Faculdade de Economia, Universidade do Porto

Master Thesis

The Negativity of Patents on R&D Investment. A panel data analysis

Alexandre Almeida

Supervisor: Aurora A. C. Teixeira

September 2007

Biographical Note

Alexandre Filipe Silveira de Almeida was born in Aveiro, Portugal, on June 10th, 1981. Student at the *Faculdade de Economia da Universidade do Porto* (FEP), he completed his undergraduate course in Economics in 2005 with the final mark of 16 *valores*.

Immediately upon the conclusion of his undergraduate course, Alexandre initiated the Master in Economics, specializing in the scientific areas of Economic Growth and Innovation. In the beginning of 2007 he completed the course part with a final grade of 17 *valores*.

He is currently enrolled in the PhD course in Economics at FEP, where he intends to broaden is knowledge on economic theory and modelling, continuing to focus on Innovation and Economic Growth related subjects.

Alexandre has recently initiated functions as a consultant in Regional Innovation Policy area for the Portuguese North Regional Coordination Commission (CCDR-N).

Acknowledgments

Scientifically, I have to express my most sincere thank you to someone who has been a true "*guru*" for me, and who has given me the honour of supervising this thesis. Professor Aurora Teixeira is an exceptional person and the best supervisor I could have wished for. I just hope I did not disappoint her in any way.

I would also like to thank Professor Óscar Afonso who is the kindest and noblest person I have ever met. He was always available to help and though directly not involved in the thesis, he was always a reference for me both in scientific and in personal terms.

Additionally, I have to thank Tiago Andrade who helped me with LIMDEP and theoretical issues regarding panel data modelling and its estimations.

In a more personal perspective, a word of acknowledgement has to go to all my family (including my cat and my dogs) who has supported my intent of proceeding studying and made it possible for me to be where I am today.

Finally, I should thank a very special person, Cristina. Without her, I would never be able to accomplish what I have accomplished so far on a personal and scientific levels. She has guided me through out my (still) short life, fighting for me and standing up for me. Cristina has brought me back. I do not know if someday I will be a great man, but for sure I already have a great woman on my side. It is to her that I dedicate this thesis.

To the woman I love:

To Cristina

Abstract

The relationship between patents and R&D involves different levels besides the ones most obvious to us. Throughout the history of economics, patents have arisen as the core of a system of incentives to private pursue of R&D investments, providing the mechanism that guaranteed the appropriability of the output of the knowledge produced. The seminal work of Romer (1990) demonstrated the need to develop a system to assure the necessary return on innovative efforts and thus privately sustain a model of continuous technological improvement and economic growth. Patenting would result in imperfect competition and legally establish the monopoly over the use of the knowledge produced. This led to patents being perceived as an intermediate output of R&D efforts. Though this relationship has been subject of intensive study by economists, the reverse causality issue remains to be thoroughly analyzed, particularly in a negative sense. Can more patents have a negative effect on R&D investment? In the present thesis we address this question, synthesizing the theoretical and empirical studies concerning both the conventional R&D-patents relationship and the reverse causality, in particular, the potential for a negative impact of patents over R&D. The theoretical survey on this issue uncovered several gaps in the literature, specifically in terms of availability of empirical analysis at the country level. Despite the literature on reverse causality direction being scarce; the macroeconomic perspective on this issue is even more unexplored. In fact, there is no evidence that ruled out the possibility of asymmetric effects of patents on R&D in accordance to the level of GDP and technology in general, and to 'convergence clubs' in particular.

Using panel data econometric estimation methods on a sample of 88 countries, over a eight-year period (1996-2003), and controlling for clubs of convergence to account for differences among countries in stages of economic development, we found mix support to the negativity of patent on R&D investment. Stratifying the sample by convergence clubs we obtain that accumulated patents positively impact on R&D intensity for the set of less developed countries whereas no statistically significant effect emerges in the case of higher developed converge clubs. Interestingly, when we restrict the highest developed convergence club down to countries with a R&D intensity above 3%, the negativity reverse causality arises, corroborating the asymmetric impact of patents on R&D investment depending on countries' development and technological stage. Finally, we demonstrate that albeit causality appears to be stronger in the most intuitive appealing traditional direction, there is evidence supporting the theoretical conveyed double causality between R&D and Patent.

Keywords: Patents; R&D; panel data; convergence clubs

JEL-codes: O31, O34

Index of Contents

Biographical Note i

Acknowledgments ii

Abstract iv

Index of Contents v

List of Tables vii

Introduction 1

Part I – Literature Review on the Relationship between R&D and Patents 6

Chapter 1. Defining the main concepts – Patents and R&D 7

1.1. Initial considerations 7
1.2. Patents and related concepts 7
1.3. R&D and related concepts 10

Chapter 2. R&D $\overset{?}{\rightleftarrows}$ Patents: surveying the traditional *versus* the reverse causality approaches 14

2.1. Initial considerations 14
2.2. The traditional direction of causality: R&D → Patents 16
2.3. The reverse causality approach: Patents → R&D 20
2.4. Identifying some gaps on the empirical literature and Thesis' main hypotheses 25
2.5. Reduced form of the theoretical model: empirical specifications for the traditional and reverse causality relation 30

Part II – Testing the Relationship between R&D and Patents. A Panel Data Estimation 32

Chapter 3. Data Gathering Methodology and Description of the Relevant Variables 33

3.1. Initial considerations 33
3.2. Data description 34
3.2.1. R&D investment 34
3.2.2. Patents 41
3.2.3. Clubs of convergence 44
3.2.4. Foreign Direct Investment (FDI) 47
3.2.5. R&D Performed by Firms 47
3.2.6. High Technology Exports 48

3.2.7. Governance Indicators: Political Stability, Government Efficiency, Regulatory Context, Law Enforcement and Corruption Control 49

Chapter 4. R&D $\overset{?}{\rightleftarrows}$ Patents: Estimation Procedures and Results 52

4.1. Initial considerations... 52

4.2. Estimation procedures for panel data.. 52

4.3. Is there evidence for the negativity of Patents on R&D?.. 60

4.4. In which direction is the relation between R&D-Patent Stronger?............................. 67

Conclusions 70

References 75

List of Tables

Table 1: Patents-R&D positive relationship 19
Table 2: Empirical studies on Patent-R&D relationship 29
Table 3: Summary statistics on missing values 36
Table 4: Data details concerning missing filling procedures 37
Table 5: Outlier countries in yearly R&D 39
Table 6: Highest and lowest R&D performers by year 40
Table 7: Statistical summary of patents issued per million of inhabitant 41
Table 8: Highest and lowest Patents granted per million of inhabitants by year 43
Table 9: Castellaci's (2006) Clubs of Convergence 46
Table 10: Descriptive Statistics for FDI 47
Table 11: Descriptive Statistics for R&D performed by Firms 48
Table 12: Descriptive Statistics for High Technology Exports 48
Table 13: Descriptive Statistics for Rule of Law 51
Table 14: Descriptive Statistics for Political Stability 51
Table 15: Descriptive Statistics for Control of Corruption 51
Table 16: Descriptive Statistics for Regulatory Quality 51
Table 17: Descriptive Statistics for Government Effectiveness 51
Table 18: Estimation results for the *traditional* causality direction (dependent variable: Patent per million inhabitants) 61
Table 19: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP) 64
Table 20: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP) 66
Table 21: Pairwise Granger Causality Tests (Sample: 1996-2003; Lags=7) 68
Table 22: Estimation results for the *traditional* causality direction (dependent variable: Patent per million inhabitants) summary table 71
Table 23: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP) – summary table (simple patents) 72
Table 24: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP) 73

Introduction

Patenting systems were built in order to guarantee the economic return necessary to induce, privately owned companies, to pursue Research and Development (R&D) activities and continuously generate technological advances. One additional justification has been put forward by Kitch (1977) who claims that patents can also be perceived as a contract between an inventor and societies in order to the former disclose information otherwise kept secret.

R&D is nowadays understood as the driving force of innovation, competitiveness, productivity growth and most importantly, of economic growth (Baudry and Dumont, 2006). Modern endogenous growth models have elected innovation and knowledge creation as the driving force of economic growth. Since knowledge presents non-rivalry characteristics, patents are perceived as a mean to guarantee economic return to R&D effort and thus the economic stimulus to innovation. In this sense, the traditional perspective on patent systems is founded on the need to protect innovators, through legally established monopoly, in order to reward their investment effort (Gilbert and Shapiro, 1990). The recognition of an innovation social return in the long run has put forward the argument of fostering innovations at the cost of a temporary monopoly (Cantwell, 2006, Encaoua et al., 2006). However, apart from the classical static loss due to the exercise of monopoly power itself, dynamic losses may occur if inventions tend to be overprotected (Cantwell, 2006), especially in technological fields where progress tends to be a cumulative or systemic process. In these industries, extension of patent protection may inhibit rather than foster further innovation (Cantwell, 2006). Hence, patents constitute the building blocks of an intellectual property rights' protection framework designed to promote innovation and knowledge diffusion as the counterpart of temporary monopoly, making the patent system a true policy instrument.

Another important question has arisen in recent literature. Theoretically, firms would be interested in patenting because it would allow them to protect their innovation and so appropriate the financial return of monopoly rents, simultaneously keeping imitators at large. Nevertheless, Levin et al. (1987) and Cohen et al. (2000) concluded that patents don't offer an effective mean of protection apart from pharmaceutical industry. Still, most of the large firms surveyed appear to have high propensity to patent. [1]

Also during the 90s, a patent upsurge is observed in several European Countries as well as in the USA and Japan whereas the private expenditures for R&D have grown only modestly as data shows. Thus, the propensity to patent, which is defined as the ration between patent applications and R&D expenditures, has increased, despite patents being recognized as a less effective mean of protection (Blind et al., 2005, Blind et al., 2006).

Here lies the so called Patent Paradox which raises the question on what is the underlying motivation to patent. Apart from very specific industries where patent protection is considered effective, what is the reason to patent if its protective bearing is reduced? According to Levin et al. (1987) or Cohen et al. (2000), patents have become a strategic asset rather than a mean to ensure R&D investment return. In fact, as it is more thoroughly analysed in sections ahead, in industries characterized by a cumulative path of innovation and knowledge production, patents block innovation since infringement is highly probable. In a rather synthetic way, if innovations are created in a cumulative technology, the development of new improvements is bound to use previous technology. This use may be forbidden through extensive patent protection impeding the innovator to produce something actually new but that is somewhat path dependent (Shapiro, 2001). This is the reason why patent protection is not available for ideas or mathematical theorems for instance since this is pure knowledge that would somehow always be infringed. Hence, the reasons why innovators continue to apply for patents, even though their protective scope is rather limited, are founded on corporative strategy of avoiding blockades by competitor, gaining bargaining power in negotiations and cross-licensing, as well as also blocking competitors and preventing lawsuits.

Less innovative firms may build a patent portfolio in order to hold up rivals and thus profiting from others' innovations, as well as protecting themselves from less successful R&D investment (Bessen and Hunt, 2007) whether the most innovative firms tend to build a broad portfolio for defensive reasons, namely to provide a credible counter-threat against competitors and, most importantly, to ensure enough technological room to develop its innovative projects (Kingston, 2001, Bessen and Hunt, 2007).

[1] There are differences in patenting propensity among different size firms. Large firms tend to patent more than small firms (Cantwell, 2006).

Strategic patenting may have a disturbing consequence since making patents easier to obtain or reinforcing their protective range rather than stimulate R&D and Innovation, may result into a kind of Prisoner's Dilemma where the private incentive to R&D investment decreases.

The increase in patent application despite its shallow protective umbrella may lie also in an increase in efficiency of the R&D process as Janz et al. (2001) have suggested to explaining the patent intensity increase. Finally, technical reasons may also concur to explain this patent upsurge observed in the 90s. The development of industries which patentability possibilities are wider such as biotechnology or software industries may also have had a positive effect over patents applied to in the three main Patent Offices (Blind et al., 2006).

But apart from the above issues, this thesis assesses in which terms we can conceive the relationship between patents and R&D.

Previous theoretical and empirical work on this subject may be subdivided into two broad categories. On one hand, there are several authors (e.g. Scherer 1965; Pakes and Griliches 1980; Griliches, 1986; Griliches, 1990; Griliches, 1994; Acs et al. 2002; Lanjouw and Schankerman, 2004) whose perspective is to perceive patents as the natural intermediate output of R&D efforts. In this sense, the causality would imply that a greater amount of investment in R&D should result in the issuing of more patents, being patents the natural intermediate output of innovative activity. But this relationship can be studied in the opposite perspective. The analysis of reverse causality seems to have been subject to considerable less attention (exceptions are Gilbert and Shapiro, 1990; Sakakibara and Branstetter, 2001; Varsakelis, 2001; Gallini, 2002), particularly the possibility of a negative effect of patents on R&D investment (Hunt, 1999; Shapiro, 2001; Bessen and Maskin, 2002; Hunt, 2006).

Most of the empirical studies that have tried to assess the different aspects of this relationship do it at firm level. The works of Pakes and Griliches (1980), Bound et al. (1982), Hausman et al. (1984), Hall et al. (1986) constitute some examples of these studies. Common to all of these studies is the positive signal relationship estimated between R&D efforts and patents. Being this the direction of the patent-R&D relationship most commonly addressed, studies tend to uphold that increasing patent's protection and easiness to obtain would guarantee higher return on R&D investment and thus increase the investment on knowledge production. However, the reverse causality issue is very pertinent since addresses how changes in patent's scope or the simple accumulation of patents influence R&D. Although the literature that departs from this standpoint is scarcer, it usually points to an equally positive signal relationship between extending patents' rights or its easiness to obtain and R&D investment. In contrast, O'Donoghue (1998) and Hall and Ziedonis (2001) have found evidence of a negative correlation between patent's scope and R&D.

The majority of studies analysing R&D-Patents reverse causality (e.g., Kortum and Lerner, 1999; O'Donoghue, 1998; Hall and Ziedonis, 2001; Sakakibara and Branstetter, 2001) explains the positive or negative correlation based on a *microeconomic analysis* of revenue/cost at the firm level. As referred earlier, despite literature on reverse causality direction being already scarce the *macroeconomic perspective* is even more unexplored.

Thus, this thesis contribution lies on the empirical macroeconomic analysis of the patent-R&D relationship in both causality directions seeking to determine whether in a cross-country analysis there is evidence of the potential negative effect of patent over R&D.

Using panel data econometric analysis techniques and a sample of 88 countries for a 8 years-period, we intend to answer this central question as well as shed additional light on related questions, in particular, in what concerns evaluating in which direction is the causality stronger and/or whether the signal varies according to countries' stage of economic and or technological development and how. For this latter aspect, we use clubs of convergence as control.

The thesis is structured as follows. In Part I, after defining the main concepts used throughout the study (Chapter 1), in Chapter 2, we review the traditional one-way causality relationship that assumes R&D as the cause of more patents, and analyze the reverse causality issue, synthesizing the main conclusions stressed by some of the authors who have address this question and studying the seminal works which point to a much more controversial issue in the reverse causality sense, the possibility of too many patents having a negative effect over R&D investment. In this chapter we survey and thoroughly analyze the empirical studies on the reverse causality issue.

Part II presents the thesis' empirical contribution to the patent-R&D issue. In Chapter 3 we proceed with data description, presenting data gathering methodology and providing a brief description of the data for each of the variables. Finally, preceding the Conclusions, the closing chapter of Part II (Chapter 4) presents the proposed panel data model, the estimation procedures, and the estimation and discussion of the results. In Conclusions we highlight the main outcomes and limitations of the present study, and point some potential paths for future research.

Part I – Literature Review on the Relationship between R&D and Patents

Chapter 1. Defining the main concepts – Patents and R&D

1.1. Initial considerations

R&D is nowadays understood as the driving force of innovation, competitiveness, productivity growth and most importantly, economic growth (Baudry and Dumont, 2006).

Modern endogenous growth models have elected innovation and knowledge creation as the driving force of economic growth. Since knowledge presents non-rivalry characteristics, patents are perceived as a mean to guarantee economic return to R&D efforts and thus the economic stimulus to innovation. However, the structural change line of thought has enriched the analysis by highlighting the different innovative potential across different stages of a country's development and also the fact that countries at the technological frontier depend mostly upon its own knowledge creation capability to grow whereas countries in a catching-up process can suffer a positive effect and grow based on knowledge transfer from the frontier. Finally, countries caught up in the under development trap may not be able to collect on those technologies due to lack of capabilities. This theoretical incursion sets the base to at least expect that countries in different stages of development may hinge on innovation differently and thus, the paten-R&D relationship may differ according to such stages.

Our aim is to study the relationship between patents and R&D, analyzing both ways of causality, testing for evidence of a negative effect, and controlling for the above mentioned different stages of development using clubs of convergence in terms of GDP per capita and technological level and evolution.

In order to clearly settle the boundaries of each concept used in this study, this first chapter is dedicated to presenting definitions concerning patents, R&D and further relevant concepts. This serves to clarify the conceptual terms used in this study thus establishing the grounds for a better perception of the critical variables to the thesis' central argument.

1.2. Patents and related concepts

According to European Patent Office (EPO), a "*patent* is a legal title granting its holder the exclusive right to make use of an invention for a limited area and time by stopping others from, amongst other things, making, using or selling it without authorization"

(EPO, 2006). The United States Patents and Trademarks Office (USPTO) defines patents in a similar way, defining it as the granting of a property right. A patent for an invention is the grant of a property right to the inventor, usually granted for 20 years. The right underlying a patent is of excludability. In other words, the owner of a patent can exclude others from using commercially an invention.

The OECD Oslo Manual (OECD, 2005) presents a similar definition stating that a "… patent is a legal property right over an invention, which is granted by national patent offices, providing to its owner a monopoly (with limited duration) for exploiting the patented invention, as a counterpart for disclosure (which is intended to allow a broader social use of the discovery)".

Thus, a patent is not a technical invention but a legal right with a possible underlying economic value. There are three types of patents (USPTO, 2007) namely, 'Utility patents', which are granted to invents or discoveries related to a new and useful process, machine or composition of matter, 'Design patents', which intend to protect original design of a manufacture, and 'Plant patents', which are granted to inventions and asexually reproduction of any new and distinct variety of plant.

In essence, a patent works as a negative right in the sense that excludes others from unauthorized use of that invention rather than entitling its owner to manufacture and commercialize an invention (Granstrand, 1999).[2] For instance, in pharmaceutical industry, when a new drug is patented, the company is not obtaining a license to sell it in the market. That requires approval by competent medical and pharmaceutical official authorities (e.g. Food and Drugs Association in the USA). Instead, the patent simply guarantees that no other company can make commercial use of that invention during the period of force of a patent. One important aspect worthy of being stressed is that a patent prevents commercial exploitation but not the use of the knowledge in the development of further innovations or in experimentation activities. In this way, a patent becomes an important vehicle of knowledge and technology transfer since on one hand forces the disclosure of information and on the other does not impede the use of that information to develop new knowledge.

[2] In addition, it is important to distinguish between a patented invention and an innovation. Innovating presupposes commercial exploitation of an invention. Patents are issued on inventions, that is, new technical or technological solutions regardless of effective implementation/commercialization of that invention.

In what concerns the basic criteria subject to which is the granting of a patent, these are three, namely, industrial applicability, novelty and non-obviousness (Granstrand, 1999). The first criterion imposes that the invention has a potential application in practice. The novelty criterion implies that in order to be issued a patent, the invention must involve something new. Finally, the non-obviousness criterion imposes that the novelty must involve a minimum level of inventive development in order to be granted.

As it is presented in the following sections, patents are commonly perceived as the natural intermediate output of R&D activities (Kleinknecht et al., 2002, Beneito, 2006) and thus are used as a way to measure innovative capacity as well as the efficiency of the knowledge creating processes (Beneito, 2006). Even though, patent counts are widely used in the literature, mainly as output indicators, most authors have identified and recognized their shortfalls. In particular, patents are a biased and poor indicator of innovation since not all innovations are patentable, not all patentable innovations are effectively patented, and the quality and hence value underlying each patent may differ greatly (Lanjouw and Schankerman, 2004; Beneito, 2006).

Two main features determine the contours of each patent and consequently, alongside with the technological and economic potential, determine a patent's value: patent length and patent scope. The patent's length is the validity period or the lifetime period conceded by each patent office where the patent was filled (Gilbert and Shapiro, 1990). In simpler terms, a patent length tells us how long will the patent be in force until it expires and with it, the temporary monopoly. For the three most important patent offices, namely the United States Patent Office (USPTO), the European Patent Office (EPO) and the Japanese Patent Office (JPO), the duration of a patent has been fixed in twenty years.[3] Due this period, the commercial exploitation of the protected invention is open to anyone.

The other determining element of a patent's value is a patent's scope. If length refers to the time of exclusive commercial exploitation granted by the patent to its owner, the scope refers to the extension of those rights. In particular, a patent scope is defined by claims on future innovations, throughout different technological fields which are recognized by the patent examiner. In a blunt fashion, it is simply setting the boundaries

[3] This period is counted from the date of filling and in principle it is not extendable however, in exceptional cases where the final development of the invention consumed a large part of that period, a supplementary time extension may be conceded by the patent office (e.g. pharmaceutical drugs).

between what is protected and what is not (Encaoua et al., 2006). In this sense, the scope defines the ability of competitors to develop substitutes or even agents in non-related technological markets to launch new products without the fear of infringing the patent holder's rights (Merges and Nelson, 1990). Hence, the broader and higher the number of claims conceded by the patent examiner, the broader the scope of a patent and the higher the patent's economic potential value (Gilbert and Shapiro, 1990). Nevertheless, a too broad scope may deter rather than induce R&D investment and result in a slowdown in innovative rhythm rather than the intended stimulus.

Recently, authors have been using the concept of patent thicket. It seeks to refer to the "dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology" (Shapiro, 2001: pp. 1-2). In other terms, a patent thicket can be perceived as the accumulation of intellectual property rights over interrelated and interdependent technologies leading to legal technological blockades, especially, when innovation follows a cumulative path. If innovation is cumulative, multiple blocking patents and stronger patent rights may constitute impeding barriers to the development of new technologies and in this sense discourage rather than instigate R&D investment and innovation (Shapiro, 2001; Bessen, 2003; Hunt, 2006; Bessen and Hunt, 2007).

In terms of patent metrics, the most common concept is that of patent propensity. It designates the ratio of the number of patents applications to the amount of R&D expenditures thus expressing patent outcome from each dollar/euro invested in R&D (Blind et al., 2006). Besides expressing the intensity of patenting deriving from R&D efforts, this measure may also serve as a proxy to evaluate R&D productivity (Griliches, 1994; Lanjouw and Shankerman, 2004).

1.3. R&D and related concepts

UNESCO and OECD define Research and experimental Development (R&D) as all activities that "comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (in Frascati Manual, OECD, 1993, p. 29). Thus R&D activities are conducted with the purpose of expanding the knowledge stock, being regarded as the major input in the innovative process (UNESCO, 2001).

Likewise to many other goods, R&D resources are far from being equitably distributed around the world (UNESCO, 2001). UNESCO's (2001) estimates for the years of 1996 and 1997 point that the developed countries, representing 22% of the world's population and 61% of its GDP, accounted for 84% of global R&D expenditure. Hence, the developing nations that concentrate 78% of the world's inhabitants and a mere 39% share of world GDP, represents even less in terms of global R&D, approximately 16%. The Declaration on Science and the Use of Scientific Knowledge of the World Conference on Science for the Twenty-first Century: A New Commitment, convened by UNESCO and the International Council for Science (ICSU) in Budapest (Hungary) in 1999, recognizes this reality and explains the need to reduce the asymmetry in R&D resources geographical distribution, stating that: "As scientific knowledge has become a crucial factor in the production of wealth, so its distribution has become more inequitable. What distinguishes the poor (be it people or countries) from the rich is not only that they have fewer assets, but also that they are largely excluded from the creation and the benefits of scientific knowledge" (UNESCO, 1999, point 5 of the Declaration).

Often, authors (e.g., Griliches, 1980; Evenson et al., 1988) use the concept of R&D capital or R&D stock to designate the accumulated knowledge that results from R&D activities. Unlike R&D intensity which is a flow variable, R&D capital is a stock variable and is thus calculated through the accumulated value of yearly R&D expenditures. The estimation of R&D capital is (still) a major issue, namely in what concerns the components to include under this concept and the issue of depreciation. Regarding the components a highly debatable item is military expenditures. Moreover, we should precise whether public and privately financed R&D ought to be included as well as basic and applied research efforts (Sveikauskas, 1986). In the present work (see Chapter 3), R&D data that has been retrieved from World Bank databases excluding defense R&D spending but including both basic and applied research. Furthermore, although data exist on where R&D activities take place (public institutions, universities, or in privately owned companies), R&D expenditures used in the present work make no such distinction.

Analogous to physical capital, depreciation can occur over knowledge and, in particular, over R&D stock (Bitzer and Stephan, 2007). In fact, the increase in R&D stock resulting from R&D efforts may be less than proportional since part of the newly generated stock makes part of the pre-existing obsolete (Bitzer and Stephan, 2007). It seems reasonable that as new knowledge is added to the stock, some of the previous conceptions might become less valuable, replaced partially or as a whole for the new discoveries/technologies. Following Schumpeter's renowned 'creative destruction', new knowledge/technologies add to the existing capital stock but, simultaneously, displace part of the previous capital (Bitzer and Stephan, 2007). Generally, R&D capital is compared to physical capital and thus its estimate, recognizing the need for depreciation, follows the accounting principle of permanent inventory (e.g. Sveikauskas, 1986, Guellec and De La Potterie, 2001). In this method, R&D capital results from the accumulated value of R&D expenditures discounted by a constant depreciation factor. A downfall of this approach is that it is implicitly assumed that, like physical capital, R&D stock depreciates with the simple passage of time. But, as Schumpeter states, physical capital is distinct from R&D capital since the latter is destroyed through the generation of new superior knowledge (Bitzer, 2005). More recently, Bitzer and Stephan (2007) proposes a new method to estimate R&D capital stock that is based on Schumpeter's creative destruction paradigm. In fact, the displacement of old knowledge instead of following a constant rate, it is linked to the previous magnitude of R&D expenditures (Bitzer and Stephan, 2007). In other words, theoretically it is acceptable that a more intense R&D country or firm will add new knowledge to the R&D stock at a superior rhythm as well as will also displace old knowledge more rapidly.

Another important related concept is that of R&D intensity, which is used in the same way as R&D effort (Falk, 2006) or R&D investment (e.g. Griliches et al., 1986, Jaffe, 1986, O'Donoghue, 1998, Kortum, 1993, Lanjouw and Schankerman, 2004, Suzuki et al., 2006). R&D intensity measures the annual effort that a company or a country endure in order to develop R&D activities (Kleinknecht et al., 2002). This is a flow variable that is generally measured as total R&D expenditures in a given country and in a given year, independently of where the R&D activities take place. Thus it presents itself as an input statistic since it measures the volume of financial resources devoted to R&D (UNESCO, 2001).[4]

[4] That is to say that under GERD we account for all R&D activities regardless of in which sector they are developed (private, public, universities or non-profit organizations) or the source of financing.

Following the Frascati Manual (2001), the common measure for R&D intensity is Gross Expenditures on R&D (GERD) that is calculated by the ratio of R&D expenditures to GDP in Purchasing Power Parity (Baudry and Dumont, 2006; Falk, 2006). This relative measure allows for international comparison on the inventive/innovative effort of different countries (Falk, 2006). In a microeconomic perspective, R&D intensity is usually the ratio of R&D firm level expenditures to sales (Lanjouw and Schankerman, 2004, Falk, 2006).

It is also possible to measure R&D intensity through R&D personnel instead of R&D expenditures. In this sense, the ratio of researchers to the total number of inhabitants indicates the density of R&D human resources in relation to the size of the population (UNESCO, 2001). A composite measure can also be estimated comprising both R&D financial resources as well as R&D human resources in each country (UNESCO, 2001). This indicator, which can serve as an alternative proxy to R&D intensity, is calculated as the ratio of R&D expenditures per R&D personnel per million of inhabitants. The value added of this measure lies in the fact that it sheds light on the access to financial resources, instruments and other capital equipment and research facilities (UNESCO, 2001). In simpler terms, this proxy expresses the supporting conditions available to each researcher and that allow for further insight on R&D activities working conditions.

The conceptual framework detailed in the present chapter defines and clarifies the concepts necessary to a better understanding of the literature and of the different approaches to the patent-R&D relationship. In the following chapter (Chapter 2), existing empirical and theoretical work on the relationship patent-R&D is analyzed, from two different perspectives. Besides analyzing both causality directions of patent-R&D relationship, we also review and distinguish between the literature following a micro and a macro perspective; additionally, we analyze and present the studies that conceive the possibility of a negative relationship.

Chapter 2. R&D $\overset{?}{\rightleftarrows}$ Patents: surveying the traditional *versus* the reverse causality approaches

2.1. Initial considerations

R&D efforts are generally accepted as the driving force of innovation and ultimately, economic growth (Baudry and Dumont, 2006). Knowledge creation and innovation are essential for technological frontier countries to sustain economic growth. For catching-up countries, its importance is also high even though these may hinge its economic growth on the knowledge transferred from technological leaders. This is extensive to developing countries, though the lack of technologic capabilities may result in lack of technological absorption skills and may turn not viable the technology transfer.

Patents are commonly used as a measure of innovation, constituting an intermediate output (Kleinknecht et al., 2002) of R&D efforts. R&D investment on the other hand is usually regarded as the input to the innovative process (Beneito, 2006). Thus, in functional terms, R&D would be the independent variable (input), whereas Patents would be the dependent (output) one (Baudry and Dumont, 2006). In this sense, causality's direction implies that more investment in R&D would lead to more Patents being applied and issued. The estimation and analysis of such relationship allows us to derive productivity measures, important to analyze the evolution of R&D's efficiency (Messinis, 2005). It is interesting to highlight here that fact that one of the major EU weaknesses' in relation to the US is often associated with its inferior innovative capacity, somewhat explained by the lower level of investment in R&D (Baudry and Dumont, 2006).

Traditionally therefore, the argument put forward to sustain the need for an intellectual property protective system regards the intrinsic non-rival characteristic of knowledge. The works of Arrow (1962), Nordhaus (1969) or Romer (1990) acknowledge this characteristic concluding that in absence of such a system, there would be no private incentive to pursue costly R&D activities. In this set, Patents function as the ex-ante incentive, granting monopoly rents in case of successful knowledge production (Encaoua et al., 2006). However, economics is truly the science of trade-offs and as always, introducing a patent system as its perks. On one hand, if patent rights granted are weak, the rents appropriable in the future from an innovation are minor and thus

R&D investment may be under-supplied (Sakakibara and Branstetter, 2001, Varsakelis, 2001). Furthermore, the spillover effects are not also paid to the innovator (Almeida, 2006). The sub-optimal rewarding leads to sub-optimal R&D investment, sub-optimal technological progress rate and consequently a smaller economic growth rate. However, conceiving generous benefits to a patent holder does not ensure by itself a higher technological progress rhythm (Heller and Eisenberg, 1998, Encaoua et al., 2006). However, on the other hand, besides the increase in static deadweight losses resulting from the monopoly power inefficient pricing, follow-on inventors may face technological blockades in accessing general knowledge due to excessive protection and this may stall the innovative process (Heller and Eisenberg, 1998, Bessen and Maskin (2002), Gallini, 2002, Encaoua et al., 2006). This is a particularly pertinent issue when it comes to technologies characterized by a cumulative and sequential innovative path (Shapiro, 2001, Bessen and Maskin (2002), Galini, 2002, Hunt, 2006). Thus patents present themselves as a second best solution (Encaoua et al., 2006), with tricky effects on the expected innovative output stimulus.

In terms of the Patent-R&D relationship, *traditionally* patents are perceived as the outcome of R&D investment. Since innovation, here measured by patent counts, tends to be crucial to sustain continuous increases in productivity (Romer, 1990) and hence, economic growth (Romer, 1990), the analysis of this direction of causality is highly pertinent. In this context, several authors (e.g. Griliches, 1990; Kortum, 1993; Lanjouw and Schankerman, 2004) have tried to devise a knowledge production function or a productivity evolution analysis using patents as output and R&D expenditures or the number of researchers as input. The evidence obtained in some of these studies, namely that of Lanjouw and Schankerman's (2004), points to a decrease in R&D productivity raising the spectra of economic growth slowdown and eventual halt.

However, the prefiguration of patents as a policy instrument imposes an opposite (*reverse*) direction causality. In fact, if we perceive patents as a policy instrument aimed at fostering and stimulating R&D investment (Encaoua et al., 2006) and, hopefully, innovation, analyzing causality in this reverse direction appears to be of utmost importance. This tends to be also critically given the tendency, observed in the last few decades, towards reinforcing patent's protection rights. During the 90s, a patent upsurge has been observed, probably due to the reinforcing of patent enforcement and legal coverage. Still, it has also been stressed that this does not necessarily mean more innovation or even invention (Merges and Nelson, 1990). This evolution might be linked to strategic reasons to patenting (Shapiro, 2001, Hunt, 2006, Bessen and Hunt, 2007) and some authors even uphold that this tendency to extend patent protections may be counterproductive in terms of R&D and consequently innovation (e.g. Shapiro, 2001, Hunt, 2006, Bessen and Hunt, 2007).

In what follows we describe in more detail the traditional (Section 2.2) and the reverse (Section 2.3) direction of R&D-Patents relation.

2.2. The traditional direction of causality: R&D → Patents

Most theoretical (e.g. Jaffe, 1986; Griliches, 1990) and empirical (e.g. Pakes and Griliches, 1980; Hall et al., 1986; Griliches, 1988) literature on the patent-R&D relationship tends to assume causality in the direction that more investment in R&D will result in more patenting. This is the direction in which patent-R&D relationship is usually addressed (Beneito, 2006). Accordingly, in the production of knowledge, R&D effort, commonly measured by expenditures, accumulated capital (Beneito, 2006) or number of scientists and engineers (Scherer, 1965) is the main input to researching new base knowledge and the development of new technological solutions leading to innovation. Therefore, patents can be perceived as the natural intermediate output of inventive activity (Pakes and Griliches, 1980). Being perhaps the most intuitively appealing way of considering this issue, it is also important to stress that theory conceives this relationship as being a positive one. In other words, devoting more resources to R&D would result in more patenting and in more innovations.

Several empirical studies have tried to assess the different aspects of this relationship, especially at firm level. The works of Pakes and Griliches (1980), Bound et al. (1982), Hausman et al. (1984), Hall et al. (1986) constitute some examples of these studies. Common to all of these studies is the positive signal relationship estimated between R&D efforts and patents.

Pakes and Griliches (1980) analyzed 121 large US companies and concluded that there is a strong positive correlation between the two variables in analysis though this correlation is stronger in cross-sectional analysis than in within firm analysis. In fact, an interesting result is that R&D efforts seem to follow a random walk which may reinforce the argument for causality. Another aspect worthy of note is the lag between R&D efforts (input) and patents (output). Intuition may lead to think that producing knowledge and being successful in order to be issued a patent requires time. Hall et al. (1986) tried to econometrically evaluate the existence of lags in the R&D-patent relationship using a sample of 642 US companies. Their results were somewhat surprising since the strongest correlation estimated is contemporaneous. In fact, though there are statistically significant lags of R&D efforts to patents, the estimated impacts are small. Though the authors simply report their findings, if the above mentioned random walk pattern of R&D is verified, this may help explain these results.

Hall et al. (1986) also built a patent production function using R&D efforts as their input and reported a proportional relationship between the number of patents attributed and the amount invested in R&D. It seems that this relationship could be characterized by constant returns to scale. However, some studies like Bound et al. (1982) argue that there may be decreasing returns to scale in this relationship. Using data on 2600 companies, Bound et al. (1982) confirm the existence of a positive correlation between R&D and patents but have noted that smaller firms and R&D programmes result in more patents per dollar invested. This raises the question of propensity to patent and productivity of R&D, which, although interesting, is beyond the (necessarily) narrow scope of the present work.

This relationship can be extended to analyze the market value of a firm. Using R&D efforts and patents as inputs, Jaffe et al. (2005) tried to relate the innovative capability of firms to their economic value. The results point again to a positive relationship, far from surprising taking into account economic theory. Beneito (2006) uses the R&D-patent relationship to study differences in performance and innovative output of R&D programs conducted in-house and subcontracted.

There are also other subjects besides R&D-patents literature where implicitly or explicitly it is assumed patents to be an output of R&D. For instance, in the Endogenous Growth Literature (e.g. Romer, 1990; Aghion and Howitt, 1992; Barro and Sala-i-Martin, 1997) theoretical models are built over an imperfect competition framework based on patents. Patents are the key element in assuring return to private R&D investment. The allocation of resources to R&D activities leads to the production of knowledge which is then patented.

The debate around Schmookler's (1966) Demand Pull Hypothesis and Schumpeter's (1942) Technology Push is another field where the causality between patents and R&D

in presumed in the “traditional” direction. This discussion tries to assess if innovation is mainly driven by demand or technology though both streams use patents to measure innovation and R&D efforts as the input. Ultimately, the purpose is to understand whether innovative efforts are channeled to anticipate or respond to a market’s stimulus or R&D efforts conduce to new technological knowledge, unrelated to market considerations, and which determine the direction of innovations. Either way, the assumption on the relationship patents-R&D is that more R&D leads to more patenting, again postulating a positive correlation.

An area of growing interest concerns R&D productivity. Again, when analysing R&D productivity, most authors (e.g. Griliches, 1988; Kortum, 1993; Porter and Stern, 2000; Lanjouw and Schankerman, 2004) use (in spite of its shortcomings) patents to measure innovative output and evaluate the evolution of R&D productivity, based either on R&D investment (e.g. Lanjouw and Schankerman, 2004) or R&D capital (e.g. Evenson, 1993). The path of investigation on this subject lead to important results, namely concerning the possibility of technological exhaustion (Evenson, 1993) and it is likely to constitute a more accurate measure of innovative output other than the traditional patents count. Lanjouw and Schankerman (2004) is an example of a study where the authors tried to develop a composite index to evaluate patents regarding not only its quantitative aspect but also a qualitative approach, conducing to a composite index.

Beneito (2006) studies the innovative performance differences deriving from R&D according to its place of execution, in-house or contracted. It is based on the traditional approach that regards patents as output to R&D. Applying an econometric panel data solution to analyse a dataset of Spanish manufacturing firms for the period 1990–1996, the results point to a overwhelming majority of the most significant innovations being developed in-house and contracted R&D’s goal, when used, is set on a more incremental type of innovation.

Table 1 briefly synthesizes some of the investigation areas that use patents-R&D relationship in the traditional direction and assume a positive correlation, that is, more R&D investment leads to more patents. From the table and the former descriptive analysis, an undisputed conclusion can be retrieved. There are many areas of investigation conveying the causality between patents and R&D assuming that more allocation of resources to R&D would definitely result into more innovative output as measured by patents issued. Furthermore, an important aspect also common to all the articles reviewed is the fact that both theoretical and empirical works support the idea of a positive relationship between R&D effort and patents, with strong correlations and surprisingly a contemporaneous pattern.

Table 1: Patents-R&D positive relationship

Patents as R&D's output	Main subject area	Mechanism	Authors (e. g.)
Explicit	Endogenous Growth Theory	Patenting is the result of successful production of valuable knowledge which, in turn, is a direct function of R&D efforts.	Romer (1990); Barro and Sala-i-Martin (1997); Aghion and Howitt (1992)
	Patents & R&D relationship	Patents are the natural intermediate output of R&D; R&D expenditures or capital constitute the main input to the patent production function.	Pakes and Griliches (1980); Bound et al. (1982); Hausman et al. (1984); Hall et al. (1986); Griliches (1986); Griliches (1990); Griliches (1994); Ernst (1998); Acs et al. (2002)
	Demand Pull vs Technology Push	Patents are considered technological output of innovative activity.	Schumpeter (1942); Scherer (1965); Schmookler (1966)
	R&D Spillovers	Patenting is the result of successful production of valuable knowledge which, in turn, is a direct function of R&D efforts.	Jaffe (1986)
	R&D, Patents and Market value	Associate Tobin's *q* and other measures of market value to R&D efforts and success (patents granted) of a firm.	Jaffe et al. (2005)
	R&D Productivity/Technological Exhaustion	Patents are the natural intermediate output of R&D; R&D expenditures or capital constitute the main input to the patent production function.	Griliches (1988); Kortum (1993); Porter and Stern (2000); Lanjouw and Schankerman (2004); Beneito (2006)
	Differences in innovative capacity: cross-country analysis	Patents are the natural intermediate output of R&D; R&D expenditures or capital constitute the main input to the patent production function.	Porter et al. (2002); Baudry and Dumont (2006)
Implicit	R&D Productivity	Patents are a proxy to innovative output resulting from R&D. A worrying but maybe illusionary productivity slowdown is observed.	Evenson (1993); Lanjouw et al. (1998)

2.3. The reverse causality approach: Patents → R&D

This section's analysis tries to shed light on the impact patents can, potentially, have on R&D investment. The public good characteristics of knowledge could refrain private investment from R&D activities since the appropriability of the knowledge produced was not guarantied and with it the economic return (Romer, 1990; Aghion and Howitt, 1992). Hence, unless the government takes on the burden of all R&D expenditures, there would be no inventive activity in the economy (Romer, 1990). Here lies the justification for the existence of a patent system to assure at least a partial return to private R&D efforts (OECD, 1997). Notwithstanding, the definition of the extent of protection of a patent involves a trade-off between static losses due to monopoly power and dynamic gains resulting from innovative output and its wide recognition as the engine of productivity and long run economic growth (Romer, 1990; Gancia and Zilliboti, 2005).[5] However, the monopoly static losses resulting from a patent are expectedly exceeded by the spillovers from new knowledge or technology developed.

One may analyse the R&D-patent relationship through two subtly different approaches, both in the reverse causality direction. On one hand, one can assess the impact of legal changes on the extent of patents rights and analyse the theoretical and empirical impact on R&D effort, and, on the other, one can directly study the impact of patent accumulation on R&D. Nordhaus' (1969) model devised a theoretical positive relationship between stronger patent rights and investment in R&D. The underline intuition is simple. The extent of patent rights has direct implications over the expected return on an innovation. Stronger patents would lead to the accrue of more revenues and this would create an additional incentive to invest in R&D. Gilbert and Shapiro (1990) and Klemperer (1990) have built analysis' frameworks which lead to the same conclusion of Nordhaus (1969).

Considering a patent race scenario, Denicolo (1996) formally derived a solution that reinforces the general theoretical presumption that broader patent scope or greater patent length will induce more R&D effort and innovation. Hence, theoretical literature on the reverse causality is almost unanimous in assuming a positive correlation (Sakakibara and Branstetter, 2001), which the conventional model predicted to be monotonic. However, it is important to stress that these results were derived considering

[5] This is the view of endogenous growth theory literature.

an isolated invention, disregarding completely the cumulative nature of innovation. Jaffe (2000) stresses the fact that analyzing the impact of changing patents' scope and assessing its effect on R&D and innovation requires distinguishing among different types of innovations. In particular, we should distinguish between independent inventions, cumulative inventions and research tools. The theoretical results of the models depend on these considerations. Nordhaus' framework and the studies of Klemperer (1990) and Gilbert and Shapiro (1990) were conceived based on the assumption of isolated or independent inventions thus leading to an undisputed conclusion that broadening patents' scope must induce more R&D investment, stimulated by the higher expected return from stronger intellectual property rights. The traditional wisdom, however, which upholds the strengthening of patents to stimulate R&D may lead to inaccurate conclusions when considering inventions across different scientific fields (Bessen and Maskin (2002), Galini, 2002, Hunt, 2006). If one conceives knowledge production and innovative output as a natural outcome of a cumulative process, then not only strengthening patents can have a surprising depressing effect over R&D investment but can also raise a new set of questions.

Kitch (1977) analyses the issue on coordination among different researchers working in related fields of technology, namely the duplication of R&D efforts and overinvestment derived from patent races. The discoveries of new technological solutions could process at a pace above what would be socially optimal. If this is the case, one would have overinvestment in R&D and innovations would be replaced before achieving its maximum return. In other words one would have an 'overdose' of innovations, constraining each other's return. Kitch (1977) argues that only the pioneer investment should be granted broad patent rights. O'Donoghue (1998) supports this insight which intuitively can be explained using the famous metaphor "Standing on the Shoulders of Giants". What is being recognized here is that knowledge is produced in a cumulative process thus the pioneer inventor provides the shoulders for many others to stand on. The intuition is that stimulating the development of a larger magnitude innovation will produce positive externalities for inventors to come (Jaffe, 2000). In this vein, pioneer innovator is under rewarded and investment in R&D is below socially desirable, laying the theoretical ground for supporting the broadening of patents' scope. However, this analysis suggests that afterwards one should restrict patents. The flip side of the coin is that, ultimately, only the pioneer would be interest in developing technology based on his prior novelty. This presents a serious constraint on innovation and technological evolution.

Notwithstanding, Kitch's (1977) conclusion that it would be beneficial to extend patent's scope granted to a pioneer and restrict downstream patenting, it appears more sustainable, in presence of a cumulative process of innovation, that extending patent scope might produce a negative effect on R&D investment and innovative activity. Gallini (2002) recognizes that in high tech industries, characterized by a continuous process of cumulative learning and innovations, it is likely that broadening patent's breadth will lead to blockings and result in an innovation slowdown.

The third type of innovative processes accounts for the special case of patented research tools. Research tools are a valuable lever to future invention but have no commercial value (Scotchmer, 1996). This is a special case among cumulative processes of innovation whose distinctive feature lies in the fact that research tools do not compete in the market place with products using them. In fact, research tools have no commercial market and in this sense, unless economic return is derived from their use as platform for other inventions, there would be no economic incentive for the development of these tools. Heller and Eisenberg (1998) and Schankerman and Scotchmer (1999) addressed this issue concluding that both the inventor of the research tool and the user want the downstream product to be produced. The difficulty arises in determining the optimal distribution of income between agents.

Some of these more recent models (e.g., Gallini, 2002) use Nordhaus' (1969) framework but introduce mechanisms to take into account this cumulative nature and assess with more theoretical accuracy the patent-R&D relationship. Despite the nuances introduced by considering different types of innovations, the general assumption of a positive correlation between R&D and strengthening patents is not really challenged.

In synthesis, the mainstream of the theoretical literature that addresses the patent-R&D relationship in the direction of reverse causality assumes a positive correlation in spite of lacking corroboration by empirical studies whose conclusions tend to be unclear or in disfavor of the positive correlation assumption.

Following these controversial and surprising empirical results which challenge the theoretical foundations of the patent system and its reinforcement, some recent studies have tried to devise a theoretical explanation at a microeconomic level (e.g. Hunt, 1999;

Shapiro, 2001; Hunt, 2006) to the lack of empirical support of the positive correlation hypothesis.[6] A major distinctive feature of these works is that instead of focusing in patent's scope or length, they use patent accumulation as a variable in analysis. Even though to some extent patent protection and the accumulation of patents are correlated, they allow the devising of complementary analysis. One innovative aspect is that these authors try to analyze the possibility of a negative correlation and what could explain it.

One of these explanations (Shapiro, 2001) stresses the fact that the patent system seems to lead to the creation of a 'patent thicket', in particular, in industries characterized by cumulative and sequential innovations like semiconductors, software or even biotechnology. The 'patent thicket' is defined (see Section 1.2, in Chapter 1) as a dense web of overlapping intellectual property rights. In other words, in some industries the accumulation of patents on overlapping technologies forces companies to cut through them in order to commercialize innovative but overlapping technologies. When innovation is a process characterized by cumulative innovation and path dependency, the enlarging of the patent thicket and the reinforcement of patent's scope may inhibit rather than stimulate R&D and innovation. Hunt (2006) has developed an analysis based on a duopoly model and derives a necessary condition in order to be verified the positive correlation assumption between R&D intensity and patent number at firm level. The author concludes that three factors may lead to the non-verification of the necessary condition and in this way firms' patenting activity has a negative effect on R&D intensity. Sufficient technological overlap in firms' technologies making it likely to incur in complements problem, high tech industries and relatively cheap patents create a set in which the probability of a negative correlation may be found. Hunt (1999) had already pointed in the direction that relaxing the requirements to obtain a patent would stimulate R&D in low tech industries and could have a negative effect on R&D in high tech industries.

Additionally, Shapiro (2001) identifies two problems - the 'complements' and the 'hold up' problems - that may explain the negative correlation. The 'complements problem' is inherent to patent issuing and theoretically offers an explanation to challenge the widespread presumption that facilitating patent issuing would stimulate R&D and innovation. There are two mechanisms by which we can infer the impact of patent

[6] O'Donoghue (1998) and Hall and Ziedonis (2001) have found evidence of a negative correlation between patent's scope and R&D.

accumulation and the perverse outcome of easing patent issuing. For innovating in industries such as semiconductors firms rely on previous technologies; even though the output of R&D efforts may be a completely new product, if built upon a technology which patent scope is wide, that implies paying the respective royalties, forcing in this way innovators to acquire several licenses and bear multiple patent burdens (Shapiro, 2001). Hence, the simple proliferation of patents is conducive to an increasingly higher cost associated to innovation resulting in a negative incentive to R&D spending. Beyond this negative effect, it is important to consider that in some cases the blocking may not be overcome. If it is not possible to obtain licensing of an essential patent, all the technological development in complementary fields is at stake. Heller and Eisenberg (1998) refer to this problem as the "tragedy of gatekeepers" in reference to excessive protection against the use of a particular resource which ultimately leads to its under use. In innovation, that means a slower technological progress and consequently a worst dynamic economic performance.

The 'complements problem' may be aggravated in case of less demanding patentability requirements. The relaxing of the nonobviousness requirement in the US patent system reported by Hunt (1999) makes patents easier to obtain and enlarges the patent thicket. Bessen (2003) presents a model where he analyses the results of having low or high standards requirements to the issuing of a patent. Similarly to Shapiro's (2001) analysis and Hunt's (1999) predictions, under low patenting standards, Bessen (2003) concludes that firms tend to assemble large patent portfolios which are used to make aggressive demands leading to blockings and higher transaction costs. This would encourage more patenting but less R&D. This may serve as a justification in why firms keep on patenting despite recognizing it as a poor innovation protection instrument (Levin et al., 1987). In sum, weakening patentability criteria will reduce R&D expected return in high tech industries and therefore have a negative impact on R&D spending and innovation however, in industries characterized by an innovative rhythm substantially slower, the effect may be positive (Hunt, 1999).

In what concerns the 'hold up problem' it is much like a heist! If the 'complements problem' derives from costs known upfront to obtain licenses or develop technology to use instead, the hold up problem occurs when a specific technology, not yet patented is used in the conception of a new product. In a patenting system of multiple overlapping technologies and in which patent applications are confidential, companies may be using technology that waits to be patented. If the patent is granted and the company's product is already in large scale production, the owner of the patent gains bargaining power to the extent that he can demand too much and capture most of the companies' profits. Thus, innovating may be a risky activity subject to opportunistic behaviour which feeds back a negative effect over R&D investment.[7]

In order to overcome these inefficiency generating problems, literature offers cross licensing and patent pools as two possible solutions. In short a cross license agreement consists of a contract in which the participants agree to license each others' patents, avoiding blockings. A patent pool is a similar solution but of a wider nature. Patent pools are conceived as a package of essential and complementary patents provided by a third party and to which companies have access in exchange of a fee. Shapiro (2001) elects this as the most natural solution to the complements problem and the best way to prevent the perverse effect over innovative activity and economic growth.

The trade-offs between static and dynamic efficiency underlying a patent issuing and in addition, the inefficiency and R&D disincentive that result from patent accumulation as we have highlighted may also be demeaned through a more flexible, almost custom made patent system. Making the patents and renewal fees crescent according to the length of protection desired will lead the inventor to acquire rights accordingly to its expected return (Scotchmer, 1999). For the more troubling innovations following a sequential and cumulative technological path, combining a mix of a patent breadth fee and introducing a buyout price, which amount may be also subject to a proportional fee, may help overcome some of the inefficiency problems through a self selection mechanism (Llobet et al., 2000, Encaoua et al., 2006).

A more flexible and custom made approach may turn the patent-system more incentive-friendly, mostly in what concerns cumulative technologies such as software, biotechnologies and ICT.

2.4. Identifying some gaps on the empirical literature and Thesis' main hypotheses

Empirical analysis of R&D-patent relationship, in particular addressing the impact of changing scope degree of a patent is still relatively scarce and, to the best of our

[7] This same problem can be analysed regarding the extension of patent's scope and length.

knowledge, restricted to firm level analysis (Jaffe, 2000; Sakakibara and Branstetter, 2001). Although this might provide insufficient guidance for further theoretical developments, there are some empirical studies which may shed some light about R&D-patent relationship in the reverse causality direction, namely that of Sakakibara and Branstetter's (2001). These latter authors' work is based on the theoretical frameworks of the models of Nordhaus (1969), Klemperer (1990), and Gilbert and Shapiro (1990). Sakakibara and Branstetter (2001) hypothesize that the impact of an increase in the scope of patent protection should translate into higher expected return to R&D and thus stimulate R&D investment. Their econometric analysis on Japan's patent law reform concludes that there seems to be no evidence that the strengthening of patent's scope leads to an increase in R&D spending. As the authors themselves recognize, their results challenge the notion that broadening patent protection stimulates inventive activity. Despite the surprise, other studies have countered the theoretical proposition of a positive correlation between patent's scope and R&D investment.

Merges and Nelson (1990) and Jaffe (2000) are part of the scarce literature that analyses empirically how patent scope or length changes impact on R&D. In particular, Merges and Nelson (1990) concluded that the reinforcement of patent breadth brought about by the Bayh-Dole Act in 1980 lifted barriers to technological development due to difficulties in obtaining cross licensing agreements and lifting patent blockades. In industries of cumulative interdependent inventions, the authors conclude that the strengthening of patents inhibit the broad development of technologies. Based on a case study approach, Merges and Nelson (1990) raise serious doubts onto the theoretical assumption of a positive relationship of patent breadth and R&D spending. They argue that it is counterproductive to broaden patent's scope in basic innovations, on which further innovations will be based upon.

Hall and Ziedonis (2001) analyse both quantitatively and qualitatively[8] the semiconductor industry in the US in the period of 1979 to 1995. This period coincides with a patent law reform reinforcing patent's breadth and an incredible increase in patent application. One might think that stronger patent rights would lead to higher investment and ultimately result in higher innovative output consubstantiated in an upsurge of patents. However, Hall and Ziedonis (2001) questioned the real effect on

[8] The authors conducted interviews to assess how strongly did R&D managers relied on patent protection having concluded that in general, patents are perceived as a weak mechanism of protection.

R&D investment and innovative output and the apparent patent paradox[9] that arose. It is important to bear in mind the distinctive features of the semiconductor industry, namely the cumulative nature of its innovations. In fact, it appears that the broadening of patent protection has led companies to incur in strategic patenting to avoid technological blocking or hold up problems rather than induced a real increase in R&D spending. In other words, according to Hall and Ziedonis (2001), the strengthening of patent's scope did not have a stimulant effect over R&D. These conclusions are supported by previous empirical studies like Kortum and Lerner (1999), which had pointed out that this patenting surge could not be explained by R&D spending alone, or Bessen and Maskin (2002) who demonstrated that R&D in information technology industries had fallen despite the pro-patent shift of the law.

Complementarily, Bessen and Maskin (2002) tried to understand why industries like semiconductors or software have been so innovative if patents conferred very little protection. In fact, the semiconductor industry is an example of a sector where the traditional rationale behind reinforcing patent's scope does not hold. Despite rapid imitation, Bessen and Maskin (2002) conclude that in industries characterized by an intense and cumulative process of innovation, patents can restrain innovation whereas in industries such as the chemical the independent character of inventions complies with standard rationale about patents and its effect over R&D investment.

It is also important to distinguish results depending on whether we are considering a static scenario or a dynamic one. In a static world, imitation inhibits innovation and policy intervention should go in the direction of broadening patent's protection. But, when considering a dynamic setting, firms tend to have more important incentives to innovation and rely on leadership and know-how to guarantee market share and economic return to R&D. Dynamically speaking; imposing stronger patents may constrict complementary innovation, and slowdown technological progress (Bessen and Maskin, 2002).

Evidence seems to show that in complex and cumulative technologies (e.g. semiconductors) patents seem to be disadvantageous (O'Donoghue, 1998; Kingston, 2001), while in industries with independent innovation processes (e.g. Chemical

[9] The patent paradox results of the fact that despite of R&D managers in semiconductor industry claiming the weak protection given by patents, there has been an upsurge in patenting by that industry. Hall and Ziedonis (2001) explain these movements as result of strategic patenting and emergence of technology specialists.

industry) or with a slower technological pace (e.g. Steel Industry), patents seem to foster innovation and the positive correlation between patents and correlation between patents and R&D appear to hold (Kingston, 2001).

Lerner (2001) is one of the few cross-country analyses that tried to evaluate the impact of extending patent protection. He concluded that the evidence seems to point to an inverted U type relationship. In this sense, strengthening patents would have a positive effect on industries where appropriation and enforcement is higher such as chemical industry and increase the incentive to innovate.[10] However, in high tech industries in which innovation follows a cumulative process of sequential innovation, the excessive patent protection may cause a decline on R&D investment and subsequently on innovative capacity.

The other cross-country analysis is signed by Varsakelis (2001) who, based on a 50 countries sample and an econometric model, tested the existence of a positive correlation between higher patent protection and R&D spending. His results point out a very strong correlation between patent's strength and R&D spending in aggregate terms. Yang and Maskus (2001) also argue in favour of this positive correlation, defending the implementation of a strong patent protection framework in order to promote R&D.

The following table offers a synthesis of (theoretical and empirical) literature on the patent-R&D reverse causality relationship.

[10] In these industries, innovations tend to be independent and not to be subject to the complements or to the hold up problems.

Table 2: Empirical studies on Patent-R&D relationship

Variable	Level of analysis	Type of analysis	Correlation	Subject area	Mechanism	Authors (e.g.)
Patent's scope	Micro	Theoretical	Positive	Patent/R&D Relationship	Broader scope increases expected return on R&D activities. Optimality at firm level implies a correspondingly higher R&D investment to seize the additional profit opportunity. Focus: appropriability	Nordhaus (1969); Kitch (1977); Gilbert and Shapiro (1990); Klemperer (1990); Denicolo (1996); Mazzoleni and Nelson[1] (1998); Jaffe (2000) Gallini (2002)
				R&D Spillovers	Broader patent scope can induce more patenting and the disclosure of more information to rivals, allowing them to use that knowledge to develop other products. R&D investment's return increases with these positive externalities. Focus: Spillovers from information disclosure	Nelson et al. (2002)
				Technology Transfer	Stronger patents give innovators a greater assurance and bargaining power, encouraging innovators to disclose and license new technologies rather then using them exclusively	Green and Scotchmer (1995) Merges (1998) Arora and Merges (2000)
			Negative	Patent/R&D Relationship	The authors state that in industries characterized by cumulative innovation, broadening patent's scope increases the risk of hold up and the transaction costs associated with the purchase of licenses. Cross licensing may not be achieved and innovation may face slowdowns.	Bessen and Maskin (2002)
		Empirical	Positive	Patent/R&D Relationship	Use data on patents issued and R&D spending for a sample of firms to devise econometric relations which are then estimated	Kortum and Lerner (1999) Sakakibara and Branstetter[2] (2001)
			Negative	Patent/R&D Relationship	In cumulative systems of technology patenting can inhibit innovation through the increasing transaction costs incurred to acquire the necessary licenses.	O'Donoghue (1998) Hall and Ziedonis (2001)
	Macro	Theoretical	Positive			
			Negative			
		Empirical	Positive	Patent/R&D Relationship	Patent's protection reduce uncertainty about appropriation possibility but are also important as incentives since they permit appropriation of temporary technological rents and affect diffusion of knowledge.	Varsakelis (2001); Lerner (2001)
			Negative		If the inventor of a basic invention could appropriate the return on all subsequent innovations, technological progress and R&D would slowdown. Only him would be interest in developing the complementary technologies.	Merges and Nelson (1990)
Number of Patents	Micro	Theoretical	Positive			
			Negative		Complementarity Problem: patent blocking impedes innovation in complementary technologies; Hold Up Problem: mine field of patents make R&D investment risky	Heller and Eisenberg (1998); Hunt (1999); Shapiro (2001); Lerner and Tirole[3] (2004); Hunt (2006)
		Empirical	Positive			
			Negative			
	Macro	Theoretical	Positive			
			Negative			
		Empirical	Positive			
			Negative			

Notes: [1] These authors develop a set of theoretical arguments in favour of a positive correlation but stress the fact that in cumulative systems of technology the positive correlation may not be verified; [2] Both these studies were conducted based on a a theoretical framework upholding a positive correlation though their results ended up being unclear or even suggesting a negative correlation; [3] This study offers a possible solution to the negative effects of patent accumulation in cumulative innovation Technologies.

2.5. Reduced form of the theoretical model: empirical specifications for the traditional and reverse causality relation

Given the aim of the present thesis, lesser attention has been devoted to causality in the traditional perspective. It is important to stress that this same literature is much wider than the one surveyed here. Nevertheless, in essential, it conveys similar conclusions (see, for instance, Beneito, 2006). In particular, when assessing patents as output of R&D, both theory and empirical data support the existence of a positive and significant correlation. This is something undisputed although several empirical studies highlight patents' insufficiency as measure of innovative output and have put forward that R&D managers use it more as a strategic weapon rather than rely on it to obtain imitation safeguard.[11]

In accordance to this thesis's goal, a higher degree of detail characterized the analysis of the reverse causality - summarized in Table 2. Two aspects should be highlighted.

Firstly, aside from Varsakelis (2001) and Lerner (2001), the rest of the studies mentioned, both theoretical and empirical, adopt a *microeconomic* approach. In fact, the mainstream of literature analysing R&D-Patents reverse causality explains the positive or negative correlation based on a microeconomic analysis of revenue/cost at the firm level and despite literature on reverse causality direction still being scarce, the macroeconomic perspective is even more unexplored. Thus, such loophole in literature is yet to be further explored both in theoretical and empirical terms. It remains to establish what is the expected aggregate outcome, that is, at the level of the economy as a whole, of a strengthening of patent's scope, in particular assessing the different impacts that this strengthening might have on different sets of countries. There is no evidence or theories that have ruled out the possibility of asymmetric effects of patents on R&D in accordance to the level of GDP in general and to 'convergence clubs' in particular.

Moreover, given the divergence among conventional wisdom supporting a positive correlation and the negative correlation upheld by Hunt (1999; 2006) and Shapiro (2001), and the unclear results of empirical studies, it urges to determine the

[11] Levin et al. (1987) and Mansfield (1986) have both concluded from their empirical study that patents are considered an effective protection only in industries characterized by either independent innovations such as the chemicals and pharmaceuticals or by slow innovation and patenting rhythms like low tech incorporating industries or heavy manufacturing industries such as steel.

macroeconomic effect of increasing patenting system's protection and the emergence of a patent thicket. In other words, it is important to pinpoint exactly on which industries there will be a negative impact on innovation and R&D and on which it will be witnessed an increase in R&D investment. In a macro level of analysis it becomes imperative to evaluate the net effect resulting from these opposing forces and determine if patenting policy should be differentiated according to per capita GDP level or industry.

In order to test the hypotheses underlying this thesis' main questions, our reduced-form theoretical specifications come as follows:

$$Pat_{it} = \alpha + \beta_1 RD_{it} + \boldsymbol{\eta}\mathbf{X} + u_{it}$$

and

$$RD_{it} = \theta + \delta_1 (Accum) Pat_{it} + \boldsymbol{\varphi}\mathbf{X} + v_{it}$$

Where *i* and t stands for, respectively the country and year indexes.

The first specification permits to test the R&D → Patent traditional relation, whereas the second aims at testing the reverse causality Patent → R&D relation. In the case the estimated values are positive, this means that R&D (Patents) would lead to more Patents (R&D). For the negative reverse causality relation to be verified, the estimated value of $\frac{\partial RD}{\partial (Accum) Pat}$ has to come up negative.

Vector **X** includes a set of relevant variables (countries' *structural characteristics* - percentage of high-tech exports, percentage of R&D performed by firms, and Foreign Direct Investment (FDI) as percentage of GDP; countries' *governance environment* – political stability, government efficiency, regulatory quality, rule of law, and corruption control) that are likely to influence the intensity of R&D and patents propensity. In order to account for the effect of countries' Club of Convergence, we estimated (see Chapter 4) aggregate (containing all countries) and disaggregate samples corresponding to each Club of Convergence. Before presenting the estimation results, in the next chapter we detail methodological and data gathering issues.

Part II – Testing the Relationship between R&D and Patents. A Panel Data Estimation

Chapter 3. Data Gathering Methodology and Description of the Relevant Variables

3.1. Initial considerations

In the previous part of this thesis we undertook a comprehensive survey on the patent-R&D relationship. We describe the debate between the traditional (R&D → Patent) and reverse causality ([Accum]Patent → R&D) relation. Furthermore, we highlighted that the most recent literature acknowledges for the possibility of a negative impact of patent accumulation on R&D investment.

In the present part, our goal is to empirically evaluate in which direction the R&D-Patent causality relation is stronger and which is its signal. Taking an innovative, macroeconomic approach, we assess whether the results differ across different levels of countries' economic growth and development. In particular, we propose the use of clubs of convergence to define different groups of analysis. This clustering process provides the framework to assess the specificities regarding the R&D-patent relationship causality direction and signal among different economic and structural realities. Such procedure may provide further insight on the importance of patents in terms of technological diffusion to less developed countries as well as evidence sustaining the existence of the potential negative effect reported earlier.

In the review of the literature concerning the R&D-patent relationship, namely in the causality direction where patents are a prime determinant of R&D investment/expenditures (that is, the reverse causality approach), we identify two starting points to analyze the impact of extending patent's protection on R&D investment decisions. One first considers the potential effect of a quantitative patent accumulation and a qualitative patent protection extension on R&D. In fact, patents' scope extension depends intrinsically on the legal framework of each country, not only regarding patent law but also the effectiveness of its enforcement. In this sense, a cross-country analysis is almost impossible to translate in numerical language to allow for the econometrical treatment. Furthermore the most important legal change (the Bayh-Dole Act) occurred much earlier than what our panel data time frame comprises. Additionally, since legal framework is country dependent, we would need to evaluate all intellectual property changes for the 88 countries which is a Homeric task if not an impossible one due to data scarcity. Thus, in our analysis we use (accumulate) patent counts instead. It does not capture scope changes effect directly but captures accumulation effects, relevant for the issues under analysis.

3.2. Data description

Given the fact that we intend to quantify and analyze the Patent-R&D relationship two variables are obviously critical, patent counts and R&D expenditures. Additional variables (for instance, percentage of high-tech exports, percentage of R&D performed by firms, Foreign Direct Investment (FDI) as percentage of GDP; political stability, government efficiency, regulatory quality, rule of law, and corruption control indicators) were gathered in order to serve as control variables and/or to demise scale effects in the cross-country analysis.

From the World Development Indicators (WDI) 2005 CD, edited by the World Bank, we retrieved most the data used in the empirical exercise. We complemented this data with partial data from WDI 2006, UNESCO Science and Technology indicators and UNCTAD reports and World Bank's Public sector governance indicators retrieved online.[12]

To gather information about patents issued we used the registry of the US Patents Office. Based on these sources we built a data panel comprising 88 countries and the following variables: Gross Expenditure on R&D (GERD) in percentage of GDP, Patent Counts per country and million inhabitants, Foreign Direct Investment (FDI) in percentage of GDP, percentage of the GERD performed by firms, percentage of high-tech exports on total manufacturing exports, country aggregation data using convergence clubs and legal system's effectiveness proxies. Due to severe truncation of data concerning GERD, the analysis period is reduced to 8 years, comprising the period between 1996 and 2003, and 88 countries. A descriptive analysis of each variables, as well as source and specificities, is presented in the following sub-sections.

3.2.1. R&D investment

The proxy used for R&D investment is Gross Expenditure on R&D (GERD) in percentage of GDP, excluding military expenditures. This information comprises

[12] Data retrieved on the 20th of December of 2006 at http://web.worldbank.org/wbsite/external/topics/extpublicsectorandgovernance/0,,contentMDK:20773712~menuPK:433525~pagePK:210058~piPK:210062~theSitePK:286305,00.html.

originally the period from 1996 till 2002 retrieved from WDI 2005 CD to which was added information for 2003 obtained from the WDI 2006 CD.[13]

The severe truncation of this variable served as reference to the sampling period of the remaining variables and also to a prior selection of the countries to be considered. The selection criterion imposes that in order to a country to be selected to the sample, data should be available for at least 2 years, otherwise it would be impossible to fill in the missing values using linear interpolation, and the analysis of patent-R&D relationship would be unviable.

As a result, from the 208 countries globally considered by the World Bank, 115 were immediately excluded. In addition, St Vincent and the Grenadines were eliminated because, despite having two observations in the reference period, the linear interpolation led to negative estimations. Furthermore, Brunei, Cuba, Myanmar, Serbia, and Montenegro were also excluded due to data unavailability concerning GDP per capita in PPP. Despite this previous selection, for some of the remaining 88 countries, data unavailability for some of the years implied the definition of an estimation procedure. As a first approach, we retrieved data from a complementary source, namely the UNESCO's Science and Technology Indicators. These tables compile information retrieved from the World Bank 2005 CD and UIS S&T Database. Besides being a highly reputed source, in the overwhelming majority of cases the data is consistent and identical to the one collected from the WDI 2005 CD. Hence it presented, in our opinion, a preferable alternative to an estimation procedure. Nevertheless, and in line with the similarity to WDI 2005 CD, the UNESCO's S&T database provided only an estimate for 3 missing values in 1996 and 1997 and 5 missing values in 1998.

For the remaining data, we use a simple linear interpolation method based on the period's average growth rate, which allowed for a smooth estimation for the rest of the sample.

The following tables synthesize data gaps, indicating the estimation procedures adopted and providing further details on the data as well preceding comments and a descriptive statistical analysis.

---

[13] The WDI 2006 CD was not available at University of Porto and the online access was not subscribed.

Table 3: Summary statistics on missing values

Year	Total missings in WDI	Data retrieved from UNESCO	Number of missings estimated by Linear Interpolation	% missings after UNESCO data retrieval per year of analysis
1996	31	3	28	31.8
1997	20	3	17	19.3
1998	24	5	19	21.6
1999	20	-	17	19.3
2000	12	-	12	13.6
2001	14	-	14	15.9
2002	17	-	17	19.3
2003	35	-	35	39.8

Table 3 presents an initial summary on the percentage of "missings" per year of analysis. Clearly that 1996 and 2003 are the worst in terms of data availability with 31.8% and 39.8% of missing values in the series. For the remaining years of the sample this percentage is, apart from 1998, below the 20%, reaching a minimum of 13.6% in the year 2000. Although, the percentage of missing values is already acceptable for most of the years of the sample, it is important to bear in mind that these values are diluted and much less significant in country terms. Additionally, the stability that characterizes the pattern of R&D expenditures across time validates the linear interpolation procedure used to estimate the missing values.

The following table presents the number of missing values by country, and the methods used to fill in the blanks.

Table 4: Data details concerning missing filling procedures

No. countries with missings (% total)	Country	Years Missing	Alternative source/ estimation method
32 (36.4)	Argentina	-	-
	Austria	-	-
	Belgium	-	-
	Canada	-	-
	Chile	-	-
	China	-	-
	Czech Republic	-	-
	Denmark	-	-
	Finland	-	-
	France	-	-
	Germany	-	-
	Hungary	-	-
	Ireland	-	-
	Israel	-	-
	Italy	-	-
	Japan	-	-
	Latvia	-	-
	Lithuania	-	-
	Netherlands	-	-
	Panama	-	-
	Poland	-	-
	Portugal	-	-
	Romania	-	-
	Russia	-	-
	Singapore	-	-
	Slovakia	-	-
	Slovenia	-	-
	South Korea	-	-
	Spain	-	-
	United Kingdom	-	-
	USA	-	-
	Venezuela	-	-
12 (13.6)	Azerbeijan	03	Linear Interpolation
	Bolivia	03	Linear Interpolation
	Croatia	98	Linear Interpolation
	Estonia	97	Linear Interpolation
	Georgia	03	Linear Interpolation
	Iceland	96	Linear Interpolation
	Mexico	03	Linear Interpolation
	Pakistan	96	Linear Interpolation
	Peru	96	Linear Interpolation
	Thailand	98	Linear Interpolation
	Trinidad and Tobago	02	UNESCO
	Turkey	03	Linear Interpolation
13 (14.8)	Armenia	96; 03	Linear Interpolation
	Brazil	97; 98	Linear Interpolation
	Cape Verde	96; 03	Linear Interpolation
	Colombia	02; 03	Linear Interpolation
	Cyprus	96; 97	Linear Interpolation
	Ecuador	99; 00	Linear Interpolation
	Kuwait	96; 03	Linear Interpolation
	Kyrgyzstan	96; 03	Linear Interpolation
	Macedonia	96; 03	Linear Interpolation
	Mongolia	96; 03	Linear Interpolation
	Uganda	02, 03	Linear Interpolation
	Ukraine	96; 03	Linear Interpolation
	Uruguay	01; 03	Linear Interpolation

(...)

No. countries with missings (% total)	Country	Years Missing	Alternative source/ estimation method
9 (10.2)	Bulgaria	96; 97; 98	UNESCO
	Costa Rica	01; 02; 03	Linear Interpolation
	Egypt	01; 02; 03	Linear Interpolation
	Hong Kong	96; 97; 03	Linear Interpolation
	India	01; 02; 03	Linear Interpolation
	Mauritius	96; 98; 99	96 – Linear Interpolation; 98; 99 – UNESCO
	Norway	96; 98; 00	Linear Interpolation
	Sudan	96; 97; 98	Linear Interpolation
	Tunisia	96; 97; 03	96; 97 – UNESCO; 03 – Linear Interpolation
9 (10.2)	Australia	97; 99; 01; 03	Linear Interpolation
	Bangladesh	96; 97; 98; 99	Linear Interpolation
	Greece	96; 98; 00; 02	Linear Interpolation
	Honduras	96; 97; 98; 99	Linear Interpolation
	Kazakhstan	98; 99; 02; 03	98; 99 – UNESCO; 02; 03 – Linear Interpolation
	Madagascar	96; 01; 02; 03	Linear Interpolation
	Malaysia	97; 99; 01; 03	Linear Interpolation
	New Zealand	96; 98; 00; 02	Linear Interpolation
	Sweden	96; 98; 00; 02	98 – UNESCO; 96; 00; 02 – Linear Interpolation
3 (3.4)	Belarus	96; 97; 98; 99; 03	96; 97; 98; 99 – UNESCO; 03 – Linear Interpolation
	Morocco	96; 97; 99; 00; 03	Linear Interpolation
	South Africa	96; 97; 99; 00; 03	Linear Interpolation
10 (11.4)	Burkina Faso	98; 99; 00; 01; 02; 03	Linear Interpolation
	Indonesia	96; 97; 98; 99; 02; 03	Linear Interpolation
	Jamaica	96; 97; 98; 99; 00; 03	Linear Interpolation
	Luxembourg	96; 97; 98; 99; 01; 02	Linear Interpolation
	Moldova	98; 99; 00; 01; 02; 03	Linear Interpolation
	Nicaragua	96; 98; 99; 00; 01; 03	Linear Interpolation
	Paraguay	96; 97; 98; 99; 00; 03	Linear Interpolation
	Sri Lanka	97; 98; 99; 01; 02; 03	Linear Interpolation
	Switzerland	97; 98; 99; 01, 02; 03	Linear Interpolation
	Zambia	98; 99; 00; 01; 02; 03	Linear Interpolation

As stated previously, in country terms, the percentage of missing values is quite acceptable. The descriptive statistics presented in the table above show that for 32 countries, which represent 36.4% of the sample, there are no missing values. 12 countries' (13.6% of the sample) statistics miss one year data, 13 (14.8%) countries miss 2 years data, 9 (10.2%) countries present 3 observations missing, 9 (10.2%) other countries 4 missing observations, 3 (3.4%) countries present 5 missing values and 10 (11.4%) countries present 6 missing values. Only 13 (14.8%) of the total 88 countries have less than one observation per each 2 years of analysis which is even less significant taking into account that GERD presents a very stable and smooth progressive evolutional path across time.

Following the completion of the series, it is important to perform a descriptive analysis, highlighting the extreme values minimums and maximums, the mean, standard deviation, and identifying potential outliers. Table 5 presents an overview of the results for GERD in all 8 years of the sample whereas Table 6 presents the cross country data, indicating, simultaneously, which countries present the 5 highest-lowest values for GERD among the sample.

Table 5: Outlier countries in yearly R&D

R&D year	N	Min.	Max.	Mean	Std. Deviation	Outliers
RD96	88	0.0121	3.46	0.839	0.8123	Sweden
RD97	88	0.0081	3.54	0.855	0.8303	Sweden, Israel
RD98	88	0.0054	3.63	0.864	0.8525	Sweden, Israel, Finland, Japan
RD99	88	0.0036	3.82	0.897	0.8925	Israel, Sweden, Finland, Japan, USA
RD00	88	0.0024	4.70	0.930	0.9520	Israel, Sweden, Finland, Japan, Iceland, USA
RD01	88	0.0016	5.04	0.974	1.0055	Israel, Sweden, Finland, Japan, Iceland, USA
RD02	88	0.0011	5.08	0.982	1.0139	Israel, Sweden, Finland, Japan, Iceland
RD03	88	0.0007	4.72	0.984	0.9888	Israel, Sweden, Finland, Japan, Iceland

An analysis of the minimum values encountered on this sample reveals that every country has a positive GERD as percentage of GDP. The minimum value corresponds in every sample year to Zambia (note that beyond 1997 the values reported for this country result from linear interpolated estimation). On the other extreme, the maximum values encountered refer to Sweden (1996, 1997, and 1998) and Israel (1999, 2000, 2001, 2002, 2003). Even though *a priori* these statistics do not include military R&D expenditures, the figure for Israel is at best suspicious in this regard. Still, we fail to collect evidence that confirmed such suspicion, and having cross-referenced these values against other statistical sources, we found nothing but small differences. Two other comments are in order. First, the sample's mean has increased steadily in the 8 year period considered, which means that there is an increasing investment in R&D activities. Second, the standard deviation, despite some oscillation, also presents a positive evolution which may reflect some divergence in countries' GERD.

Additionally, statistical procedures used to identify outliers do so only in upper bounds, that is to say that outliers refer only to countries with high levels of GERD, namely Sweden in all the 8 sample years, Israel from 1997 until 2003, Finland and Japan in 1998 and all subsequent years, USA from 1999 till 2003, and Iceland from the year 2000 beyond.[14]

The following table presents the top 5 and the bottom 5 countries for each sample year.

[14] It is important to define what SPSS software considers to be an outlier. SPSS identifies outliers as cases with values between 1.5 and 3 box lengths from the upper or lower edge of the box. The box length is the interquartile range.

Table 6: Highest and lowest R&D performers by year

Extreme Values			Country	Value	Extreme Values			Country	Value
RD96	Highest	1	Sweden	3.4607	RD97	Highest	1	Sweden	3.5441
		2	Israel	2.9163			2	Israel	3.1464
		3	Japan	2.7756			3	Japan	2.8399
		4	Switzerland	2.6712			4	Finland	2.7141
		5	USA	2.5475			5	Switzerland	2.6447
	Lowest	1	Zambia	0.0121		Lowest	1	Zambia	0.0081
		2	Jamaica	0.0289			2	Jamaica	0.0347
		3	Paraguay	0.0348			3	Paraguay	0.0414
		4	Cape Verde	0.0523			4	Cape Verde	0.0509
		5	Honduras	0.0598			5	Honduras	0.0582
RD98	Highest	1	Sweden	3.6275	RD99	Highest	1	Israel	3.8231
		2	Israel	3.3214			2	Sweden	3.6510
		3	Japan	2.9478			3	Finland	3.2327
		4	Finland	2.8841			4	Japan	2.9637
		5	Switzerland	2.6186			5	USA	2.6478
	Lowest	1	Zambia	0.0054		Lowest	1	Zambia	0.0036
		2	Jamaica	0.0417			2	Cape Verde	0.0364
		3	Cape Verde	0.0434			3	Jamaica	0.0500
		4	Paraguay	0.0493			4	Honduras	0.0552
		5	Honduras	0.0567			5	Paraguay	0.0587
RD00	Highest	1	Israel	4.6984	RD01	Highest	1	Israel	5.0442
		2	Sweden	3.7369			2	Sweden	4.2709
		3	Finland	3.3982			3	Finland	3.4097
		4	Japan	2.9923			4	Japan	3.0726
		5	Iceland	2.7571			5	Iceland	3.0641
	Lowest	1	Zambia	0.0024		Lowest	1	Zambia	0.0016
		2	Cape Verde	0.0346			2	Cape Verde	0.0369
		3	Honduras	0.0538			3	Honduras	0.0459
		4	Jamaica	0.0600			4	Indonesia	0.0500
		5	Nicaragua	0.0603			5	Nicaragua	0.0549
RD02	Highest	1	Israel	5.0801	RD03	Highest	1	Israel	4.7177
		2	Sweden	4.3713			2	Sweden	3.9810
		3	Finland	3.4551			3	Finland	3.4897
		4	Japan	3.1222			4	Japan	3.1450
		5	Iceland	3.0954			5	Iceland	2.9410
	Lowest	1	Zambia	0.0011		Lowest	1	Zambia	0.0007
		2	Indonesia	0.0400			2	Indonesia	0.0300
		3	Cape Verde	0.0443			3	Cape Verde	0.0431
		4	Honduras	0.0498			4	Nicaragua	0.0455
		5	Nicaragua	0.0500			5	Honduras	0.0496

From the observation of the data it is clear that the overwhelming majority of countries (over 60% of the sample) perform GERD in an amount inferior to 1% and only a few (about 20% of the countries) are spending more than 2% of their GDP per capita in Purchasing Power Parity (PPP).

3.2.2. Patents

The source used for Patents is not the World Bank but the US Patent and Trademark Office (USPTO). We retrieved data on all patent types which included utility patents, design patents, plant patents, reissues, defensive publications, and statutory inventions registrations.

In what concerns how the country of origin is determined, the criterion is the country residence of the first-named inventor. In particular, the USPTO data reports on all patents issued to each country from January 1st of 1977 to 31st December of 2004. With the exception of Cape Verde, Mongolia, Sudan, Zambia and Burkina Faso, all the other 83 countries had residents on whose behalf had been issued patents. For the five cases mentioned, we assume the value zero for the entire time frame. In addition, in order to demise from any scale effects we use as variable not patent counts but patent counts per million of inhabitants. In this way we minimize scale effects. For the total population data we used the WDI 2005. The following table summarizes some basic statistical measures and identifies the countries which observations constitute outliers as SPSS defines them.

Table 7: Statistical summary of patents issued per million of inhabitant

	N	Min.	Max.	Mean	Std. Deviation	Outliers
PAT96	88	0	257.7	19.9	44.079	USA, Japan, Switzerland, Sweden, Israel, Canada, Finland, Germany, Denmark, Luxembourg, Netherlands
PAT97	88	0	256.5	20.9	45.203	USA, Japan, Switzerland, Sweden, Israel, Canada, Finland, Germany, Denmark, Luxembourg, Netherlands
PAT98	88	0	328.8	27.3	57.933	USA, Japan, Switzerland, Sweden, Israel, Canada, Finland, Germany, Denmark, Luxembourg, Netherlands, Belgium, South Korea
PAT99	88	0	337.2	28.3	59.457	USA, Japan, Switzerland, Sweden, Israel, Canada, Finland, Germany, Denmark, Luxembourg, Netherlands
PAT00	88	0	343.7	30.2	61.933	USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg
PAT01	88	0	345.8	32.6	65.454	USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg
PAT02	88	0	336.8	32. 6	65.555	USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg, Singapore, Netherlands, Israel
PAT03	88	0	339.1	33.2	66.144	USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg, Singapore, Israel

An analysis of Table 7 allows a first glance on patent counts statistics evolution in cross-country terms. Firstly, unlike GERD which despite minimal, was positive for every country, on what concerns patent counts several countries present a zero value, namely Cape Verde, Mongolia, Sudan, Zambia and Burkina Faso. On the other extreme, the maximum patenting per inhabitant values have increased steadily throughout the entire sample period. Also the mean value has been rising over the years along with an increasing dispersion (higher standard deviation) among countries patenting output.

In comparison to GERD data, for the Patent count per inhabitant variable, the sample presents a higher number of outliers. In concrete, for 1996, 1997 and 1999's observations, the SPSS® software identifies USA, Japan, Switzerland, Sweden, Israel, Canada, Finland, Germany, Denmark, Luxembourg and Netherlands as outliers. In 1998, Belgium and South Korea join this group. For the years 2000 and 2001 the outliers are USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg and for the last two sample years, for 2002 the outliers are USA, Japan, Switzerland, Sweden, Canada, Finland, Germany, Denmark, Luxembourg, Singapore, Netherlands, Israel and for 2003 this group looses Netherlands.

Table 8 presents a country rank in terms of patent counts per inhabitant pinpointing the top 5 patenting countries and the bottom 5 countries.

An important first note is that the same countries we found on the top of the pyramid in terms of GERD are the same that patent the most. Nevertheless, a closer analysis reveals that although high levels of GERD are, on average, related to relatively high levels of Patenting, we observe that in this sample, the same countries present distinct rankings in those variables. For instance Sweden or Israel, which have the two highest GERD values appear around the 4th and 5th position; in contrast, countries such as the USA perform considerably less R&D but patent a lot more.

A crude preliminary analysis seems to reveal that for the top 5 group of countries in terms of GERD and Patent counts per inhabitant, there may be a negative correlation among the variables. Still, this conclusion needs further and more rigorous empirical validation - this relation is one of the issues in analysis in Chapter 4.

Table 8: Highest and lowest Patents granted per million of inhabitants by year

Variable	Extreme Values		Country	Value
PAT96	Highest	1	United States	257.7
		2	Japan	191.1
		3	Switzerland	168.5
		4	Sweden	109.8
		5	Israel	92.2
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Tunisia	0
		4	Sudan	0
		5	Paraguay	0(a)
PAT97	Highest	1	United States	256.45
		2	Japan	191.85
		3	Switzerland	166.34
		4	Sweden	109.61
		5	Luxembourg	99.64
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Sudan	0
		4	Paraguay	0
		5	Panama	0(a)
PAT98	Highest	1	United States	328.8
		2	Japan	254.1
		3	Switzerland	193.3
		4	Sweden	152.1
		5	Israel	137.3
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Tunisia	0
		4	Sudan	0
		5	Paraguay	0(a)
PAT99	Highest	1	United States	337.19
		2	Japan	256.72
		3	Switzerland	194.68
		4	Sweden	174.09
		5	Finland	134.56
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Tunisia	0
		4	Sudan	0
		5	Sri Lanka	0(a)
PAT00	Highest	1	United States	343.74
		2	Japan	259.49
		3	Switzerland	203.06
		4	Sweden	195.96
		5	Israel	132.93
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Tunisia	0
		4	Trinidad and Tobago	0
		5	Sudan	0(a)
PAT01	Highest	1	United States	345.78
		2	Japan	274.43
		3	Sweden	217.34
		4	Switzerland	215.32
		5	Israel	160.12
	Lowest	1	Zambia	0
		2	Uruguay	0
		3	Tunisia	0
		4	Sudan	0
		5	Paraguay	0(a)
PAT02	Highest	1	United States	336.81
		2	Japan	285.24
		3	Switzerland	210.15
		4	Sweden	204.39
		5	Israel	168.75
	Lowest	1	Zambia	0
		2	Trinidad and Tobago	0
		3	Sudan	0
		4	Paraguay	0
		5	Nicaragua	0(a)
PAT03	Highest	1	United States	339.05
		2	Japan	291.98
		3	Switzerland	195.26
		4	Israel	188.40
		5	Sweden	181.89
	Lowest	1	Zambia	0
		2	Uganda	0
		3	Tunisia	0
		4	Sudan	0
		5	Paraguay	0(a)

Note: (a) Only a partial list of cases with the value 0 is shown in the table of lower extremes.

3.2.3. Clubs of convergence

The concept of Convergence Club was first introduced by Baumol (1986) in reaction to the empirical evidence regarding long run economic growth. In fact, against traditional growth models predictions (Azariadis and Drazen, 1990), there seems to be no overall convergence among countries. Baumol (1986) observed the existence of three *convergence clubs* which due to their differences in terms of initial conditions, tend to follow diverging growth trajectories over time (Azariadis and Drazen, 1990).

Durlauf and Johnson (1995) empirical study also concluded for the existence of different convergence clubs with structural differences and consequently, different growth trajectories. Gerschenkron (1962) argued that "developing countries may exploit their backwardness position by imitating and adopting new technologies produced in advanced economies" and this would act as a convergence force. Abramovitz (1986) further add that the process of imitations costly and in order to a successful knowledge and technology transfer a basic amount of capabilities is required to exist in the receiving country. Without this effort and this critical mass, its absorptive capacity will not allow the country to benefit from its backwardness. Thus, instead of differentiating countries through Gross Domestic Product (GDP) level, we opted for aggregating them into groups designated as clubs of convergence. The advantage of using clubs of convergence rather than simple GDP is that using a clubs of convergence methodology, it allows us to identify cross time similarities in the evolution of some variables, allowing the aggregation of countries according to those structural similarities.

A club of convergence is composed of the set of countries that converge on level and slope. This is also particularly useful in a sample comprising many countries. In fact, the estimations are per country and their individual interpretation would be incredibly time consuming and of little insight gain. Our goal is not to estimate and analyze the parameters for each country but evaluate differences among distinct stages of development, in particular, technological development as we shall see. By using clubs of convergence, we capture the main characteristics for each set of countries aggregated in a club and thus allow us to easily compare to other clubs and the whole panel of data.

Using Castellaci's (2006) results, we identify three clubs of convergence based on their technological capabilities. Since knowledge and technology are key elements for economic growth, these clubs are, in our opinion, particularly adequate to assess R&D-Patent relationship.

Methodologically, Castellaci uses an algorithm to clusterize countries according to two composite factors: technological infra-structures and human capital and codified knowledge creation and diffusion. Though a robust process, these data grouping techniques have some perks namely the fact that the number of clusters to be identified is predefined. You must previously set the number of clubs you wish the sample to be grouped by. The algorithm will stop as soon as countries are assigned to these different clubs, though it is possible to have unassigned countries if there are no significant structural similarity between these isolated cases and the clubs derived. Since it is not our aim in this study to describe in a very detailed way the methodology used by renowned authors' like Baumol (1986) or Quah (1996, 1997), we advice the reference to original studies for a more detailed description.

In brief, the clubs of convergence used in this study were retrieved from those computed by Castellaci (2006) for the reference year of 2000 and which aggregation we present in the Table 9. [15] The isolated countries were not part of Castellaci's (2006) sample. Thus they are not assigned to any of the convergence clubs of the following table and will not be estimated apart since the reduced number of observations would impede the computation of the high number of parameters involved in the estimation of advanced panel data models or in simple more complex regressions.[16]

[15] The advantage of using convergence clubs' is that gouping is made by identifying similar structural characteristics among countries. This constitutes a more dynamic approach when compared to a static grouping according to the GDP level at one particular point in time (Baumol, 1986). During this study we came across several different analyses (e.g. Quah (1996), Desdoigts (1999) or Hobijn and Franses (2000) but we eventually choose Castelacci's. The reason is simple. Traditional analysis, including the ones of Quah (1996), Desdoigts (1999) or Hobijn and Franses (2000) are mostly based on GDP. Castellaci approach is technological. He groups countries in accordance to their technological characteristics which seems more pertinent to the issue we are analysing here. Furthermore, some of the above analysis comprise a reduced sample of countries whereas Castelacci's comprises a wider set of countries which is more adequate for the type of wide range study that we intended to do.

[16] The number of observations regarding these two countries is too reduced to allow any estimation of an independent model for these two countries. Furthermore, our purpose is not individualizing one country's specific Patent-R&D relationship but, identify whole sample and group similarities, in particular, through the use of Convergence Clubs. We will use data regarding Cape Verde and Burkina Faso only when computing the whole sample, estimating an "overall picture".

Table 9: Castellaci's (2006) Clubs of Convergence

Club1 - Leaders	Club2 - Catching Up	Club 3 – Laggards	Isolated Countries
Austrália	Argentina	Bangladesh	Burkina Faso
Áustria	Armenia	Egypt	Cape Verde
Belgium	Azerbaijan	Índia	
Canada	Belarus	Madagascar	**Nisol=2**
Denmark	Bolivia	Mongolia	
Finland	Brazil	Morocco	
France	Bulgaria	Pakistan	
Germany	Chile	Sri Lanka	
Hong Kong	China	Sudan	
Iceland	Colombia	Uganda	
Israel	Costa Rica	Zambia	
Japan	Croatia		
Netherlands	Cyprus	**N3=11**	
New Zealand	Czech Republic		
Norway	Equador		
Singapore	Estonia		
South Korea	Georgia		
Sweden	Greece		
Switzerland	Honduras		
United Kingdom	Hungary		
United States	Indonesia		
	Ireland		
N1=21	Italy		
	Jamaica		
	Kazakhstan		
	Kuwait		
	Kyrgyz Republic		
	Latvia		
	Lithuania		
	Luxembourg		
	Macedonia		
	Malaysia		
	Mauritius		
	Mexico		
	Moldova		
	Nicaragua		
	Panama		
	Paraguay		
	Peru		
	Poland		
	Portugal		
	Romania		
	Russian Federation		
	Slovak Republic		
	Slovenia		
	South Africa		
	Spain		
	Thailand		
	Trinidad and Tobago		
	Tunisia		
	Turkey		
	Ukraine		
	Uruguay		
	Venezuela		
	N2=54		

3.2.4. Foreign Direct Investment (FDI)

FDI is one of our control variables in this estimation and its presence is justified since FDI may be an important source of knowledge transfer and stimulate innovation. Both positive and non-significant effects are theoretically justifiable under two different perspectives. On one hand, FDI is an important source of knowledge transfer from multinationals and thus this would increase the critical mass for creating knowledge in a country and stimulate an increase in R&D and in Patenting (thus, we would expect a positive signal relation). However, on the other hand, most multinationals keep there R&D labs in the home country externalizing only productive or service segments. In this sense, FDI would have no significant effect over patenting or R&D.

The data used here was retrieved from the World Bank CD 2006 and is relative to GDP in Purchasing Power Parity (PPP). Thus, the variable FDI is defined in terms of its percentage to GDP in PPP. Since this is not a core variable of the model, its descriptive statistical analysis is computed for the entire panel data and not discriminated by year as we did for R&D and Patents.

Table 10: Descriptive Statistics for FDI

N	Min	Max	Mean	Std Deviation
All=704	-3.03 (Indonésia in 2000)	5285.60 (Luxembourg in 1996 – outlier)	28.16 (4.29 removing the outlier)	279.88 (overrated due to the outlier)
CLUB=1 N_{C21}=168	0.004 (Japan 1996)	94.15 (Belgium 2000)	5.50	9.948
CLUB=2 N_{C22}=432	-3.03 (Indonesia in 2000)	5285.57 (Luxembourg in 1996)	42.28	352.53
CLUB=3 N_{C23}=88	0.005 (Sudan 1996)	10.32 (Mongolia 2003)	2.06	2.02

3.2.5. R&D Performed by Firms

This variable expresses the share of the private, profit seeking sector on R&D execution. The data was obtained from UN Science & Technology statistics and comprises the whole sample in both time and sectional terms. In both directions of causality, this is a relevant variable to include since the commercial and innovation drive is expectedly more intense among firms than public R&D institutions (State Laboratories and Universities). The output achievement is the main goal and this might consubstantiate in more patents being issued. On the opposite direction perspective, firms commitment to R&D efforts may contribute to explaining a country's R&D

investment. In fact, it is a reality that the state cannot, alone, financially sustain this burden. Thus, the expected signal would be positive in both directions of causality.

Table 11: Descriptive Statistics for R&D performed by Firms

N	Min	Max	Mean	Std Deviation
All=640	1.60 (Panama 1996)	77.24 (Sweden 2001)	33.04	27.35
CLUB=1 N_{C21}=168	17.97 (Hong Kong 2000)	77.24 (Sweden 2001)	61.74	13.31
CLUB=2 N_{C22}=408	1.60 (Panama 1996)	76.73 (Romania 1998)	28.93	24.28
CLUB=3 N_{C23}=48	1.65 (Sri Lanka 1996)	31.96 (Sudan 2003)	5.75	10.42

From the observation of the previous table we observe that more advanced technological countries (Club=1) have a higher share of R&D performed by firms, whereas the intermediate convergence club (Club=2) occupies the intermediate position in terms of mean. The technological laggards have the smallest share of R&D performed by firms.

3.2.6. High Technology Exports

In theory, the more innovative a country, the higher its R&D investment. The literature review offers a double way to perceive the causality direction between patents and R&D. In what concerns high technology exports, in the direction that patents are a function of R&D, a high technology level of exports indicates that a country is technologically developed and thus probably more capable of innovating and thus obtaining patents. On the reverse causality perspective, a productive specialization in high tech products requires a continuous R&D effort to sustain competitiveness. Thus, the expected signal on both directions of causality is positive.

Analogous to what is done to the other variables, in the following table a brief descriptive statistical analysis is presented added by some brief comments.

Table 12: Descriptive Statistics for High Technology Exports

N	Min	Max	Mean	Std Deviation
All=704	0.0001 (Sudan 1997)	62.56 (Singapore 2000)	11.87	12.65
CLUB=1 N_{C21}=168	3.22 (Iceland 2001)	62.56 (Singapore 2000)	21.63	10.96
CLUB=2 N_{C22}=432	0.038 (Jamaica 1999)	59.53 (Malaysia 2000)	9.70	12.17
CLUB=3 N_{C23}=88	0.0001 (Sudan 1997)	25.09 (Zâmbia 1997)	3.88	5.17

In average terms, the technological leader club of convergence has the highest proportion of high technology exports, more than the double of catching-up countries (Club=2) and seven fold the club grouping the technological laggards.

3.2.7. Governance Indicators: Political Stability, Government Efficiency, Regulatory Context, Law Enforcement and Corruption Control

The innovation process is largely dependent on the country's governance context, namely in what respect to the role of the government, law enforcement and regulatory framework in general. Therefore a study aiming at evaluation R&D-Patent relationship at cross-country level should include indicators that might (even grossly) measure the country's context in this regard.

Kaufmann et al. (2005: 6), researchers associated with the World Bank, constructed measures of six dimensions of governance:[17]

1. Voice and Accountability – measuring the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.

2. Political Stability and Absence of Violence – measuring perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including domestic violence and terrorism.

3. Government Effectiveness – measuring the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.

[17] These estimates of governance are based on a large number of individual data sources which provide authors with information on perceptions of governance. These data sources consist of surveys of firms and individuals, as well as the assessments of commercial risk rating agencies, non-governmental organizations, and a number of multilateral aid agencies. For the present round of the governance indicators, Kaufmann et al. (2005) relied on a total of 352 individual variables measuring different dimensions of governance. These are taken from 37 different sources, produced by 31 different organizations. A full list of the data sources, as well as a detailed description of how individual perceptions measures are assigned to our six dimensions of governance, can be found in Kaufmann et al. (2005).

4. Regulatory Quality – measuring the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.

5. Rule of Law – measuring the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, the police, and the courts, as well as the likelihood of crime and violence.

6. Control of Corruption – measuring the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

Out of these six dimension we include in our study five - all six excluding 'Voice and Accountability'. Each of these dimensions analyses a specific aspect, potentially relevant to firms' performance and, in particular, in terms of the relationship between patents and R&D in both directions of causality.

The data concerning all five variables were obtained from the Worldwide Governance Indicators at www.govindicatores.org, a project of World Bank Research. The data retrieved comprises the eight years' time frame of this panel data as well as allowed the gathering of data for all the 88 countries in the sample.

Common to all these variables was the transformation required to ease the estimations' interpretation. All variables were originally defined ranging from -2.5 to +2.5 which would make it harder and less intuitive the interpretation of the model estimations. Thus, we decided to perform a simple transformation. Unfortunately, though this is the preset interval by the data source, there are values violating this range, thus we may find, after the transformation procedures, a few observations still presenting negative values or above 5. Since these observations constitute a very reduce amount of exceptional cases, we will proceed using the transformed variables simply obtained through the addition of 2.5 to each observation and resetting the range from 0 to 5. In general, as we observe in the following tables more developed countries (i.e., those that belong to Club of Convergence 1, Club=1) are better ranked in terms of legal environment, political stability, corruption, regulation, and government efficiency.

Table 13: Descriptive Statistics for Rule of Law

N	Min	Max	Mean	Std Deviation
All=704	0.93 (Sudan 2003)	4.77 (Switzerland 1998)	2.88	1.01
CLUB=1 N_{C21}=168	3.00 (S. Korea 2001)	4.77 (Switzerland 1998)	4.21	0.36
CLUB=2 N_{C22}=432	1.25 (Georgia 2002)	4.51 (Luxembourg 2002)	2.51	0.76
CLUB=3 N_{C23}=88	0.93 (Sudan 2003)	2.93 (Mongolia 1996)	2.09	0.50

Table 14: Descriptive Statistics for Political Stability

N	Min	Max	Mean	Std Deviation
All=704	-0.31 (Sudan 1996)	4.15 (Finland 2003)	2.64	0.90
CLUB=1 N_{C21}=168	0.96 (Israel 2002)	4.15 (Finland 2003)	3.43	0.56
CLUB=2 N_{C22}=432	0.15 (Indonesia 2001)	4.12 (Luxembourg 2003)	2.53	0.76
CLUB=3 N_{C23}=88	-0.32 (Sudan 1996)	3.53 (Mongolia 2001)	1.70	0.84

Table 15: Descriptive Statistics for Control of Corruption

N	Min	Max	Mean	Std Deviation
All=704	1.18 (Sudan 2003)	5.02 (Switzerland 1998)	2.90	1.13
CLUB=1 N_{C21}=168	2.54 (S. Korea 1999)	5.02 (Switzerland 1998)	4.42	0.55
CLUB=2 N_{C22}=432	1.21 (Paraguay 2003)	4.60 (Luxembourg 1998)	2.49	0.81
CLUB=3 N_{C23}=88	1.18 (Sudan 2003)	2.91 (Mongolia and Madagascar 1996)	2.01	0.42

Table 16: Descriptive Statistics for Regulatory Quality

N	Min	Max	Mean	Std Deviation
All=704	-0.46 (Belarus 2001)	4.57 (Singapore 2000)	2.96	0.81
CLUB=1 N_{C21}=168	2.73 (Iceland 1996)	4.57 (Singapore 2000)	3.79	0.39
CLUB=2 N_{C22}=432	-0.46 (Belarus 2001)	4.45 (Luxembourg 2003)	2.77	0.73
CLUB=3 N_{C23}=88	0.80 (Sudan 1996)	3.13 (Sri Lanka 1998)	2.27	0.49

Table 17: Descriptive Statistics for Government Effectiveness

N	Min	Max	Mean	Std Deviation
All=704	0.80 (Sudan 1998)	5.09 (Singapore 1999)	2.96	1.04
CLUB=1 N_{C21}=168	2.94 (S. Korea 1998)	5.09 (Singapore 1999)	4.32	0.45
CLUB=2 N_{C22}=432	1.20 (Belarus 1996)	4.84 (Luxembourg 1996)	2.62	0.78
CLUB=3 N_{C23}=88	0.80 (Sudan 1998)	2.77 (Egypt 2000)	2.06	0.41

Chapter 4. R&D $\overset{?}{\rightleftarrows}$ Patents: Estimation Procedures and Results

4.1. Initial considerations

In this chapter we estimate the traditional and reverse causality relation between R&D and Patents. The aim is to assess the extent to which the negativity of patents on R&D emerges in more developed countries, as put forward by recent contributions in the area (e.g., Hunt, 2006).

For pursuing this goal we use a longitudinal dataset or, in other words, a panel dataset. In the next section (Section 4.2) we detail and describe the estimation procedures and models. Afterwards (Section 4.3) we present the estimation results with the associate economic analysis.

4.2. Estimation procedures for panel data

A panel dataset contains cross-sectional information for numerous observations and for several time periods (Greene, 2003). In our particular case, we use an unbalanced panel data comprising observations of 88 countries and a time frame of eight periods (1996 till 2003). The panel data used is unbalanced since there are some missing values for some of the variables, namely R&D performed by firms. A balanced panel implies that all variables contain information for all subjects and time periods. To obtain such a panel we have one option, eliminate from the sample those subjects. However, the use of an unbalanced panel does not imply great alterations to theoretical modeling[18] and currently, some econometric packages[19] are able to cope with this type of datasets. Thus, we see no point in limiting our sample and thus we use an unbalanced rather than a shortened and reshaped balance panel dataset.

What are the advantages and disadvantages of using panel data? Why not do a simpler pooled OLS estimation procedure or a one period standard cross-country analysis?

Panel datasets are typically wide but short in terms of time span thus being more suitable for cross-section analysis, being central the question of heterogeneity across subjects (Greene, 2003). The usually short time span makes time series analysis

[18] For further details, see Greene (2003: 289-290).
[19] In particular, we use LIMDEP 8®.

procedures troublesome (Greene, 2003) leading to the need of using adequate models to econometrically estimating and handling panel datasets.

The main advantage of panel data models is its flexibility in modelling differences across individuals (Greene, 2003) and the increase precision of estimators since, in less rigorous terms, they are derived based on an individual customized estimation process.

In order to answer the above mentioned questions we first should (briefly) describe the main methods used in this context: Pooled OLS; Fixed Effects Model; and Random Effects Model.

Pooled OLS

A first method to estimate panel data structured samples is the Pooled OLS. This model is somewhat analogous to normal OLS cross-section estimations. In simple terms, using different points in time for the same subject's sample allows to increase the sample size, which leads to estimators more precise and test statistics with more power (Wooldridge, 2003). This is in fact an adaptation of OLS standard procedures to a pooled data sample. The model can be expressed as follows (for both causality directions):

$$PAT_{it} = Z_i^{'}\alpha + \beta_1 RD_{it} + \mathbf{X}_{it}'\theta + \nu_{it} \quad (1)$$

And

$$RD_{it} = G_i^{'}\alpha + \delta_1 (Accum) PAT_{it} + \mathbf{X}_{it}'\phi + \mu_{it} \quad (2)$$

Composite error (group effects only): $\varepsilon_{it} = a_i + \mu_{it}$ (3)

Equations (1) and (2) are similar in modeling terms though in the first one we are testing the Patent-R&D traditional causality directions and in the second one we are econometrically estimating the reverse causality relationship. Equation (3) presents the composite error which considers includes two components, the unobserved group specific – a_i – and the stochastic disturbance - ε_{it}.

To this basic framework we add some potential control variables that are described in Chapter 3 and will be present in some of the estimations further ahead in the present chapter.

Pooled OLS is adequate when $Z_i^{'}$ (or $G_i^{'}$) contain only a common constant term. However, if $Z_i^{'}$ (or $G_i^{'}$) is unobserved and correlated with one of the explanatory variables (that is, the constant term is endogenous), the estimators resulting from polled OLS would be biased and inconsistent due to the violation of the classical hypothesis of correct model specification (the unobserved effect results in the omitted variable problem). Additionally, unlike more advanced panel data models [namely, Fixed Effects Models (FEM) and Random Effects Models (REM)], pooled OLS estimations do not take into account individual change across time. In other words, it processes for each observed individual, all variables for each period of time, completely independently, loosing information in the estimation. This model is adequate if the relationship between the dependent variable and at least some of the explaining variables remain constant over time (Wooldridge, 2003). The pooled OLS estimation process is intended to precise estimators through a larger sample but neglects individual heterogeneity revealed in the unobserved effect which is group specific (Greene, 2003). It does not aggregate each individual's information to compute a group specific estimator. Instead, what it performs is, in rough terms, an average of different independent estimations. Note that, the slope estimation is common to the entire sample, not being individualized, something that can be achieved through the introduction of group-specific dummies under interaction slope variables. However, this process under advanced panel data models is troublesome, namely, under FEM assumption. Since dummies are usually time-invariant (e.g. gender, race, club of convergence), aggregating all data of each individual would lead to multicolienearity between a dummy and an interaction variable. Furthermore, in terms of intercept, if dummies are time invariant, their average matches with all observations and thus the time-demeaning Fixed Effects implicit transformation will eliminate them along with the unobserved group specific effect a_i. Not removing a_i makes the pooled OLS estimators biased and inconsistent.

The results relevant to the thesis' main questions are the derivative of Patent on R&D and of R&D on (accumulated) Patents. In the case of pooled OLS, we could control directly for club of convergence using dummies for both intercept and slope. Instead, we adopt the procedure that what panel data users usually do, estimate independently for each sub-group by adjusting the sample in the econometrics package.

$$\frac{\hat{\partial} Pat}{\partial RD} = \hat{\beta}_1 \quad and \quad \frac{\hat{\partial} RD}{\partial (Accum)Pat} = \hat{\delta}_1$$

Even if theoretically, as detailed below, the more advanced models are more appealing, statistically we can test their adequacy by testing the significance of group effects. The F-test (to determine whether we use FEM or Pooled OLS) tests the null hypothesis that the constant terms are all equal (Green, 2003) - in all the estimations we performed, this hypothesis was rejected for a 5% significance level. To test for Random Effects versus Pooled OLS, we use the Lagrange multiplier (LM) test (Breusch and Pagan 1980).

Though we have tested pooled OLS, it is always statistically more adequate to use FEM or REM, according to significance tests and for all the models and groups used.

Fixed Effects model

The Fixed Effects Model (FEM) assumes that all the differences across sections are captured in the constant term (Greene, 2003). It is possible to analyse slope variations[20] but this is too complex for our aim and thus, a simple sampling is usually used to detect slope group specific (e.g. Terra, 2003).

In comparison to Pooled OLS it has the advantage that takes into consideration the time (t) variation in explanatory variables for each individual country.

Similar to first differencing (equivalent when t=2), this method follows an analogous procedure to eliminate the unobserved effect (a_i) contained in v_{it} or u_{it} (the composite error[21]), and thus re-establish the classical hypothesis underlying OLS estimation, in particular, that v_{it} is uncorrelated with any of the independent variables. a_i represents the omitted variables and thus OLS estimators will be inconsistent and biased if a_i is correlated with one of the independent variables. Thus, in order to produce consistent estimators, the fixed effects method recurs to a transformation to eliminate this unobserved effect. This ensures that the OLS fixed effects estimators are unbiased. If the unobserved effect is uncorrelated, then the random effects model offers a very attractive alternative (Wooldridge, 2003).

In sum, a fixed effects estimation procedure is preferable to pool OLS because it takes into consideration each variable change stratified by each observation and also because if there are group specific effects, it always produces consistent estimators. In comparison to REM, FEM is always a safe choice whenever Hausman test is not executed. REM estimators are more efficient if a_i is not correlated with any of the

[20] For further information, check Cornwell and Schimdt (1984).

[21] $v_{it} = a_i + u_{it}$, where a_i is the unobserved or fixed effect since it does not vary across time.

independent variables but it is inconsistent in the affirmative case. FEM estimators are consistent in both cases (Wooldridge, 2002, 2003; Greene, 2003), though not efficient in the first case. The within estimator under the fixed effects assumption is the best linear unbiased estimator (BLUE) whereas the Random Effects estimators are more efficient if group specific effects and the independent variables are uncorrelated.

In relation to Random Effects procedures, which are analyzed in the following section, Fixed Effects are preferable when our model specification is so complete that offers some reassurance that no relevant variable as been omitted and so guaranteeing that a_i is uncorrelated with all independent variables.

As it was previously mentioned, in order to remove the a_i and re-establish the classical hypothesis framework to ensure the estimators' consistency, the estimated model is a time-demeaned one which underlying transformation from the original one is the following:

Original Models:

$$PAT_{it} = \beta_0 + \beta_1 RD_{it} + ... + \beta_n X_{it} + a_i + \varepsilon_{it}$$

$$RD_{it} = \beta_0 + \beta_1 PAT_{it} + ... + \beta_n X_{it} + a_i + \varepsilon_{it}$$

Transformation[22]

$$PAT_{it} - \overline{PAT_{it}} = \beta_1 \left[RD_{it} - \overline{RD_{it}}\right] + ... + \beta_n \left[X_{it} - \overline{X_{it}}\right] + (u_{it} - \overline{u_{it}})$$

$$RD_{it} - \overline{RD_{it}} = \beta_1 \left[PAT_{it} - \overline{PAT_{it}}\right] + ... + \beta_n \left[X_{it} - \overline{X_{it}}\right] + (u_{it} - \overline{u_{it}})$$

Time-demeaned model:

$$\dot{RD}_{it} = \beta_1 \dot{PAT}_{it} + ... + \beta_n \dot{X}_{it} + \dot{u}_{it}$$

Summing up, in Fixed Effects the estimator is a pooled OLS one but time-demeaned, which better to capture group effects but harder to interpret in just for looking at the time-demeaned model. This process allows us to estimate the β_j coefficients in consistent manner using OLS and its interpretation is to be made based on the original model. The constant term β_0 in this particular model is eliminated in the transformation process along with a_i.

[22] Since a_i is time invariant then $a_i = \overline{a_i} \Rightarrow a_i - \overline{a_i} = 0$ and the unobserved effect creating is removed.

Random Effects Model

The Random Effects Model (REM) is based on the same unobserved effects model as the fixed effects. However, the underlying assumption is that this unobserved group specific effect is uncorrelated to any of the independent variables. If this is the case, as stated above, the REM estimators would be BLUE. However, in the presence of correlation, REM estimators are not only inefficient but inconsistent, invalidating statistical inference (Wooldridge, 2002; 2003). The pay-off of using REM is that the number of parameters to be estimated is greatly reduced in comparison to FEM (which implicitly introduces a wide set of dummy variables to compute individual specific effects - this is why some times the FEM is also designated as the Least Squares Dummy Variable (LSDV) model). Another advantage of REM is that time-invariant variables (e.g. Club of convergence) can be introduced while in FEM they are wiped out by the transformation procedure.

The REM is based on the same unobserved model as the FEM be estimated under the random effects hypothesis is simply:

$$PAT_{it} = \beta_0 + \beta_1 RD_{it} + ... + \beta_n X_{it} + a_i + \nu_{it}$$

$$RD_{it} = \beta_0 + \beta_1 (Accum) PAT_{it} + ... + \beta_n X_{it} + a_i + \mu_{it}$$

Note that since a_i is part of the composite error for each time period, the latter are serially correlated across time implying that the REM has to be estimated using Generalized Least Squares (GLS) when the variance structure is known and Feasible Generalized Least Squares (FGLS) when the variance is unknown (Park, 2006).[23] However, the estimations for the model coefficients (β_j) are consistent and more efficient than fixed effects estimators.

Like FEM, REM is also subject to a transformation. Due to this the need to eliminate serial correlation in the error terms, GLS or FGLS consist on OLS estimation of a quasi-demeaned model (Wooldridge, 2003):

[23] This can be dealt with using GLS procedures. Such issue however goes beyond the (necessary) limited scope of the present study. For further information, see Wooldridge (2003: 470-473).

Transformation[24]

$$PAT_{it} - \lambda\overline{PAT_{it}} = \beta_0(1-\lambda) + \beta_1\left[RD_{it} - \lambda\overline{RD_{it}}\right] + ... + \beta_n\left[X_{it} - \lambda\overline{X_{it}}\right] + (v_{it} - \lambda\overline{v_{it}})$$

$$RD_{it} - \lambda\overline{RD_{it}} = \beta_0(1-\lambda) + \beta_1\left[PAT_{it} - \lambda\overline{PAT_{it}}\right] + ... + \beta_n\left[X_{it} - \lambda\overline{X_{it}}\right] + (u_{it} - \lambda\overline{u_{it}})$$

From this transformation results a quasi-demeaned model, where the serial correlation does no longer exist, making OLS estimators in REM BLUE.

FEM and REM with Group and Time Specific Effects

In addition to Group specificities, we can try to evaluate whether there also time effects in what is denominated Two Way effects model. In these models while group specific effects (a_i) correspond to a group specific intercept, the time effect corresponds to a contrast of each period (λ_t) towards the base period. Before presenting the model basic formulation framework, one note is in order. In essence, the concept behind each model (FEM or REM) is not affected by considering time effects, though the estimation procedures involve some minor changes (Greene, 2003).[25] This a more complete model than the preceding ones. We computed estimates for every one of the models having chosen in each case the one with higher statistical adequacy determined by the adequate tests (F-test, Lagrange Multiplier Test and Hausman Test). In determining whether we have group effects, time effects or both, the F-test for significance must be performed.

Thus the model is formulated, in general terms, as follows:

$$PAT_{it} = \beta_0 + \beta_1 RD_{it} + ... + \beta_n X_{it} + a_i + d_t + v_{it}$$

$$RD_{it} = \beta_0 + \beta_1 PAT_{it} + ... + \beta_n X_{it} + a_i + w_t + \mu_{it}$$

Composite error in general: $\varepsilon_{it} = a_i + w_t + \mu_{it}$ or $\varepsilon_{it} = a_i + w_t + v_{it}$,

where, w_t and d_t are the elements corresponding to a time specific intercept.

The transformation required here to use FEM or REM is analogous to the one presented above for each model despite some necessary adaptations.[26]

---

[24] $\lambda = 1 - \left[\sigma_u^{\,2} / \left(\sigma_u^{\,2} + \sigma_a^{\,2}\right)\right]^{0,5}$

[25] For further information see Greene (2003: 291-292).

[26] For further details, check Greene (2003: 291-292) or Park (2006).

Pooled OLS, FEM, REM, Group and/or Time Effects: which is most suitable model?

Fortunately, several tests have been devised to help us choosing the adequate procedure. Pooled OLS is standard OLS with a bigger sample, not taking into consideration the within observation variation of the dependent and independent variables thus loosing precious information and conducing to less efficient estimators. FEM and REM are theoretically more appealing and empirically more suitable as long as there are group specific effects to be accounted for. The F-Test is a global significance test that captures if group dummies are relevant for the analysis. If the null hypothesis is rejected, then there is evidence supporting the presence of group effects and thus FEM is preferable to Pooled OLS. In an analogous way, Lagrange Multiplier Test does the same for REM in comparison to Pooled OLS. Finally, a more advanced model would include also period specific effects where dummies are generated to provide contrast towards the base year. To test for its presence we must simply extend the above testing procedures to incorporate the analysis of the statistical significance of time effects.

The F-test and the Lagrange Multiplier test allows to detect if there are group specific effects and thus if FEM or REM, respectively, are preferable to Pooled OLS. The F significance test is always suitable to test if there are group, time or both types of effects to be considered. Finally, to choose between FEM and REM in general, we use the Hausman test. When it is not possible to compute such test, cautiousness and time-saving concerns lead us to adopt FEM whose estimators are consistent both when $a_i \text{ and / or } w_t$ are correlated or uncorrelated with any of the independent variables.

Thus, Fixed or Random, which are the most advanced models to handle panel data (though, more demanding in terms of assumptions), are more adequate. For choosing the best among these two we might use the Hausman Test. The Hausman specification test compares the fixed versus random effects under the null hypothesis that the individual specific effects (a_i) are uncorrelated with the other regressors in the model (Hausman, 1978; Park, 2006). If correlated, the null hypothesis is rejected and the best choice is the Fixed Effects. The Random Effects would lead to obtaining biased estimators. When the Hausman test does not reject the null hypothesis, Random Effects estimators are more appropriate since they lead to more efficient results (Greene, 2003).

In the following section we present the estimated regressions using (depending on the Hausman Test) Fixed or Random Effects Model.

4.3. Is there evidence for the negativity of Patents on R&D?

As surveyed in Chapter 2, the existing literature on R&D and Patents relationship embraces two main causality directions – a traditional one, according to which more investment in R&D (as percentage of the GDP) leads to higher amount of patents (per million inhabitants), and the reverse causality, which focuses on the fact that higher amount of patents might lead to higher or *lower* R&D investments. This later possibility – *the negativity of patents on R&D* – is the most recent 'hot' issue, being the subject of interesting and intense debate. In the present thesis, we aim at contributing for this debate by adding new empirical evidence at the country level instead of focusing on micro/firm level reference unit, as the scarce existing empirical literature on the subject does.

Although our focus is on the reverse causality relation, we estimate both the traditional (Table 18) and the reverse causality (Tables 19 and 20) relation. We consider four distinct models: an aggregated one, which encompasses all the countries during the period in analysis; three models that comprise each of the three Clubs of Convergence considered in Castellaci (2006); and one model which consider highly R&D intensive countries, that is those that present an R&D intensity over 3%. In the case our data verifies Hunt's (2006) recent argumentation on the negativity of patents on R&D, we would expect that the estimate associated with the patents' coefficient, more rigorously, accumulated patents' coefficient, emerges with a negative sign for high developed countries (i.e., countries belonging to Club of Convergence 1) and/or high technology intensive countries (with R&D intensity above 3%). Estimates presented in the following tables are based on a panel of 88 countries and a six-year period (1996-2003). The models present in general a reasonable fit (in general with adjusted R^2 above 80%).

Results evidenced in Table 18 reflect the traditional positive relation between R&D investment and patents counts. As surveyed in Chapter 2, patents are commonly used as a measure of innovation, constituting an intermediate output (Kleinknecht et al., 2002) of R&D efforts. R&D investment on the other hand is usually regarded as the input to the innovative process (Beneito, 2006). Thus, in functional terms, R&D would be the independent variable (input), whereas Patents would be the dependent (output) one (Baudry and Dumont, 2006). In this sense, causality's direction implies that more investment in R&D would lead to more Patents being applied and issued.

Table 18: Estimation results for the *traditional* causality direction (dependent variable: Patent per million inhabitants)

		All			R&D>3%			Club Convergence 1			Club Convergence 2			Club Convergence 3		
R&D (in % of the GDP)		30.44***	31.70***	30.05***	-11.38	-10.21	-10.91	22.67***	25.13***	24.41***	1.02	-0.512	-0.481	0.105	0.289**	0.570
R&D performed by Firms (%)			-12.98	-12.60		60.53	78.57		-112.6**	-113.2**		-2.12	-2.23		4.70***	3.94***
FDI (in % of the GDP)			-0.005**	-0.003		0.561	0.347		-0.101	-0.08		-0.01***	-0.01***		0.007	-0.003
High-Tech Exports (%)			.0.162	-0.145		0.724	-0.053		-0.845*	-0.99**		-0.007	-0.014		-0.002	-0.002
Governance Indicators	Political stability			4.91**			-14.28			4.42			0.440			0.065
	Government effectiveness			-16.76***			-24.07			2.08			-0.362			0.232
	Regulatory context			8.62***			-5.66			10.49			1.16*			0.039
	Law enforcement			-7.67*			-28.45			-29.16*			0.260			0.071**
	Corruption			-2.49			25.49			-13.30			-1.26			0.064
Constant		0.24	9.37*	55.20***	184.0***	125.5*	305.3	51.05***	139.6***	262.2***	3.41***	6.77***	6.01*	-	-	-
Hausman Test [Fixed Effects Model (FEM) vs. Random Effects Model (REM)]		FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM	FEM
Effects [Group (G); Time (T)]		G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G	G	G
N (Observations)		704	640	640	40	40	40	168	168	168	432	408	408	88	48	48
Adjusted R^2		0.973	0.973	0.976	0.968	0.968	0.970	0.973	0.974	0.974	0.957	0.975	0.976	0.402	0.544	0.570

Estimation results presented in Table 18 show that the traditional causality relation between R&D and Patents is observed for the sample as a whole regardless the restrictiveness of the model chosen (see 'All' in the Table 18). Accordingly, a higher investment in R&D would lead, on average, to more patents counts. Such result holds for the most developed set of countries (Club of Convergence 1 – CC1) and (partially) for the less developed (Club of Convergence 3 – CC3, in the model without controlling for governance indicators), but not for highly R&D intensive countries (R&D>3%) and the intermediate developed countries (Club of Convergence 2 – CC2).

The non-significance obtained for the highly R&D intensive set might be due to the different specialization pattern of the five countries complying with the 3% in RD intensity threshold. When analyzing case by case, we find that Finland, Sweden and Israel have a similar pattern of patent per R&D intensity whereas Iceland and Japan are distinct and opposite cases. Japan though presenting a R&D intensity close to the 3% barrier, is the country that patents more. We can speculate that Japan, being a highly industrialized country may have a different patenting pattern than European Nations and Israel where ICT's have a higher weight in overall patents. If European firms approach is that ICT technologies, mainly in hardware terms, are not that patentable due to fast technological evolution, this may account for the relatively smaller patent output in spite of a considerably higher input. Such explanations might hold also in the case of countries belong to the CC 2, where a large heterogeneity (and larger than for the other sets) is observed in terms of specialization pattern. Nevertheless, for a more rigorous analysis it would be necessary a more in-depth study to each of the countries that constitute the sample.

The percentage of the R&D that is performed by firms (by opposition to that that is performed by public R&D labs and universities) constitute a promoter for patents in the case of laggard countries (CC3) but a hampering factor in the case of the highly developed country set (CC1). This later result might be at a first glance surprising. The negative estimate for CC1 means that a higher proportion of R&D performed by firms would lead to a reduction in patenting. Two effects may account for this negativity. First, when analyzing the sample we observe that the largest part of R&D performed in countries composing CC1 is performed at firm level. Since this R&D has usually more emphasis in the D (Development) it would mean that the basic knowledge production (made in Universities and Governmental Laboratories) would decrease. Eventually, the slower expansion of knowledge basis would result in a smaller developing capability. Second, patents are currently used more for strategic purposes rather than protection. As stated in the literature review (see Chapter 2), firms rate patents as a less effective protection element and thus, universities may have a higher propensity to patent. Reducing their weight would reduce patenting activity. For CC3 countries the signal is positive which means that a higher share of R&D conducted in firms rather than on public or non-profitable sectors would conduct to more patenting. In here the effect may be accounted for by the fact that there is no critical mass in knowledge creation and an increase in investment by firms would statistically result in a higher share and thus stimulate patenting. To a large extent, laggards are decaying countries with a very small R&D intensity. Thus, a higher R&D share by firms would mean a higher commitment and absolute investment in R&D and consequently positively influence patent grants.

High Technology Exports are only relevant, in statistical terms, to CC1. However, the relationship is (surprisingly) negative. This might be explained in the case these high tech exports involve products that have a relatively short life cycle. The excessive dynamics of these products might not advice patenting. Such result however, would need further and more in-depth empirical analysis.

The role of governance in explaining countries' patent propensity during the period in analysis is tricky and in some aspects hard to explain. For the whole sample ('All'), the perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including domestic violence and terrorism (i.e., *Political Stability*) and the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development (*Regulatory Quality*) are important foster factor for patenting, whereas the quality of the public services (*Government effectiveness*) and the capacity for governments to implement sound policies and regulations (*Rule of Law*) emerges as a preventing factor for patenting. Interestingly, however, in laggard countries (CC3) the higher confidence by agents in abide by the rules of society, and in particular the quality of contract enforcement, the police, and the courts, as well as the likelihood of crime and violence, the higher is these countries' patenting propensity. In the case of intermediate developed countries (CC2), the regulatory quality is the only governance indicator that (positively) influences their patent propensity.

Table 19: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP)

		All			R&D>3%			Club Convergence 1			Club Convergence 2			Club Convergence 3		
Patents (per million inhabitants)		0.006***	0.006***	0.006***	-0.006	0.005	0.004***	0.008***	0.005***	0.004***	0.001	-0.0007	-0.0006	0.228	0.268	-0.273*
R&D performed by Firms (%)			0.770***	0.760***		8.19***	5.80***		3.94***	3.78***		0.362***	0.345***		-4.67**	2.78***
FDI (in % of the GDP)			0.0001	0.00005		-0.020	0.004		0.0007	0.002		-0.000	-0.000		-0.08***	-0.12***
High-Tech Exports (%)				-0.045		0.039	0.036***		-0.003	-0.003		0.002**	0.002**		0.005	0.021***
Governance Indicators	Political stability			-0.045			-0.54***			-0.195**			0.029			0.043
	Government effectiveness			0.114***			0.381			0.219**			0.005			0.489***
	Regulatory context			0.018			0.594***			0.065			0.011			0.288***
	Law enforcement			-0.006			0.553			-0.047			-0.021			-0.329***
	Corruption			-0.006			-1.03***			-0.156			0.048			-0.344***
Constant		0.737***	0.531***	0.270	4.15***	-	-1.57	1.33***	-0.612**	-0.203	0.529***	0.447***	0.262**	0.37***	1.16***	-0.076
Hausman Test [Fixed Effects Model (FEM) vs. Random Effects Model (REM)]		FEM	FEM	FEM	FEM	REM	REM	REM	REM	REM	FEM	FEM	FEM	REM	FEM	FEM
Effects [Group (G); Time (T)]		G&T	G&T	G&T	G&T	G	G	G	G	G	G	G&T	G&T	G	G&T	G&T
N (Observations)		704	640	640	40	40	40	168	168	168	432	408	408	88	48	48
Adjusted R^2		0.977	0.977	0.977	0.846	0.926	0.969	0.931	0.952	0.956	0.938	0.937	0.937	0.848	0.894	0.921

Considering now the reverse causality relation between R&D and Patents, we detailed in Chapter 2 that the bulk of the literature on the reverse causality is almost unanimous in assuming a positive correlation (Sakakibara and Branstetter, 2001), in spite of lacking corroboration by empirical studies whose conclusions tend to be unclear or in disfavor of the positive correlation assumption. This empirical controversy has recently stimulated the emergence of several theoretical explanations at a microeconomic level (e.g. Hunt, 1999; Shapiro, 2001; Hunt, 2006) for the lack of empirical support of the positive correlation hypothesis.

As we recall in Section 2.2 of Chapter 2, the theoretical results that point to a solution reinforcing the general theoretical presumption that broader patent scope or greater patent length will induce more R&D effort and innovation (Denicolo, 1996) were derived considering an isolated invention, disregarding completely the *cumulative* nature of innovation.

Our results (Tables 19 and 20), to some extent, capture this subtle, but critical, point. When we use simple patent counts (Table 19), the evidence is that a higher amount of patents (per million inhabitants) leads, ceteris paribus, to higher investment in R&D both for the aggregated ('All') and disaggregated (R&D>3% and CC) samples. In the case of considering instead *accumulated* patent counts (Table 20), the relation between Patents and R&D is positive and significant for laggard countries (CC3), non significant for more developed countries (CC1 and CC2), and *negative* for the set of countries that are highly developed and present very high investment rates in R&D (R&D intensity above 3%).

Making the analogy with Shapiro's (2001) arguments for industries, we might put forward that in this later set of countries (highly developed and technology advanced), the patent system might lead, to a larger extent than in other countries, to the creation of a 'patent thicket' - dense web of overlapping intellectual property rights -, in particular, in industries, in which these countries tend to be specialized, characterized by cumulative and sequential innovations like semiconductors, software or even biotechnology. As referred earlier, when innovation is a process characterized by cumulative innovation and path dependency, the enlarging of the patent thicket may inhibit rather than stimulate R&D and innovation (Hunt, 2006).

Table 20: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP)

		All			R&D>3%			Club Convergence 1			Club Convergence 2			Club Convergence 3		
Accumulated Patents (per million inhabitants)		0.0003***	0.0003***	0.0003***	-0.0008***	-0.0004**	-0.0004***	0.0006**	0.0002***	0.00007	0.00004	0.0001	0.00007	-0.0000	0.295***	0.328***
R&D performed by Firms (%)			0.850***	0.836***		6.24***	3.73***		4.90***	3.78***		0.359***	0.345***		-4.85***	5.03***
FDI (in % of the GDP)			0.00006	0.00003		-0.012	-0.004		0.00018	0.0017		-0.0000	-0.0000		-0.05**	-0.01
High-Tech Exports (%)			0.0008	0.0004		0.045***	0.019***		0.0028	-0.0085		0.002**	0.002**		0.009**	0.007
Governance Indicators	Political stability			-0.015			-0.515***			-0.238**			0.028			-0.190**
	Government effectiveness			0.054			0.760***			0.391***			0.006			-0.193
	Regulatory context			0.051			0.518***			0.172			0.009			-0.228**
	Law enforcement			-0.035			-0.498			-0.265			-0.021			0.046
	Corruption			-0.012			-1.563***			-0.412**			0.048			-0.031
Constant		-1.08***	-1.04***	-1.14***	8.29***	1.26***	8.52***	1.80***	-	1.05	0.500***	-0.206	-0.207	0.441***	-	-
Hausman Test [Fixed Effects Model (FEM) vs. Random Effects Model (REM)]		FEM	FEM	FEM	FEM	FEM	REM	REM	FEM	FEM	REM	FEM	FEM	FEM	FEM	FEM
Effects [Group (G); Time (T)]		G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G&T	G	G	G
N (Observations)		704	640	640	40	40	40	168	168	168	432	408	408	88	48	48
Adjusted R^2		0.973	0.973	0.973	0.878	0.947	0.987	0.925	0.943	0.948	0.938	0.937	0.937	0.872	0.884	0.919

In general, whatever the model and the stratified sample considered, the proportion of R&D that is performed by firms has a positive impact on (accumulated) patents counts (per million inhabitants), which might in part reflect the issue of private incentives to R&D investment.

FDI (in percentage of the GDP) does not have, in general, any significant impact on patents. The interestingly exception is for laggard countries (CC3), where higher amounts of FDI lead, ceteris paribus, to lower levels of patenting. This finding is likely to be related to the *type* of FDI these countries tend to attract, often based on activities requiring very low investment in R&D (Tavares and Teixeira, 2006). This issue, although beyond the necessarily strict scope of the present thesis, would deserve further investigation. High Tech Exports, in contrast with FDI related variable present, in general, a positive and significant estimate – countries that tend to export higher shares of high tech products tend, on average, all the rest constant, to invest more in R&D. Nevertheless, such results only hold for stratified samples, not for the aggregated one.

The context emerges as an important variable for explaining countries' R&D intensity. In particular, the higher the perceptions on government effectiveness (quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies) and regulatory quality (the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development), higher, on average, is the investment in R&D, particularly on the higher developed (CC1 and CC2) and technology advanced (R&D>3%) countries.

4.4. In which direction is the relation between R&D-Patent Stronger?

In Chapter 2 we presented the literature on both ways of R&D-Patent relationship. In theoretical terms, it is unambiguous that a double causality exists between these variables. Notwithstanding, it is important to gather rigorous evidence in which direction is the relation might be more significant. It is possible in econometric terms to rigorously assess, using a causality evaluation procedure, a probable direction of stronger causality.

Note that correlation does not necessarily imply causation (Granger, 1969). We can test for causality using the Granger causality test procedure. However, we should bear in mind that this tests for the presence of precedence and relevant information of a lagged variable, for instance R&D, to explain Patents in addition to Patents' lagged values. If R&D lagged values enhances the estimation of Patents, then it contains important information and precedence is established (Granger, 1969). In this sense, we say that there is Granger Causality (Granger, 1969). The procedure itself is easily described. We run bivariate regressions illustrated by the following equations:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + ... + \alpha_t y_{t-1} + \beta_1 x_{t-1} + ... + \beta_1 x_{-1} + \varepsilon_t$$

$$x_t = \alpha_0 + \alpha_1 x_{t-1} + ... + \alpha_t x_{t-1} + \beta_1 y_{t-1} + ... + \beta_1 y_{-1} + u_t$$

Then we test the null hypothesis[27] that *y* does not Granger cause *x* and do the same for the opposite direction.

In order to evaluate causality between Patents and R&D, we can use a panel data framework. *E-views*© software package allows us to execute Granger Causality Test, however it requires a balanced panel data. In this vein, we needed to remove from the sample variables that presented missing values which were impossible to estimate by linear interpolation. Such missing values do not affect our core variables, Patent per million inhabitants and GERD. Thus, we removed the variables causing the unbalancement (namely, R&D Performed by Firms - RDPE), and then executed the routine to testing for causality in the Granger sense.

The lags included were based on the cross correlogram that suggests that only the first 7 lags are significant, reinforced by the fact that a large number lags is recommended. Table 21 summarizes the results.

Table 21: Pairwise Granger Causality Tests (Sample: 1996-2003; Lags=7)

Null Hypothesis	Observations (years×countries)	F-Statistics	Probability
Patent does not Granger cause R&D	8×88	2.120	0.052
R&D does not Granger cause Patent	8×88	4.961	0.000

[27] H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \ldots = 0$; that is to say, all lagged values of *x* are not significant to estimate *y* and vice-versa for the second equation.

Results reflect that, at 5% statistical significance, the traditional causality direction (R&D ‘causes’ Patent) in the Granger sense is verified whether as for the reverse causality (Patent ‘causes’ R&D) it is only valid at 10% significance level.

Based on the evidence above, we conclude that there is enough statistical evidence that for our sample the traditional sense of causality, evaluated in Granger terms, is stronger although the reverse causality is also acceptable.

Albeit causality appears to be stronger in the most intuitive appealing traditional direction, the evidence also supports the theoretical conveyed double causality between R&D and Patent.

Conclusions

Due to the influence of popular themes like economic growth and innovation, the most natural and intuitive way to think of patenting is as an output of R&D. Empirical studies on this direction have found support to the theory both at the firm and cross-country levels. In fact, empirical studies are unanimous in their results, obtaining clear evidence of a positive correlation between higher R&D intensity and patent production. However, it should be stressed the fact that this causality has been tested, in the majority of cases, in a microeconomic approach, that is using sample of firms being scarce the studies reporting on cross-country analysis. Despite the absence of many macro surveys, the empirical studies have brought into light some important insights. Firstly, it seems that correlation is stronger in cross-firm analysis than within firms. This is an important result since Pakes and Griliches (1980) characterize R&D expenditures observed as a random walk process which may imply that though a higher intensity in R&D leads to more patenting, the opposite may not be true, i.e. R&D investment might not respond to patenting.

Given this later debate, it seems imperative to evaluate the reverse causality issue. If patents constitute a basic institutional foundation, then it should influence R&D investment decisions. In particular, it has been demonstrated that Patent's breadth and the number of patents influence R&D economic return and therefore R&D investment decisions. Within this theoretical framework, the majority of the few studies that exist predict in theory a positive correlation between patents and R&D but empirically the evidence is at best inconclusive (and scarce). Microeconomic studies often reveal a negative outcome, in particular when analysing industries characterized by cumulative innovative processes such as semiconductors in which technologies tend to overlap. In such industries, competition and imitation seems to actually have a positive effect on R&D investment.

These controversial results have led to the emergence of several theoretical studies (e.g. Hunt, 1999; Shapiro, 2001; Hunt, 2006) which account for the hypothesis of a negative effect of patent's scope broadening, or the enlargement of the patent thicket, over R&D investment. Accordingly, making patents easier to obtain may actually cause R&D expenditures to decline. In this sense, raising patent costs and increasing criteria standards would stimulate R&D.

In what concerns the macroeconomic analysis of the reverse causality, this issue is rather unexplored. In theoretical terms, it is not clear what stance that should be attributed to patent protection. If highly innovative sectors may be harmed by patenting, sectors like chemicals or pharmaceuticals rely heavily on them and they are the primary incentive to R&D, otherwise probably not pursued. Empirical analysis is almost inexistent, being Varsakelis (2001) and Lerner (2001) two exceptions. Both of these studies point to the existence of a positive correlation in aggregate terms. Thus, there is a need for gathering further empirical evidence in these matters.

In the present thesis we aimed at adding empirical *macroeconomic* evidence on the patent-R&D relationship in both (traditional and reverse) causality directions trying to evaluate whether in a cross-country analysis there is evidence of the potential negative effect of patent over R&D put forward by recent debates in the area.

Using panel data econometric analysis techniques and a sample of 88 countries for a 8 years-period, we demonstrated that the *traditional causality* relation between R&D and Patents is observed for the sample as a whole regardless the restrictiveness of the model chosen. Thus, a higher investment in R&D would lead, on average, to more patents counts. Such result holds for the most developed set of countries and (partially) for the less developed, but not for highly R&D intensive countries and the intermediate developed countries. The non-significance obtained for the highly R&D intensive set could be attributed to the different specialization pattern of the five countries complying with the 3% in RD intensity threshold.

Table 22: Estimation results for the *traditional* causality direction (dependent variable: Patent per million inhabitants) summary table

		All	RD>3%	CC1	CC2	CC3
R&D (in % of the GDP)		+	0	+	0	0
R&D performed by Firms (%)		0	0	-	0	+
FDI (in % of the GDP)		0	0	0	-	0
High-Tech Exports (%)		0	0	-	0	0
Governance Indicators	Political Stability	+	0	0	0	0
	Government Effectiveness	-	0	0	0	0
	Regulatory Quality	+	0	0	0	0
	Law Enforcement	-	0	-	0	+
	Corruption Control	0	0	0	0	0
Constant		+	0	+	+	-
Adjusted R^2		0.976	0.970	0.974	0.976	0.570

Respecting the reverse causality relation, theoretical results point to a solution reinforcing the general theoretical presumption that broader patent scope or greater patent length will induce more R&D effort and innovation. However, such results were derived considering an isolated invention, disregarding completely the *cumulative* nature of innovation. Our results point that when we use simple patent counts (Table 23), the evidence is that a higher amount of patents (per million inhabitants) leads, ceteris paribus, to higher investment in R&D both for the aggregated and disaggregated samples.

Table 23: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP) – summary table (simple patents)

		all	Rd>3	Cc1	Cc2	Cc3
Patents (per million inhabitants)		+	+	+	0	-
R&D performed by Firms (%)		+	+	+	+	+
FDI (in % of the GDP)		0	0	0	0	-
High-Tech Exports (%)		0	+	0	+	+
Governance Indicators	Political Stability	0	-	-	0	0
	Government Effectiveness	+	0	+	0	+
	Regulatory Quality	0	+	0	0	+
	Law Enforcement	0	0	0	0	-
	Corruption Control	0	-	0	0	-
Constant		0	0	0	+	0
Adjusted R^2		0.977	0.969	0.956	0.937	0.921

In the case of considering instead *accumulated* patent counts (Table 24), our results go in the line of Hunt's (2006) argument. In fact, we found that the relation between Patents and R&D is positive and significant for laggard countries, non significant for more developed countries, and *negative* for the set of countries that are highly developed and present very high investment rates in R&D (R&D intensity above 3%).

In this vein, we suggest that in this later set of countries (highly developed and technology advanced), the patent system might lead, to a larger extent than in other countries, to the creation of a 'patent thicket', in particular, in industries, in which these countries tend to be specialized, characterized by cumulative and sequential innovations.

Table 24: Estimation results for the *reverse* causality direction (dependent variable: R&D in percentage of the GDP)

		All	Rd>3	Cc1	Cc2	Cc3
Accumulated Patents (per million inhabitants)		+	-	0	0	+
R&D performed by Firms (%)		+	+	+	+	+
FDI (in % of the GDP)		0	0	0	0	0
High-Tech Exports (%)		0	+	0	+	0
Governance Indicators	Political Stability	0	-	-	0	-
	Government Effectiveness	0	+	+	0	0
	Regulatory Quality	0	+	0	0	-
	Law Enforcement	0	0	0	0	0
	Corruption Control	0	-	-	0	0
Constant		-	+	0	0	-
Adjusted R^2		0.973	0.987	0.948	0.937	0.919

Finally, concerning the strength of causality, our data indicate that the traditional sense of causality, evaluated in Granger terms, is stronger although the reverse causality is also acceptable. Summing up, although causality appears to be stronger in the most intuitive appealing traditional direction (R&D → Patents), there is evidence that supports the theoretical conveyed double causality between R&D and Patent (R&D → Patents; R&D ← Patents).

It is important to stress at this stage several limitations of the present study, which nevertheless would constitute interesting points for further future research. A first point is the failure to account for the role of patent scope and length. These aspects constitute, as surveyed in Chapter 2, important issues for explaining the negativity of reverse causality relation between R&D and Patents. However, in order to proper test and evaluate such issues, we would need to have a richer and longer term sample. Focusing on a restrict number of countries and considering a longer time period would be an adequate strategy providing potential illuminating clues. Moreover, to re-estimate the models accounting for the different nature of patents - using high tech patents instead of patents as a whole – would permit to uncover further interesting results. This could also involve industry and cross country analysis. Finally, it would be interesting to stratify the samples using different taxonomies of clubs of convergence besides the one used here (Castellaci's).

References

Abramovitz, M. (1986), "Catching-up, forging ahead and falling behind." *Journal of Economic History*, 46, pp. 385-406.

Acs, Z.J., Anselin, L. and Varga, A. (2002). "Patents and innovation counts as measures of regional production of new knowledge", *Research Policy,* 31, pp. 1069–1085.

Aghion, P. and Howitt, P. (1992). "A model of growth through creative destruction", *Econometrica,* Vol. 60, issue 2, pp. 323-351.

Arora, A. and Merges, R. (2000), "Property Rights, Firm Boundaries and R&D inputs", *Working Paper*, Carnegie Mellon.

Arrow, K.J., (1962), "Economic welfare and the allocation of resources for invention", *Universities-National Bureau of Economic Research Conference*, The Rate and Direction of Economic Activities: Economic and Social Factors, Princeton University Press.

Azariadis, C. and Drazen, A. (1990), "Threshold externalities in economic development." *Quarterly Journal of Economics*, pp. 501-526.

Barro, R. and Sala-i-Martin, X. (1997), "Technological Diffusion, Convergence and Growth", *Journal of Economic Growth*, issue 2, pp. 1-27.

Baudry, M. and Dumont, B. (2006), Comparing firms' triadic patent applications across countries: Is there a gap in terms of R&D effort or a gap in terms of performances?, *Research Policy*, 35, pp. 324–342.

Baumol, W. (1986), "Productivity growth, convergence and welfare: what the long-run data show." *American Economic Review*, 76 (5), pp. 1072-1085.

Beneito, P. (2006), "The innovative performance of in-house and contracted R&D in terms of patents and utility models ", *Research Policy,* 35, pp. 502–517.

Bessen, J. (2003), "Patent Thickets: Strategic Patenting of Complex Technologies", *Working Paper*, Research on Innovation. Available at SSRN: http://ssrn.com/abstract=327760.

Bessen, J. and Hunt, R. (2007), An Empirical Look at Software Patents, *Journal of Economics & Management Strategy*, Vol. 16, Number 1, Spring 2007, pp. 157–189.

Bessen, J. and Maskin, E., (2002), "Sequential Innovation, Patents, and Imitation," *Working Paper,* MIT Dpt. of Economics, revised version.

Bitzer, J. (2005), "Measuring knowledge stocks: a process of creative destruction", *Kyklos*, 58, pp. 379–93.

Bitzer, J. and Stephan, A. (2007), "A Schumpeter-inspired approach to the construction of R&D capital stocks", *Applied Economics*, 39, pp. 179–189.

Blind, K. and Jungmittag, A. (2005), "Trade and the impact of innovations and standards: the case of Germany and the UK", *Applied Economics*, 37, pp. 1385–1398.

Blind, K., Edler, J., Frietsch, R. and Schmoch, U. (2006), "Motives to patent: Empirical evidence from Germany", *Research Policy*, 35, pp. 655–672.

Bound, J., Cummins, C., Griliches, Z., Hall, B. and Jaffe, A., (1982), "Who Does R&D and Who Patents?", *working paper* nº 908, NBER.

Cantwell, J. (editor) (2006), *The Economics of Patents*, The International Library of Critical Writings in Economics, 197, Edward Elgan – Cheltenham.

Castellacci, F. (2006), "Convergence and Divergence among Technology Clubs," *DRUID Working Papers,* 06-21.

Cohen, W., Nelson, R.R. and Walsh, J. (2000), "Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent (or not)", *NBER Working Paper*, nº 7552.

Cornweel, C. and Schmidt, P. (1984), "Panel Data with Cross Sectional Variations in Slopes as well as in Intercept", *Econometrics workshop paper*, nº 8404, Michigan State University, Department of Economics.

Denicolo, V. (1996), ''Patent Races and Optimal Patent Breadth and Length.'' *Journal of Industrial Economics,* Vol. 44, pp. 249–265.

Desdoigts, A. (1999), "Patterns of economic development and the formation of clubs." *Journal of Economic Growth*, 4, pp. 305-330.

Durlauf, S. and Johnson, P. (1995), "Multiple regimes and cross-country growth behaviour." *Journal of Applied Econometrics*, 10, pp. 365-384.

Encaoua, D., Guellec, D. and Martínez, C. (2006), "Patent systems for encouraging innovation: Lessons from economic analysis", *Research Policy* 35, pp. 1423-1440.

EPO (2006), "Annual Report - 2006", available for download and consultation at http://www.epo.org/about-us/publications/general-information/annual-reports.html and accessed on 01/09/2007.

Ernst, H. (1998), "Industrial Research as a source of important Patents", *Research Policy* 27, pp. 1-15.

Evenson, R. (1993), "Patents, R&D and Invention Potential: International Evidence", *American Economic Review*, Vol 83, issue 2 (May), pp. 463-468.

Evenson, R., Englander, S. and Hanazaki, M. (1988), "R&D, Innovation and the Total Factor Productivity Slowdown", *OECD Economic Studies*, nº. 11.

Falk, M. (2006), "What drives business Research and Development (R&D) intensity across Organisation for Economic Co-operation and Development (OECD) countries?", *Applied Economics*, 38, pp. 533–547.

Gallini, N. (2002). "The Economics of Patents: Lessons from Recent US Patent Reform", *Journal of Economic Perspectives*, 16 (2), pp. 131-154.

Gancia, G. and Zilibotti, F. (2005). "Horizontal Innovation in the Theory of Growth and Development", in *Handbook of Economic Growth*, eds: Aghion, Phillipe e Durlauf, Steve.

Gerschenkron, A. (1962), *Economic Backwardness in Historical Perspective*. Harvard University Press, Cambridge.

Gilbert, R. and Shapiro, C. (1990), "Optimal Patent Length and Breadth", *RAND Rand Journal of Economics*, Vol. 21, nº1, pp. 106-112.

Grandstrand, O. (1999), "Patents and Intellectual Property: a general framework", in *The Economics and Management of Intellectual Property: Towards Intellectual Capitalism*, chapter 3, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 55-106.

Granger, C.W.J. (1969), "Investigating Causal Relations by Econometric Methods and Cross-Spectral Methods," *Econometrica,* 34, 424-438.

Green, J. and Scotchmer, S., (1990), “Novelty and disclosure in patent law”, *Rand Journal of Economics*, 21 1, pp. 131–146.

Greene, W. H. (2003), Econometric Analysis, 5th edn, Prentice-Hall, New Jersey.

Griliches, Z. (1980), "R&D and the productivity slowdown", *American Economic Review,* May, pp. 343-348.

Griliches, Z. (1988), “Productivity Puzzles and R&D: another nonexplanation”, *Journal of Economic Perspectives*, Vol. 2, issue 4, pp. 9-21.

Griliches, Z. (1990), “Patent statistics as economic indicators: a survey”, *Journal of Economic Literature,* 92, pp. 630–653.

Griliches, Z. (1994), “Productivity, R&D, and the data constraint”, *American Economic Review,* 84, pp. 1–23.

Griliches, Z., (1986). “Productivity, R&D, and basic research at the firm level in the 1970s”, *American Economic Review,* 76, pp. 141–154.

Griliches, Z., Pakes, A. and Hall, B. (1986), "The value of patents as indicators of inventive activity", *Harvard lnstitute of Economic Research Discussion Paper*, nº 1285.

Guellec, D. and De la Potterie, B. (2001), “R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries”, *OECD Economic Studies,* No. 33.

Hall, B.H. and Ziedonis, R.M. (2001), “The patent paradox revisited: an empirical study of patenting in the US semiconductor industry 1979–1995”, *The Rand Journal of Economics*, 32 (1), pp. 101–128.

Hall, B.H., Griliches, Z. and Hausman, J.A. (1986), “Patents and R&D: is there a lag?”, *International Economic Review,* 27 (2), pp. 265–283.

Hausman, J. (1978), "Specification Tests in Econometrics" *Econometrica*, 46 (6), pp. 1251-1271.

Hausman, J., Hall, B.H. and Griliches, Z., (1984), “Econometric models for count data with and application to the patents-R&D relationship”, *Econometrica,* 52 (4), pp. 354–383.

Heller, M. and Eisenberg, R., (1998), “Can patents deter innovation? The anticommons in biomedical research”, *Science,* 280, pp. 698–701.

Hobijn, B. and Franses, P. (2000), “Asymptotically perfect and relative convergence of productivity.” *Journal of Applied Econometrics*, 15, pp. 59-81.

Hunt, R. M. (1999), "Nonobviousness and the Incentive to Innovate: An Economic Analysis of Intellectual Property Reform," *Working Paper* No. 99-3, Federal Reserve Bank of Philadelphia.

Hunt, R. M. (2006), “When do more Patents reduce R&D?”, *American Economic Review*, Vol. 96 Issue 2 (May), pp. 87-91.

Jaffe, A. (1986), “Technological Opportunity and Spillovers of R&D: Evidence from Firms’ Patents, Profits and Market Value”, *American Economic Review*, Vol 76, issue 5 (December), pp. 984-1001.

Jaffe, A. (2000), “The U.S. patent system in transition: policy innovation and the innovation process”, *Research Policy*, 29, pp. 531–557.

Jaffe, A., Trajtenberg, M. and Hall, B.H., (2005). “Market value and patent citations”, *working paper*, NBER.

Janz, N., Licht, G.and Doherr, Th. (2001), “Innovation activities and European patenting for German firms”, Proceedings of the *Annual Conference of the European Association of Research of Industrial Economics* (EARIE), EARIE, Dublin.

Kingston, W. (2001), “Innovation needs patents reform”, *Research Policy*, 30, 403–423.

Kitch, E., (1977), “The nature and function of the patent system”, *Journal of Law and Economics*, Vol. 20, issue 2, pp. 265-290.

Kleinknecht, A., Van Montfort, K. and Brouwer, E., (2002), “The Non-trivial choice between innovation indicators”, *Econ. Innov. New Techn.,* 2002, Vol. 11(2), pp. 109–121.

Klemperer, P., (1990), “How broad should the scope of patent protection be?”, *Rand Journal of Economics*, 21, pp. 113–130.

Kortum, S. (1993), “Equilibrium R&D and the Patent-R&D ratio: U.S. Evidence”, *American Economic Review*, Vol 83, issue 2 (May), pp. 450-457.

Kortum, S. and Lerner, J., (1999), “What is behind the recent surge in patenting?”, *Research Policy*, 28, pp. 1–22.

Lanjouw, J., Pakes, A. and Putnam, J. (1998), "How to Count Patents and Value Intellectual Property: The Uses of Patent Renewal and Application Data", *The Journal of Industrial Economics*, 46 (4), pp. 405-32.

Lanjouw, J.O. and Schankerman, M. (2004). "Patent Quality and Research Productivity: Measuring Innovation with multiple indicators", *The Economic Journal*, 114 (April), pp. 441–465.

Lerner, J. (2001), "150 years of Patent Protection", *working paper*, Harvard Business School.

Lerner, J. and Tirole, J. (2004), "Efficient Patent Pools", *American Economic Review*, Vol 94, issue 3, pp. 691-711.

Levin, R.C., Klevorick, A.K., Nelson, R.R. and Winter, S.G., (1987), "Appropriating the returns from industrial research and development", *Brookings Papers on Economic Activity*, 3, pp. 783–820.

Llobet, G., Hopenhayn, H., Mitchell, M., (2000), "Rewarding sequential innovators, patents, prizes and buyouts", Federal Reserve Bank of Minneapolis, *Research Department Staff Report*, 273.

Mansfield, E. (1986), "Patents and Innovation: An Empirical Study", *Management Science*, 32 (2), pp. 173-181.

Mazzoleni, R. and Nelson, R. (1998), "The benefits and costs of strong patent protection: a contribution to the current debate", *Research Policy* 27, pp. 273–284.

Merges, R. (1998), "Antitrust Review of Patent Acquisitions: Property Rights, Firm Boundaries and Organizations", in *Competition Policy and Intellectual Property Rights in the Knowledge-Based Economy*, Eds Robert Anderson and Nancy Gallini, University of Calgary Press, pp. 111-132.

Merges, R. and Nelson, R., (1990), "On the complex economics of patent scope", *Columbia Law Review*, 90, _4, pp. 839–916.

Messinis, G. (2005), "Patent Quality and R&D Productivity in Pharmaceuticals: The Role of Inflation and International Collaboration", *Working Paper*, nº. 27, Centre for Strategic Economic Studies, Victoria University of Technology.

Nelson R., Cohen W., Goto A., Nagata A. and Walsh J. (2002), "R&D spillovers, patents and the incentives to innovate in Japan and the United States", *Research Policy* 31, 8, December, pp. 1349-1367.

Nordhaus, W. (1969). "Invention, Growth, and Welfare; A Theoretical Treatment of Technological Change", Cambridge, Mass. 1969, ch 5.

O'Donoghue, T., Scotchmer, S., Thisse, J., (1998), "Patent breadth, patent life and the pace of technological progress". *Journal of Economics and Management Strategy*, 7 (1), pp. 1–32.

OECD (1993), *"The Measurement of Scientific and Technological Activities: Standard Practice for Surveys of Research and Experimental Development – Frascati Manual*", OECD, Paris.

OECD (1997), "Patents and innovation in the international context", *mimeo*, Paris.

OECD (2005), *"Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*", 3rd Edition.

Pakes, A. and Griliches, Z. (1980). "Patents and R&D at the firm level: a first look", *working paper*, nº 561, NBER.

Park, H. (2006), *"Linear Regression Models for Panel Data Using SAS, STATA, LIMDEP, and SPSS*", The Trustees of Indiana University.

Porter, M. and Stern, S. (2000), "Measuring the "Ideas" Production Function: Evidence from International Patent Output", *working paper*, nº 7891, NBER.

Porter, M., Stern, S. and Furman, J. (2002), "The determinants of national innovative capacity", *Research Policy,* 31, pp. 899–933.

Quah, D. (1996), "Convergence empirics across economies with (some) capital mobility." *Journal of Economic Growth,* 1 (1), pp. 95-124.

Quah, D. (1997), "Empirics for growth and distribution: stratification, polarization, and convergence clubs. " *Journal of Economic Growth,* 2, pp. 27-59.

Romer, P. (1990), "Endogenous technological change", *Journal of Political Economy*, Vol. 98, No. 5, pp. S71-S101.

Sakakibara, M. and Branstetter, L. (2001), "Do stronger patents induce more innovation? Evidence from the 1988 Japanese patent law reforms**",** *RAND Rand Journal of Economics*, Vol. 32, No. 1, Spring 2001, pp. 77–100.

Schankerman, M. and Scotchmer, S., (1999), "Damages and injunctions in the protection of proprietary research tools", *NBER Working Paper*, nº 7086, April.

Scherer, F., (1965), "Firm size, market structure, opportunity, and the output of patented inventions", *American Economic Review* 55, pp. 1097–1125.

Schmookler (1966), *"Invention and economic growth*", Harvard University Press Cambridge.

Schumpeter, J. (1942), "*Capitalism, Socialism and Democracy*", New York: Harper, 1975.

Scotchmer, S., (1996), "Protecting early innovators: should secondgeneration products be patentable", *Rand Journal of Economics*, 27, pp. 322–331.

Scotchmer, S., (1999), "On the optimality of the patent renewal system", *Rand Journal of Economics* 30 (2), pp. 181–196.

Shapiro, C. (2001), "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard-Setting," in Adam B. Jaffe, Josh Lerner, and Scott Stern, Eds., *Innovation Policy and the Economy*, Vol. I. Cambridge, MA: MIT Press.

Suzuki, J., Gemba, K., Tamada, S., Yasaki, Y. and Goto, A. (2006), "Analysis of propensity to patent and science-dependence of large Japanese manufacturers of electrical machinery"**,** *Scientometrics*, Vol. 68, 2, pp. 265–288.

Sveikauskas, L. (1986), "The contribution of R&D to productivity growth", *Monthly Labor Review* , March, pp.16-20.

Tavares, A.T. and Teixeira, A.A.C. (2006), *Multinationals, Clusters and Innovation. Does Public Policy Matter?*, New York: Palgrave Macmillan.

Terra, M. (2003), "Credit constraints in Brazilian firms: evidence from panel data", *Revista Brasileira de Economia*, vol. 57, nº2, pp. 443-464.

Unesco (1999), Declaration on Science and the use of Scientific Knowledge", proceedings from the *World Conference on Science* held in Budapest in 1999, accessed on 27/09/07 atin http://www.unesco.org/science/wcs/eng/declaration_e.htm#knowledge, accessed on 27/09/2007.

UNESCO (2001), *The State of Science and Technology in the World 1996-1997*, UNESCO Institute for Statistics.

USPTO (2007), *Patent typology*, accessed in 27/09/07 at http://www.uspto.gov/web/patents/types.htm. accessed in 27/09/2007.

Varsakelis, N.C. (2001), “The impact of patent protection, economy openness and national culture on R&D investment: a cross-country empirical investigation”, *Research Policy,* 30, pp. 1059–1068.

Wooldridge, J. (2002), *Econometric Analysis of Cross Section and PanelData*, Cambridge, MA: MIT Press.

Wooldridge, J. (2003), *Introductory Econometrics: A Modern Aproach,* 2nd Edt, Thomson South Western.

Yang, G. and Maskus, K., (2001), “Intellectual property rights and licensing: an econometric investigation”, *Weltwirtschaftliches Archiv*, 137, pp. 58–79.