IPR, on various proxies of innovation and of technology diffusion, in developing countries, empirical studies focused on Africa can help understand the impact of IPR in this part of the world.

Empirical Framework

This chapter investigates the impact of IPR on the creation of valuable innovation and on the diffusion of valuable technology in Africa, where innovation and technology diffusion are computed according to the family size and composition patent valuation method. The main goal is, therefore, twofold. (i) First, to determine whether stronger IPR favor the generation of valuable innovation, through resident patenting (ii) second, whether stronger IPR is positively correlated with the diffusion of valuable technology, i.e., whether IPR attract valuable technology owned by non-resident patent applicants. In other words, can IPR be considered as a critical part of the broader institutional environment that favors the generation of valuable innovation and the diffusion of valuable technology?

The question above is answered by regressing country level patent-portfolio, evaluated according to the family size and composition method, on the Ginarte-Park de jure patent protection index. I also run the regressions using simple patent count, as a dependent variable. Before running regressions, and in order to also unravel patterns of technology diffusion within and towards African countries, I use technology diffusion matrices constructed according to the family and citation methods.

A Technology Diffusion Matrix Using the Family and the Citation Methods

Before investigating innovation and technology diffusion with regression analysis, descriptive techniques are used to uncover patterns of technology diffusion at country level. The unit of analysis, i.e., an observation, is a country-year. In addition, patenting information for all 8 African countries is not available in the sample, for every year, during the 36 years covering the period of 1970 to 2005. As a result, discriminating further between resident and non-resident patent publications shows that flows of innovation mainly come from non-residents. Hence, in order to further investigate technology diffusion, I construct technology diffusion matrices, based on either the citation method or the family method, as explained below.

A Technology Diffusion Matrix Using Family Size:

Consider the following squared matrix:

Country	X	Y	Z
X	j	k	l
Y	m	n	o
Z	p	q	r

where the entries represent patent families of the column country that include the row country. Diagonals are patent families that include itself. For example if X is the U.S.A, then j is the quantity of patent families that include the U.S.A. The off-diagonals represent international knowledge transfers. If X is the U.S.A and Y is South Africa, then k is the number of times the U.S.A is included in a South African patent family. The ratio $\frac{k}{n}$ tells us how important the U.S.A is to South Africa in relative terms. If the set of patent families used is the total number of patent families, available per country, then diagonals would represent the total patent families. In this study, I focus only on patents protected in at least one African country. This allows a study of the technology diffusion network that Africa benefits from. An additional matrix based on citations is also used to uncover patterns of technology diffusion.

<u>A Technology Diffusion Matrix Using Citation Method:</u>

Consider the following squared matrix:

Country	X	Y	Z
X	a	b	c
Y	d	e	f
Z	g	h	i

where X, Y, Z are countries and $a, b, c,$ etc. are numbers of citations. More specifically, the columns represent citing countries, and the rows represent cited countries. Then, each element in the matrix tells us the number of patents of the row country cited by the column country. This would show how important inventions, developed in the row country, influence inventive activity in the column country. For example, if X represents the U.S.A and Y South Africa, the entry b tells the number of times South African patents cite U.S. patents, and the ratio $\frac{b}{(b+e+h)}$ tells how important the U.S.A is to South African innovation, in relative terms, as the denominator is the total number of patents cited by South Africa. The diagonal simply represents self-citations (i.e. countries citing their own inventions).

The use of citations, as evidence of patent value and technology diffusion, has been well documented in the literature (see Trajtenberg (1990), Albert and al. (1991), Jaffe and al. (1993), Jaffe and Trajtenberg (1996) and (1999), Peri (2005), Malerba and

Montobbio (2003), Malerba and al. (2007)). A citation diffusion matrix has been used namely by Montobbio and Sterzi (2010). If a patent A from an inventor[36] from South Africa cites a patent B from an inventor from the U.S.A, I could infer that the knowledge imbedded in patent B from the U.S.A has been useful in the generation of new knowledge B in South Africa. I design tables to show technology diffusion between African countries and from G11 to the African countries, before and after the TRIPS in 1995.

Empirical Specification for Regression Analysis

Without loss of generality, define, $\gamma_{i,t}$, the flows[37] of innovation and technology diffusion in country i, up until year t, as follows:

$$\gamma_{i,t} = G(IPR_{i,t}, X^h_{i,t}) \tag{1}$$

Equation (1) implies that, $\gamma_{i,t}$, the flows of new innovation and of technology diffusion, from resident and non-resident inventors, depend on the level of IPR and a vector of control variables X^h.

The implicit equation (1), above, can be specified empirically as follows:

[36]From PatStat (April 2011 edition), I use information about the country of the applicant who is also the inventor.

[37] I use flows, instead of stocks, among other things, because the data available for the different countries are not consecutive. Using only consecutive data reduces the panel data drastically. I rely also on the prior studies that use flows of innovation, namely, Xu and Chiang (2005), Park and Lippoldt (2008).

$$\ln(\gamma_{i,t}) = \alpha + \beta IPR_{i,t} + \lambda \ln(\cos t_{i,t}) + \mu \ln(trade.pc_{i,t}) + \eta \ln(GDP.pc_{i,t} + \xi \ln(pop_{i,t}) + \varphi_i$$
$$+ \phi_t + s_{i,t} \qquad (2)$$

In equation (2), $i = 1,2,3..8$ represents countries and $t \in [1970, \quad 2005]$ the year of patent publication. The dependent[38] variable, $\ln(\gamma_{i,t})$, is considered, here, as a proxy for innovation when it represents the value of knowledge available in country i and originating from the resident inventors in country i. $\ln(\gamma_{i,t})$ is a proxy for technology diffusion when it represents the value of knowledge available in country i but originating from the inventors in country j, with $i \neq j$. In the regression analysis, the dependent variable is computed in two different ways. For the first one, the dependent variable is computed as the family size and composition value of the patent portfolio at country level. For the second one, the dependent variable is, just, the number of patents, protected in country *i*.

Equation (2) means that the value of technology available in country i, during year t, depends on the level of IPR, the cost of patenting, the level of R&D in the rest of the world that influences country i, as measured by the amount of trade per capita,

[38]This chapter extends a paper in progress on Intellectual Property Rights, Innovation and Technology Transfer in Sub-Saharan Africa. That paper used count data method, i.e., innovation is proxied by the total number of patent applications. The current paper uses the new patent valuation method developed in chapter two, i.e., the family size and composition patent valuation method. It also compares the regression results with the count data method. The results of the previous paper was presented in an experts meeting on innovation and development in Geneva on March 26th, 2010. The meeting was jointly organized by the World Intellectual Property Organization (WIPO) and the World Bank Poverty Reduction and Economic Management unit (PREM).

$\ln(trade.pc)$, in country i. I am building on Coe and Helpman (1995) [39] and also on Xu & Chiang (2005), who consider international trade as the carrier of foreign R&D, and I consider trade per capita, *ln(trade.pc)*[40], as a proxy for productivity. The level of trade is defined, here, as the sum of exports and imports of goods and services. The rationale for including imports is that imports of high quality products may be correlated with international patenting of valuable technology. Firms that market high technology products are likely to protect their innovations in importing countries, so as to prevent imitation of their products. In addition, high quality imported products may be intermediary products for production in importing countries. So the level of imports may be related to productivity. I also include GDP per capita, *ln(GDP.pc)*. I then estimate equation (2) using AR1 Feasible Generalized Least Squares (FGLS), for heteroskedastic panels, when AR1 autocorrelation is panel specific. I also estimate equation (2) with fixed effects Poisson, for panel data[41], when the dependent variable is the simple count data. φ_i and ϕ_t are respectively country and year dummies that capture country and year specific characteristics and, as such, are correlated with the regressors.

When the dependent variable is the family size and composition weighted patent portfolio, FGLS is used in regression analysis. GLS takes heteroskedasticity into account

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[39] I use trade not only because it can be considered as the carrier of foreign R&D but also because R&D data in African countries are mostly missing, while there is available and more reliable data on trade to GDP levels.

[40] The use of trade, as an independent variable, could also raise an endogeneity issue, namely, reverse causality. Innovation and technology transfer could also determine the level of trade.

[41] For more details about the motivation for using the Poisson specification for patent count data, please see Hausman, Hall and Grilliches (1984), which I build on for this paper. See also Greene (2008), chapter 8 for the motivation for FGLS and chapter 9 for the use of Poisson regression for count data.

and Feasible GLS estimates the heteroskedasticity before performing GLS. The 8 African countries studied, here, are heterogeneous in terms of their innovative capacity, level of IPR protection, potential market for innovation, etc. This results in heteroskedastic variance of the error term across countries. In addition to not having homoskedastic variances, errors terms are likely to be correlated within panels. This justifies the use of AR1 panel specific autocorrelation. When using FGLS, the dependent variable is the log of innovation estimated, according to the family size and composition patent valuation method. I build on Park and Lippoldt (2008), in their study of technology transfer and the implications of the strengthening of IPR in developing countries, to use FGLS for the current study.

When the dependent variable is the number of non-resident patent applications, at country level, the fixed effects Poisson regression for panel data is used. The rationale for using the Poisson regression is that I want to predict the average number of patent applications per country over the period of 1970 to 2005, using simple count data. In that regards, two characteristics of the data determine the choice of the empirical method. First, the dependent variable is a count data. Second, the dataset has repeated observations for the same countries, i.e., the dataset is a combined time-series-cross-sectional panel. Building on Hausman, Hall and Griliches (1984) and Hall, Grilles and Hausman (1986), I analyze the relationship between IPR and innovation, using Poisson regressions, because patent applications are random and independent events. As such, the Poisson distribution is the most reasonable description of it.

Empirically, I follow the established tradition that uses resident patent applications as a proxy for local innovation and non-resident patent applications as a proxy for international knowledge (see Bottazzi and Peri (2007), Xu and Chiang (2005)). Analysis is conducted at country level. The next section provides an overview of the data used to study the impact of IPR on the generation of valuable knowledge and on technology diffusion, proxied by the flows of technology produced by resident and non-resident applicants.

The Data and the Analysis of the Results

The Raw Data

I use four sets of data: (i) an IPR index, (ii) the World Bank's World Development Indicators (WDI, henceforth), (iii) the April 2011 edition of PatStat, and (iv) Global IP estimator. The IPR index is constructed by Juan Ginarte and Walter Park (1997), using a coding scheme applied to national patent laws. Five categories of the patent laws were examined: (i) extent of coverage, (ii) membership in international patent agreements, (iii) provisions for loss of protection, (iv) enforcement mechanisms, and (v) duration of protection. The index is the unweighted sum of those categories which were, each, scored on a scale of 0 to 1. The index itself, therefore, ranges from 0 to 5, and higher numerical values indicate stronger levels of patent protection.

The second set of data, the World Bank WDI, include a large set of macroeconomic indicators that cover a long period from the time of independence[42] of most African countries in the 1960s until 2005. Among the annual time series available in

[42]Most African countries became independent of colonial powers in the 1960s. Ghana, first, in Sub-Saharan Africa, claimed independence in 1958. However, other countries such as Zimbabwe were not recognized as independent until as late as 1980. The most recent independent African country is South Sudan (July 9th, 2011).

the World Bank WDI, I use variables such as GDP per capita, trade per capita and population for the purpose of this study.

I use the April 2011 edition of PatStat, the worldwide patent statistical data set described in chapter two. My sample comprises 8 African countries spread over the different economic regions of Africa (see table 15).

Table 15: Sample of 54 Source Countries and Destination Countries

Algeria[a]	Denmark	Ivory Coast	New Zealand	Switzerland
Australia	Egypt[a]	Japan	Nigeria	Thailand
Austria	Finland	Kenya[a]	Norway	Togo
Belgium	France	Korea	Peru	Tunisia
Botswana	Germany	Madagascar	Philippines	Turkey
Brazil	Ghana	Malawi[a]	Portugal	United Kingdom
Burundi	Greece	Mali	Singapore	United States
Cameroon	India	Mauritius	Spain	Zambia[a]
Canada	Ireland	Mexico	Sri Lanka	Zimbabwe[a]
Chile	Israel	Moroco[a]	South Africa[a]	Venezuela
Colombia	Italy	The Netherlands	Sweden	

[a]The 8 African source countries. A source country is the country of origin of a patent applicant. A destination country is the country where a patent has legal protection.

Patent applicants are originally from 54 countries and their patents are protected in 40 countries: 8 in Africa and 32 in the rest of the world, as shown in table 15. The data covers 36 years period, i.e., from the period of the independence of most African countries in 1970 to 2005. The data set contains 231,987 patents priorities protected in the 8 African countries and 234,941 patents applications, protected in the same African countries. The sample studied gathers 226 observations, where the unit of analysis is a country-year, and where each patent family includes at least one African country. Finally, data on cost of patenting in the 8 African countries is available from Global IP estimator

2010. It provides overall costs in 2000 constant dollars, including cost of applications and maintenance fees.

My dependent variable, $\ln(\gamma_{i,t})$, is the logarithm of the value of innovation or technology diffusion, as defined in equation (2), above. When AR1 FGLS for heteroskedastic panels is used for regression, patents are weighted by the sum of GDP created in the countries where they have legal protection[43]. The dependent variable is the total number of resident and non-resident patent applications, when fixed effects Poisson regression for panel data is used. This allows an interpretation of the coefficients, in both FGLS and Poisson regressions, as elasticities. The main independent variable of interest is the Ginarte-Park IPR index, that reflects the level of IPR protection in a country. Four other important independent variables, that are controlled for, include the logarithm of cost of patenting, the logarithm of trade per capita in 2000 constant dollars, the logarithm of GDP per capita in 2000 constant dollars, and the logarithm of population. FGLS regression analysis also includes country and year dummies to capture country and year specific characteristics. By construction of the model, only year dummies are included in the regression of the fixed effect Poisson model. Table 16 below provides an overview of the summary statistics and table 17 shows the correlation matrix. The next subsection analyses the results of both the technology diffusion matrices and the regression analysis.

Table 16: Table of Summary Statistics (Average over the Period 1970 to 2005)

Variable	Log(Family Innovation)	#applications[a]	IPR Index	Log(Trade p.c.)	Log(GDP p.c.)	Log (pop)	#obs[b]

[43] In another chapter (chapter II of this dissertation), Walter Park and I, provide details on the construction of the family size and composition patent valuation method.

Table 16 continued

Algeria	13.41	20	2.82	6.89	7.52	17.09	24
Egypt	15.17	117	1.55	6.22	6.90	17.79	36[a]
Kenya	14.37	37	1.59	5.48	6.01	16.66	24
Malawi	11.38	6	1.48	4.47	4.97	15.82	22
Morocco	15.66	167	1.96	6.50	7.08	17.04	27
S. Africa	18.64	4036	3.27	7.38	8.06	17.31	36[a]
Zambia	13.99	50	1.56	5.76	6.05	15.73	31
Zimbabwe	15.55	112	1.12	5.77	6.40	16.15	26

Note: # applications= number of patent applications over the 36 years period, from 1970 to 2005 and #obs= number of observations.

[a]South Africa and Egypt are the only countries in the sample for which information is available for every single year, covering 36 years from, 1970 to 2005.

Table 17: Correlation Matrix Between the Main Variables

	Log(Family Innovation)	# Patents Applications	Log(IPR index)	Log (Trade p.c)	Log (GDP p.c.)	Log (Population)
Log(Innovation)	1.0000					
#Patent Applications	0.7159	1.0000				
IPR Index	0.5009	0.7066	1.0000			
Log (Trade p.c)	0.6987	0.6041	0.7266	1.000		
Log(GDP p.c)	0.7038	0.6222	0.7393	0.9682	1.000	
Log(population)	0.4311	0.3318	0.3925	0.6173	0.6965	1.0000

Note: -p.c.: per capita and #patent applications means number of patent applications over the 36 years period, from 1970 to 2005.

Analysis of the Results

Analysis of the Matrices for Technology Diffusion

Three tables (18, 19 and 20) show coherent and concordant results of the matrices of technology diffusion, using techniques based on the family and citation approaches. Table 18 contains two parts. The first part is a squared matrix to analyze technology diffusion within the 8 African countries using the family size method as explained above, in section 3. The second part of the table analyses technology diffusion from 11 leaders in technology (G11 countries) to the 8 African countries. To further investigates technology diffusion in Africa, table 19 and 20 show technology diffusion from G11 countries towards the 8 African countries, before and after 1995 when the Trade Related IP agreement was signed in Morocco. The TRIPS[44] Agreement is Annex 1C of the Marrakesh Agreement establishing the World Trade Organization, signed in Marrakesh, Morocco on April 15th, 1994. To implement the investigation of technology diffusion, before and after the TRIPS, I focus on inventors of patent applications that are, at least, protected in one of the 8 Africa countries.

There is almost no technology diffusion among African countries when using the family diffusion matrix. The first matrix (table 18) shows that, patent priorities protected in a particular African country mostly originate from the same African country. African patent priorities protected in any of the 8 African countries are also mostly protected in South Africa. Priorities protected in Zimbabwe are also protected in each of the 8 African countries. This might indicate the importance of the African Regional Intellectual Property Organization (ARIPO, henceforth) whose headquarters are located in Zimbabwe. In this study, I use only patents protected in Zimbabwe, regardless of whether they are also filed through the ARIPO or not. As a matter of fact, ARIPO uses direct and indirect filings through national offices, but at the time of application, applicants must designate which State they wish the application to extend to. ARIPO covers seventeen countries, mostly in Eastern and Southern Africa[45].

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[44] Please see the TRIPS Agreement, from the website of the World Intellectual Property Organization (WIPO) at http://www.wto.org/english/docs_e/legal_e/27-trips_01_e.htm

[45]The 17 member states of ARIPO are the following as of 2011: Botswana, Gambia, Ghana,

Because of possible duplications, I cannot use summations from columns for comparison, even if they might give good indications of how attractive a country is as a place to protect patents. However, the main information, from the first part of this table, is that there is little technology diffusion happening within African countries, as measured by patent priorities protected in the different countries. In the opposite, the second part of table 18 clearly shows that most technology, available in Africa, originates from the top 11 innovation leaders in the world. In particular, the U.S.A is the top source of technology transfer for the 8 African countries considered. On the other hand, Japan that is a top innovation leader within OECD countries is not a major source of technology diffusion towards Africa.

The tables 19 and 20 use citations as a means of technology diffusion as explained earlier, in section 3. The results of the descriptive method, using citation, agree with the patterns uncovered with the family method. Table 14 shows that African countries do not cite each other, before and after TRIPS. Three patterns emerge from the two tables (19 and 20). The first one is that the average number of citations, from G11 countries, by African countries, increased substantially before and after the TRIPS. On average, the increase in average citations is at least twofold. This suggests that the TRIPS have allowed African inventors to be more aware of the innovation from non-resident inventors and to acknowledge it in their own patents. The second pattern is that South Africa is, by far, the African country that cites G11 patents the most; and the U.S.A is the country that is the most cited by African countries. The third pattern that emerges, from

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Kenya, Lesotho, Liberia, Malawi, Mozambique, Namibia, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe.

the two tables of the diffusion matrices, is that, even if technology diffusion is relatively weak in Africa, Africa benefits primarily from the technology of the top patenting countries: the U.S.A, Germany, Japan and France.

The troubling finding though, from the different tables analyzed, is that African inventors benefit from technology diffusion originating from outside the continent but do not benefit from each other's innovation, except from South Africa. This might be the case because African inventors do not have valuable innovation to share or because African inventors just do not communicate, and lack the opportunity to "stand on the shoulders" of their African peers. Information in the data does not allow for a rigorous discrimination between these two different possibilities. However, given the difficulties of access to information and the poor level of stable governance in Africa, I favor the argument that African innovators do not have the opportunity, or even the possibility, to know about each other's inventions. The descriptive patterns of technology diffusion, discussed here, are confirmed by the results from the regressions, using, both, AR1 FGLS for heteroskedastic panels, and fixed effect Poisson, for panel data.

Table 18: Matrix of Technology Diffusion in Africa

(Family size=number of patent priorities from 1970 to 2005)
Within the 8 African Countries

Row countries	Column countries							
	Algeria	Egypt	Kenya	Malawi	Morocco	S.Africa	Zambia	Zimbabwe
Algeria	350	50	3		139	429	2	29
Egypt		3952	23		47	600	70	14
Keya			749[a]	1	7	356[b]	55	69
Malawi				94		16	78	14
Morocco		11		1	3,806	1915	21	206
S. Africa						154,364	64	63
Zambia							1,327	38
Zimbabwe								2,652

Table 18 continued

From G11								
	Column countries							
Row countries	Algeria	Egypt	Kenya	Malawi	Morocco	South Africa	Zambia	Zimbabwe
Brazil	135	1,282	55	37	1943	49,344	118	1,069
Canada	207	1,530	76	21	1965	70,871	157	875
France	15	1,029	378	12	240	34,527	743	453
Germany	210	2,028	229	34	1,955	74,747	321	1,568
Italy	13	940	224	8	259	26,726	447	450
Japan	1	45	6	3	51	1,735	7	74
Korea	31	645	52	5	601	23,845	42	640
Switzerland	7	333	191	3	52	8,361	262	53
Turkey	69	846	51	2	929	11,752	228	424
U.K.	22	270	73	6	117	8,227	129	343
U.S.A	161	2,278	382	23	1,919	91,257	598	1,577[c]

Note: How to read the tables

[a]749: there are overall 749 patent priorities protected in Kenya.

[b]356 patent priorities protected in South Africa are also protected in Kenya

[c]1,577patent priorities protected in Zimbabwe are also protected in the U.S.A

Table 19: Technology Diffusion within the 8 African Countries

(Value of diffusion=Average number of citations made)
Before TRIPS (1995): Average over 26 years period (1970-1994)

Source countries	Destination countries							
	Algeria	Egypt	Kenya	Malawi	Morocco	S.Africa	Zambia	Zimbabwe
Algeria								
Egypt		0.04						
Kenya								
Malawi								
Morocco					0.08			
S. Africa						16.32[a]		
Zambia								
Zimbabwe								

After TRIPS (1955): Average over 11 years period (1995-2005)

Source countries	Destination countries							
	Algeria	Egypt	Kenya	Malawi	Morocco	S. Africa	Zambia	Zimbabwe
Algeria								
Egypt		0.09						
Kenya								
Malawi								
Morocco					0.18			
S. Africa						37.09[b]		
Zambia								

Table 19 continued

Zimbabwe

Note: how to read the tables: Each number tells how many times, on average, a source (row) African country is cited by a (column) African country.

[a]Before the TRIPS, South African patents cite South African patents 424 times (=16.32*26).

[b]Ather the TRIPS, and within 11 years only, South African patents cite South African patents 408 times (=137.09*11).

Table 20: Technology Diffusion from G11 to the 8 African Countries

(Value of Diffusion=Average Number of Citations Made)

Before TRIPS (1995): Average over 26 Years Period (1970-1994)

Source	Destination countries							
countries	Algeria	Egypt	Kenya	Malawi	Morocco	S. Africa	Zambia	Zimbabwe
Brazil						0.08		
Canada	0.04	0.08	0.04		0.04	4.16		
France	024	0.28			0.36	7.4		0.04
Germany	0.08	0.04			0.12	11.48		
Italy		0.04			0.08	1.84		
Japan	0.04		0.08		0.16	9.92		
Korea						0.08		
Switzerland		0.24			0.08	3		
Turkey								
UK						8.2		0.08
USA	0.16	0.68	0.6		1.12	92.76[a]		0.32

After TRIPS (1955): Average over 11 Years Period (1995-2005)

Source	Destination countries							
countries	Algeria	Egypt	Kenya	Malawi	Morocco	S. Africa	Zambia	Zimbabwe
Brazil						0.18		
Canada	0.09	0.18	0.09		0.09	10.82		
France	0.55	0.63			0.82	16.81		0.09
Germany	0.18	0.09			0.27	26.09		
Italy		0.09			0.18	4.18		
Japan	0.09		0.18		0.36	22.55		
Korea	0.36					0.18		
Switzerland		0.55			0.18	6.82		
Turkey								
UK						18.64		0.18
USA		1.55	1.36		2.55	210.82[b]		0.73

Note: How to read the tables: Each number tells how many times, on average, a source (row) African country is cited by a (column) African country.

[a]Before the TRIPS, South African patents cite U.S. patents 2411 times (=92.762*26).

[b]Ather the TRIPS, and within 11 years only, South African patents cite U.S. patents 2319 times (=210.82*11).

Results of Regression Analysis on the Impact of IPR on Innovation and Technology Diffusion

Table 21 and table 22 display the results of the estimation of the impact of IPR on innovation and technology diffusion, for the period of the independence of most African countries, i.e., from 1970 until 2005, using both AR1 FGLS for heteroskedastic panels, and fixed effect Poisson regressions for panel data (see table 21). Given the heterogeneity across countries, and given that South Africa is, by far, the technology leader in the data, regression results without South Africa (sample II) are reported in table 22, for robustness purposes.

Coefficients of the four regressions, from the full sample I (table 21) are, all, positive and statistically significant. Doubling the level of IPR protection in the African countries induces a 127% increase, in the generation of valuable innovation, when using the family method. The increase is only by 44% on technology diffusion. The average level of IPR is 2.07 in the sample. An increase by 50% in the IPR level, to 3.1, would be between the average level of IPR in Algeria (2.8) and South Africa (3.3). The results, thus, suggest that if Morocco strengthens its IPR regime (which is almost 2) to reach a level between the level of protection in Algeria (2.8) and South Africa (3.27), this will result in an increase by 63.5% (i.e. [127/2)%] in the generation of valuable innovation in Morocco. Although positive and statistically significant, the impact of IPR on the diffusion of valuable technology is lower in magnitude then the impact on the generation of valuable innovation (127% for innovation versus 44% for technology diffusion, see column 1 and 3 of table 21).

When innovation (technology diffusion) is proxied by simple count data, elasticity is interpreted as the impact of IPR on the number of resident or non-resident patents filed (i.e., regardless of the quality of the patents). Hence the results suggest that the same increase, by 50% of the IPR protection in Morocco, will induce a 22% decrease in the number of resident patents and a 10% increase in non-resident patenting (see column 3 and 4 of table 21). When using the new patent family size and composition valuation method, coefficients are also elasticities. However, they are interpreted as the percentage change in the generation of "*valuable innovation"* or in the diffusion of "*valuable technology"*, induced by one percent increment in the IPR index.

When I use the simple count data method, the impact of IPR on innovation is negative (-44%). This might justify the conflicting results discussed in the literature. Therefore, my results reconcile prior conflicting results by shedding light on two important issues. (i) The first one is that conclusions of prior research that suggested a negative impact of IPR on innovation were likely driven by the proxy used for innovation, namely the simple patent count. (ii) The second point is that prior finding that suggest that IPR has a positive impact on technology diffusion is confirmed. Moreover, my findings suggest that the impact on local innovation is even stronger in magnitude than the impact on technology diffusion (127% for innovation versus 44% for technology diffusion, see table 21).

Results also show that a 1% increase in cost of patenting has a strong negative effect on technology transfer (a decrease by 130.2% for family method and a decrease by 171% for count data). Trade per capita, GDP per capita, as well as population, has a positive impact on the generation of valuable knowledge. The positive impact of trade agrees with prior studies that consider trade as a channel of technology diffusion. Moreover, trade is rightly considered as a contribution of foreign R&D to the generation of innovation, in a particular country (Coe and Helpman (1995)).

Table 21: Impact of IPR on Innovation and Technology Diffusion in Africa

(Full Sample I: all 8 Countries)

Dependent	Impact on Innovation		Impact on Technology Diffusion	
	Family Method FGLS (1)	Count data Fixed Poisson (2)	Family FGLS (3)	Count data Fixed Poisson (4)
IPR Index	1.272^{**}	-0.447^{*}	0.440^{*}	0.201^{***}
	(0.41)	(0.19)	(0.23)	(0.04)
Log(Patenting Cost)	-2.233^{***}	-0.289	-1.302^{***}	-1.709^{***}
	(0.41)	(0.41)	(0.39)	(0.04)
Log(Trade p.c)	0.474	-1.123^{***}	0.125	0.243^{***}
	(0.42)	(0.28)	(0.18)	(0.04)
Log(GDP p.c)	-2.503^{***}	-0.847	1.915^{***}	1.375^{***}
	(0.67)	(0.70)	(0.45)	(0.07)
Log(Population)	-17.17^{***}	-11.25^{***}	2.335	-1.800^{***}
	(2.85)	(1.65)	(2.22)	(0.22)
Constant	317.8^{***}		-26.71	
	(48.09)		(36.82)	
Year Dummies	Yes	Yes	Yes	Yes
Country Dummies	Yes	No	Yes	No
Observations	92	92	190	190
chi2	5528.8	1140.7	486.3	3405.8

Note: Definition and interpretation
-Innovation vs. technology diffusion: amount of innovation (patents or weighted patents) protected in a country and originating from inventors of that same country. Technology diffusion is the amount of innovation originating from inventors from other countries, i.e., non-resident inventors.
- Given that IPR is not in log the coefficients are technically semi-elasticities even if I use the term elasticity for simplicity. IPR has a positive and significant impact, both on the generation of valuable local innovation as well as on valuable technology diffusion in Africa. The impact on innovation is larger than the impact on technology diffusion. IPR, however, has a negative impact on the number of resident patent applications and a positive impact on the number of non-resident patent applications in Africa.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; p.c=per capita, Standard errors in parentheses.

Table 22 shows that results, from regressions, are not driven by South Africa, as the technology leader on the continent. In addition, the impact on technology transfer is even stronger when South Africa is excluded from the sample (a 44% increase in the full sample, table 21 versus 113% in sample II, table 22, when South Africa is excluded). The impact of IPR on innovation is also positive (when South Africa is excluded) even if it is not statistically significant, at conventional levels. These results provide two pieces of information. (i) The first one is that results are robust to the sample used, for this study. (ii) The second piece of information is that the elasticity of valuable technology diffusion with respect to IPR is greater in the countries where IPR protection is not, already, as high as it is in South Africa. Doubling the level of IPR protection in these countries make these countries more attractive for international technology. This results in an increase by 113% in valuable technology diffusion or in a 24% increase in non-resident patenting.

Conclusion

I use data from 8 African countries over a period of 36 years, from 1970 to 2005, to study the impact of IPR on the generation of valuable innovation and on the diffusion of valuable technology. I find that IPR positively impact the generation of valuable innovation and the diffusion of valuable technology.

At a more disaggregated level, a descriptive study of technology diffusion, based on the family size and composition valuation method as well as the citation method, supports that IPR positively matter for technology diffusion. My results suggest that after the TRIPS agreement in 1995, technology diffusion, as measured by the average flows of patent citations intensified, between innovation leaders (G11) and African countries. This result is, to some extent, confirmed by the fact that trade positively impacts the transfer of valuable knowledge. These results also agree with Xu and Chiang (2005) who find that IPR positively impact technological change.

Table 22: Impact of IPR on Innovation and Technology Diffusion in Africa

(Sample II: without South Africa)

Dependent	Impact on Innovation		Impact on Technology Diffusion	
	Family Method FGLS (1)	Count data Fixed Poisson (2)	Family FGLS (3)	Count data Fixed Poisson (4)
IPR Index	0.753	0.0575	1.129***	0.238***
	(0.55)	(0.56)	(0.27)	(5.63)
Log(Patenting Cost)	7.555	-1.244	-5.244***	-3.433***
	(5.84)	(3.72)	(0.74)	(-27.27)
Log(Trade p.c)	-1.118	-1.122	-0.00386	0.666***
	(1.24)	(0.72)	(-0.20)	(11.70)
Log(GDP p.c)	0.0438	-1.711	0.524	0.488***
	(3.24)	(1.73)	(0.55)	(4.45)
Log(Population)	-24.24***	-8.775*	0.448	-1.576***
	(5.87)	(4.4)	(2.74)	(-4.52)
Constant	343.8***		45.89	
	(4.28)		(44.92)	
Year Dummies	Yes	Yes	Yes	Yes
Country Dummies	Yes	No	Yes	No
Observations	56	56	190	190
chi2	1394.5	412.0	486.3	3405.8

Note: Definition and interpretation
--Innovation vs. technology diffusion: amount of innovation (patents or weighted patents) protected in a country and originating from inventors of that same country. Technology diffusion is the amount of innovation originating from inventors from other countries, i.e., non-resident inventors.
-IPR has a positive and significant impact on valuable technology diffusion in Africa. The impact on the generation of valuable innovation is also positive, but not significant, at conventional levels. IPR has, also, a positive, and statistically significant, impact on the number of non-resident patent applications in Africa. The impact on the number of resident patent applications is positive, but not statistically significant.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; -p.c=per capita, Standard errors in parentheses.

Another important finding of this study is that there is low, or hardly any, technology diffusion, as measured by citation and family size methods, among African countries. In addition, African inventors cite patents from abroad but not patents filed by African inventors. This suggests a lack of interaction between African inventors that results from either a low quality of innovation, on the continent, or a lack of opportunity to communicate among inventors. African countries benefit from the technology of world leaders in innovation such as the U.S.A, Germany and Canada.

Results of AR1 Feasible GLS regressions, for heteroskedastic panels, and of fixed effect Poisson regressions for panel data, provide evidence that IPR protection positively impacts the diffusion of valuable technology towards Africa. A comparison of the results, between the family method and the count data method, suggests that the count data method underestimates the impact of IPR. Different samples, used for the study, confirm also that results are robust across different samples. Moreover, the fact that the impact of IPR on the diffusion of technology is stronger, in the absence of South Africa, agrees with the findings of Falvey et al. (2006) that IPR matter more for low income countries. However, our findings suggest that IPR matter positively for technology diffusion. My results suggest that conclusions of prior research that suggested a negative impact of IPR on innovation were likely driven by the proxy used for innovation, namely the simple patent count. As for technology diffusion, my findings confirm prior research by Park and Lippold (2008) that IPR positively impact technology diffusion in developing countries. My results, also, confirm the finding by Xu and Chiang (2005) that poor countries benefit from foreign patenting. The U.S.A is the main source of technology diffusion for African countries. This result, therefore, confirms, and extends the findings by Eaton and Kortum (1996) that the US is the largest technology diffusion leader in OECD countries.

Studies that could help unravel the channels of the positive impact of IPR on the generation of new valuable knowledge would complement the current study. Last but not least, this research will benefit from the use of a richer set of data, on patenting across

African countries. Innovation is weak in Africa, but African inventors are not even aware of that little invention from their peers. The regional property rights organization (the OAPI and ARIPO) and the forthcoming Pan-African Intellectual Property Organization (PAIPO) could foster collaboration so that both inventors and researchers have access to the little innovation happening on the continent. OAPI stands for « Organisation Africaine de la Propriété Intellectuelle » and gathers together 16 countries in Africa that are mostly French speaking: Benin, Burkina Faso, Cameroon, Central Africa Republic, Congo, Gabon, Guinée-Conakry, Guinée Bissau, Guinée Equatoriale, Ivory Coast, Mali, Mauritania, Niger, Senegal, Chad, Togo. The headquarters of OAPI is located in Yaoundé, in Cameroon. Please, see note 12 on the members of ARIPO (The African Regional Intellectual Property Organization). PAIPO is a project spearhead by the African Union. The idea of Pan-African Intellectual Property Organization started in 2006. But the Organization is not yet fully functional.

Last but not least, better data collection is therefore one the most important implications of this study, in addition to the cautious strengthening of IPR, to favor the flows of valuable technology diffusion towards Africa.

CHAPTER 5

SUMMARY OF THE RESEARCH

This research is a thorough investigation on patent valuation and the impact of IPR on innovation, technology diffusion and total factor productivity (TFP) in developed and developing countries, principally in Africa. Three main questions are investigated.

(i) The first question checks whether the value of a patent depends on its family size and composition. The new family size and composition patent valuation method developed in the second chapter of this dissertation provides a method to assess the value of a patent in a way that fills the gap of the widely used citation method. Namely, the new method predicts patent value based on the number of jurisdictions covered and the potential market value of those jurisdictions instead of waiting for time to elapse in order for patents to reveal their values. Moreover, results show that value of patent portfolio, as predicted by the new valuation method highly predicts patent renewal and survival.

(ii) The second question asks whether the impact of IPR on the production of valuable innovation, the diffusion of valuable innovation and TFP is positive. Prior research has studied the impact of IPR on the generation of knowledge as proxied by trademark and patent applications. However, given that most of the prior studies used either the count data or citation method, my study adds to the literature by providing new findings based on a novel valuation method. Comparing our results to prior findings suggests that the citation method tends to underestimate the impact of IPR on valuable knowledge diffusion. The study also provides evidence that both local valuable innovation and technology diffusion drives TFP up. IPR, in addition to trade, is also shown to be one of the key drivers of TFP.

(iii) The third question investigates whether the impact of IPR on the generation of valuable innovation is positive in developing countries, in general, and in Africa, in particular. My findings suggest that IPR have a positive impact on the production of local valuable innovation in Africa and make African countries attractive to foreign valuable technology.

Prior studies on the impact of IPR on the generation of local innovation found that IPR have a negative impact. I conduct my study using both the novel patent family size and composition method and the simple patent count method. My findings confirm that the impact of IPR on local innovation is indeed negative when using simple patent count. However, the impact is positive when using the family method. This suggests that earlier results were driven by the proxies used for local innovation. In addition, my results show that the impact on the generation of local innovation is larger in magnitude than the impact on technology transfer.

Chapter four thus provides policy implications in matters of IPR protection in developing countries in order to expand technological frontiers either through the generation of new knowledge or through the diffusion of existing one. Our results are qualitatively similar to Falvey et al. (2006). IPR are more likely to favor technology transfer than local innovation. It is therefore important for local and national authorities to find the right and optimal level of IPR protection in order to spur innovation and economic growth.

Given that in the innovation literature, patents are the most widely used intangible rights to proxy for innovation, the intellectual contribution of my dissertation is threefold. (i) First, by developing a new patent valuation method, my advisor and I significantly contribute to the current debate on patent valuation. (ii) Second, my findings on the impact of IPR on valuable knowledge and TFP show that the impact of IPR has rather been, so far, underestimated in the literature. Future study could investigate the determinants of IPR efficiency. (iii)Third, by testing the impact of IPR on innovation and technology transfer in Africa, I suggest a novel and alternative path for development, through the development of technology, beyond the traditional aid-based or government-led development policies. Moreover, there is hardly any rigorous empirical work on IPR, innovation and technology transfer in developing countries, in general, and in Africa, in particular. Consequently, chapter four of my dissertation not only confirms the robustness of our new valuation method, but also provides one of the first empirical works on IPR in Africa. In addition, the heterogeneity of the impact of IPR, on innovation and technology transfer, not only helps explain patenting behavior across countries but also contribute to the North versus South debate over the consequences of stronger patent protection.

The results of my work will also have implications for governments, policy-makers and development institutions that want to optimally allocate their technical assistance and cooperation with developing countries. The main policy implication of my research is therefore threefold. (i) For developing countries, the results of my research provides policy implications for an optimal level of IPR as economic institutions that ensure the protection of individual rights to recoup their initial investment in R&D in order to spur innovation and hence economic growth. (ii) In addition, finding the relative optimal level of IPR in a developing country encourages both the generation of valuable local innovation and technology transfer from developed countries through Foreign Direct Investment, trade, licensing, etc. (iii) As far as developed countries are concerned, the results of my study would suggest policy implications on how to further push out technology frontiers and TFP, not only within those countries, but also across the world through a carefully structured strengthening of IPR.

APPENDIX

Definition of the Main Concepts in Patenting

Application (Patent Application): an application is the description of the invention in addition to related official forms and documentation. A patent application is hence the request (documentation and forms, specification, drawings, claims, oath or declaration, filing fees) submitted by an inventor to a patent office for the grant of a patent, for the invention described and claimed by an application.

Authority (=patent authority): the legal authority that receives, processes and issues patents. Ex: the patent authority in the U.S. is the USPTO, the U.S. Patent and Trade Office.

Citation (patent citation): a reference made by a patent to another patent that embodies relevant prior art and which may have contributed to narrowing the claim of the original application. A citation may be made by the inventor or the examiner during the examination process. Technical journals or textbooks, i.e., “non patent literature” (NPL) may be cited.

To keep in mind the form and objective of a citation reference, the following definition from paragraph nine of International Standard ISO 690:1987 is noted. “A citation is a brief form of reference inserted parenthetically within the running text or appended as a note at the foot of the page, at the end of a chapter, or at the end of the complete text. The citation serves to identify the publication from which a quoted matter within the text, an idea paraphrased, etc. was taken, and to specify its precise location within the source publication.”

Three points from this definition appear to be relevant to citation practices, namely, a citation: - is brief, - can be expected to appear within one or more of several parts of a document, and - serves to unambiguously identify the publication, as well as the precise location therein, of the cited material.

http://www.wipo.int/export/sites/www/standards/en/pdf/archives/07-09-01arc2008.pdf

Destination country: country where a patent is legally protected. Ex: If an U.S. inventor is issued patent P in Japan, the U.S.A is the source country and Japan the destination country. See source country.

EPO: European Patent Office. Headquarters are located in Munich (Germany) with subsidiaries in Berlin, The Hague, Vienna and Brussels.

Family (patent family): patents protected in different patent authorities (countries) for a single invention. For instance, a U.S. inventor can file for a priority application in the U.S.A. Subsequently, the same inventor could protect their invention in Japan, Korea and Burkina Faso. In such a case, the patents filed in the four countries constitute a patent family. Triadic patents are patent families that gather patents filed for at the European Patent Office (EPO), the JPO (Japanese Patent Office) and the USPTO (U.S. Patent and Trade Office).

First Filing: an application not claiming the priority of any other application. The family size of a first filing is necessarily one country, since such a patent is protected in only one country.

Infringement: the act of using the rights of a patent without permission or license from the patentee in a country where a patent is protected. Infringement is a violation of the intellectual property of the assignee, i.e., the person who is entitled to the patent.

Intellectual Property Rights: legally protected rights related to creations, including inventions, artistic works, names and designs. Examples: patents, copyrights, trademarks and trade secrets.

License: a transfer of patent rights that does not give the licensee the legal title to the patent, but allow him to use the rights temporarily, often conditional on the payment of license fees.

Lapse: the fact of a patent being no longer valid or in force, i.e., no longer protected by a patent authority due to failure to pay renewal (maintenance) fees. A lapsed patent can be re-instated within a limited time period.

Legal status: states whether a patent has expired or is still in force. See status.

Patent: document issued by a patent office that gives an inventor/applicant the exclusive property right to an invention.

Patent Cooperation Treaty (PCT): 144 countries are members of the PCT that was concluded in 1970, amended in 1979 and modified in 1984 and 2001. PCT is open to States that are part of Paris Convention for the Protection of Industrial Property (1883). Any member of the contracting state may file simultaneously applications for patent protection in a large number of the contracting states.

http://www.wipo.int/pct/en/treaty/about.html

PatStat: World wide patent statistical database issued by the Vienna Sub-Office of the EPO. The current study uses the April 2011 edition of PatStat, that is PatStat 4.21. See section 5 for a detailed description of PatStat.

Prior Art: aka, state of the art, is previously published publicly, available technology that may be referred to in a patent application or examination report. Similar technology described in prior art would invalidate a patent or limit its scope.

Priority: a time limited right (usually 12 months for patents and utility models) during which an inventor who filed a first filing may file a subsequent application in another country for the same invention. The 12 months, aka "priority year" starts from the date of the first filing.

PRS codes: codes used in different patent authorities to indicate the legal status of a patent or legal events in the life of a patent.

Publication (patent publication): printed (published) document that is presumptively available to the public about a patent application.

Pure Priority: Priority is defined according to the Paris Convention for the Protection of Industrial Property (1883). See priority

Renewal (Patent renewal): fact of keeping a patent in force by paying the renewal (maintenance) fees at the patent office so as to prevent the patent from lapsing.

Source country: country of origin of an inventor/applicant of a patent. Example: If an US inventor is issued patent P in Japan, the USA is the source country and Japan is the destination country.

Status (Legal Status): state of protection of a patent in a particular patent authority. Legal status of a patent indicates whether a patent is in force or not, i.e., lapsed.

USPTO: U.S. Patent and Trade Office. Office of the U.S. Department of Commerce that is responsible for examining and issuing patents.

Utility Model: type of patent that involves a simpler inventive step than a traditional patent.

Validity: the fact of a patent being legally in force. See renewal.

WIPO: World Intellectual Property Organization (see www.wipo.int)

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