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Abstract:

Although the conventional R&D-patents relationship is a long stand and relatively undisputed issue within the innovation literature, the reverse causality, in particular, the potential for a negative impact of patents over R&D has only recently received wide attention boosting interesting (mainly) theoretical debates. The macroeconomic perspective on this issue, however, remains largely unexplored. In fact, no evidence exists that 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. Using panel data estimation methods on a sample of 88 countries, over an eight-year period (1996-2003), and controlling for clubs of convergence to account for differences on countries' stages of economic development, we found mix support to the negativity of patent on R&D investment. The 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; restricting 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. We further demonstrate that albeit causality appears to be stronger in the most intuitive appealing traditional direction, evidence supports the theoretical conveyed double causality between R&D and Patent.

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

JEL-codes: O31, O34

1. Introduction

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. 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).

Most of the empirical studies that have tried to assess the different aspects of the relationship between R&D and Patents 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 is scarce the *macroeconomic perspective* is even more unexplored.

Thus, this paper's 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 (1996-2003), 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 Castellaci's clubs of convergence.

The paper is structured as follows. The next section surveys the literature on the relation between R&D and Patenting. Afterwards (Section 3), we assess for a panel data of 88 countries over 1996-2003 period whether the negativity of patents on R&D emerges at a macroeconomic level and which direction of the relation R&D-Patents is stronger, the traditional (R&D → Patents) or the reverse causality (Patents → R&D). Finally, Section 4 concludes.

2. On the relation between R&D and Patenting. A survey

2.1. 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)

2.2. 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).[1] 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 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,

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

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.[2] 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 as a dense web of overlapping intellectual property rights. In other words, in some industries the accumulation of patents on overlapping technologies

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

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 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.

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.

2.3. Identifying some gaps on the empirical literature and main hypotheses of the study

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 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 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 consubstantiate in an upsurge of patents. However, Hall and Ziedonis (2001) questioned the real effect on R&D investment and innovative output and the apparent patent paradox 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 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. 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.

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.

3. Assessing the relationship between R&D and Patenting. A Panel Data Estimation

3.1. Theoretical specification and main hypotheses

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 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 paper's 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 aggregate (containing all countries) and disaggregate samples corresponding to each Club of Convergence.

3.2. Data sources and proxies for the variables in the model

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.[3]

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.[4] 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).

The source used for Patents is 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.

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

[4] The severe truncation of the R&Dvariable 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. In Almeida (2007) a detailed account of data gaps is provided, indicating the estimation

Using Castellaci's (2006) results, we identify three clubs of convergence based on their technological capabilities.[5] 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.[6]

Foreign Direct Investment (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).

R&D Performed by Firms 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

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procedures adopted and providing further details on the data as well preceding comments and a descriptive statistical analysis.

[5] 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 analyses 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 (in Appendix we present Castelacci's list of countries by club of convergence).

[6] Though a robust process, these data grouping techniques have some perks namely the fact that the number of clusters to be identified is predefined. One should 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.

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. 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.

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. 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.

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. From Kaufmann et al. (2005: 6) we gathered five dimensions of governance: 1) 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; 2) 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; 3) Regulatory Quality – measuring the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development; 4) 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; and 5) 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.

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. 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 control, regulation, and government efficiency.

3.3. Results of the estimation

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).[7] 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.

Several tests have been devised to help choosing the adequate estimation procedure. Fixed Effects Model (FEM) and Random Effects Models (REM) are theoretically more appealing and empirically more suitable than the Pooled OLS as long as there are group specific effects to be accounted for.[8] A more advanced model should also include 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.[9]

To choose between FEM and REM in general, we use the Hausman test. The Hausman specification test compares the fixed versus random effects under the null hypothesis that the individual specific effects are uncorrelated with the other regressors in the model (Hausman,

[7] 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.

[8] 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.

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).

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 3 reflect the traditional positive relation between R&D investment and patents counts. As surveyed in Section 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.

[9] 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.

Table 3: 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	582	582	40	40	40	184	184	184	432	350	350	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 3 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 3). 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 Section 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 4: 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	582	582	40	40	40	184	184	184	432	350	350	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 Section 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, 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 4 and 5), to some extent, capture this subtle, but critical, point. When we use simple patent counts (Table 4), 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 5), 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 5: 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	582	582	40	40	40	184	184	184	432	350	350	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 paper, 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. 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 paper 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.

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, 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.

In the case of considering instead *accumulated* patent counts, 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.

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 Section 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).

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Appendix - Castellaci's (2006) Clubs of Convergence

Club1 – Leaders (21)	Club2 - Catching Up (54)	Club 3 – Laggards (11)	Isolated Countries (2)
Austrália	Argentina	Bangladesh	Burkina Faso
Áustria	Armenia	Egypt	Cape Verde
Belgium	Azerbaijan	Índia	
Canada	Belarus	Madagascar	
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		
New Zealand	Czech Republic		
Norway	Equador		
Singapore	Estonia		
South Korea	Georgia		
Sweden	Greece		
Switzerland	Honduras		
United Kingdom	Hungary		
United States	Indonesia		
	Ireland		
	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		

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