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Article

The R&D-patent relationship: An industry perspective

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ABSTRACT

This paper re-visits the empirical failure to establish a clear link between R&D efforts and patent counts at the industry level. It is claimed that the “propensity-to-patent” concept should be split into an “appropriability propensity” and a “strategic propensity”. The empirical contribution is based on a unique panel dataset composed of 18 industries in 19 countries over 19 years. The results confirm that the R&D-patent relationship is affected by research productivity, appropriability propensity and strategic-propensity factors. The observed increase in the propensity to file patents is much stronger for supra-national (that is, triadic or regional) patents than for national priority filings, suggesting that the current patent hype is essentially the result of a globalization phenomenon.

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The R&D-patent relationship: An industry perspective

1. Introduction

Patent data are the most widely used indicators of technology output. They are used for instance to assess the rate of technological change, to gauge firms' competitive positions, to measure industrial structure, or to evaluate scientific progress and knowledge spillovers. The success of patent statistics is rooted in their wide availability, their intrinsic relatedness to inventions, and their relatively homogeneous standards across countries. International treaties such as the Paris Convention for the protection of industrial property of 1883 or the Patent Cooperation Treaty of 1978 have indeed set some degree of minimum legal and quality standards.

The quality of patents as indicators of technological change has however been criticized or challenged for several decades (see Griliches 1990). There are noticeable differences in the reliance on patents across firms, industries and countries, which make patent data rather difficult to interpret. It is well known that not all inventions are patentable and not all patentable inventions are actually patented. In addition, patented inventions differ in their quality or "inventive step". This latter shortcoming means that patents vary greatly in their technical and economic significance, with a majority apparently mirroring minor technological improvements. A growing stream of research has therefore analyzed the extent to which patents are a reliable indicator of technological change. Schmookler (1957) is probably the first formal attempt to investigate what patent statistics actually indicate. The literature has mainly focused on correlations between patent counts and one or several other variables that measure either innovative input, such as R&D expenditures, or ultimate output measures, such as productivity growth or the stock market value of firms.

Studies on the R&D-patent relationship performed on cross-sectional data lead to the conclusion that there is a strong and highly significant correlation between R&D inputs and patent counts across firms. However, this correlation almost vanishes when within-firm time-series are considered. Patents do react to firm changes in R&D expenditures, but much less than expected. Investigations at the industry level lead to even more incongruous results, with a weak or almost absent correlation between R&D and patents. Some industries have a high propensity to rely on the patent system but file much fewer patents than other industries with a weaker orientation towards patent protection (Levin *et al.* 1987). This conundrum is probably what led Zvi Griliches (1990) to conclude that it would be "misleading to interpret such [patent] numbers as indicators of either the effectiveness of patenting or the efficiency of the R&D process". The tacit convergence amongst research scholars has been that patent data would reflect a propensity behaviour, rather than innovation performance or research productivity.

Despite this wide empirical scepticism of landmark contributions to the economic literature on patent-based indicators, the latter are still intensely used nowadays to measure firms' or countries' innovation performance. In a recent contribution, de Rassenfosse and van Pottelsberghe (2009) produce cross-country empirical evidence in favour of patent statistics. In particular, they show that some patent indicators are more reflective of a research productivity effect whereas others indicate more varying propensities to patent. The authors show that the R&D-patent relationship is affected by a "research productivity" component and a "patent propensity" component, as illustrated by the impact of three types of policies on countries' patent performances: education, science and technology, and the design of patent systems. Yet, their study lacks a time dimension and is performed at the country level and therefore does not contribute to explaining the failures of the firm or industry-level attempts to identify a relationship between R&D and patents over time.



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Gaétan de Rassenfosse



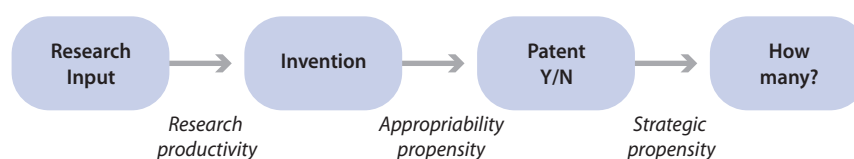
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R&D expenditure is related to patents through research productivity and the propensity to file for patent protection.

The present paper aims at re-visiting the failure to establish a clear empirical link between patent counts and changes in R&D expenditures at the industry level. The intended contribution to the literature is both conceptual and empirical. In addition to differentiating the “research productivity” effect from the “patent propensity” effect, the conceptual contribution claims that the latter effect should be disentangled into two main components: the “appropriability propensity” and the “strategic propensity”, as illustrated in Figure 1. The appropriability propensity relates to the share of inventions that are patented by firms, as measured in classical surveys (e.g. Levin *et al.* 1987, Arundel and Kabla 1998 or Cohen *et al.* 2000). The strategic propensity is defined as the number of patents filed to protect a given invention and has barely been measured so far. The failure to take into account both types of patent propensity is probably a major reason underlying the failure to identify a strong relationship between an increase in research activities and the evolution of patent applications at the industry level.

The empirical contribution of this paper consists in evaluating the R&D-patent relationship with a unique panel dataset covering 18 industries in 19 countries over 19 years. In addition, several patent-based indicators are used to test the robustness of the results: priority filings, “regional” filings and triadic filings.¹ Priority filings are first applications at national patent offices, which are potentially converted into regional patents later on (such as the European patent office (EPO) for Belgian applicants or the US Patent Office (USPTO) for Canadian applicants) or into triadic patent applications (patents filed simultaneously at the USPTO, the EPO and the Japanese Patent Office (JPO)). The average quality or value of patent indicators increases from priority filings to triadic applications, as witnessed by a larger geographical coverage and higher expenses due to legal and attorney fees, as well as translation costs.

Figure 1. The R&D-patent relationship



Our results confirm, first, that the research productivity dimension matters and explains part of the variation in the patent-to-R&D ratio over time. This productivity effect is captured by the share of basic research and of higher education in total R&D expenditures, and by an indicator of international-trade performance, which reflects the ultimate success of innovation efforts. Second, taking into account the two components of the propensity to patent – appropriability propensity and strategic propensity – helps to refine the relationship between R&D and patents at the industry level. If the long-term elasticity of patents with respect to R&D expenditures of about 0.12 is much lower than in cross-country or cross-firm estimates, it is nonetheless significant, suggesting that more R&D leads indeed to more patents. The low elasticity is probably due to the role of the strategic propensity, which is difficult to measure and is only partially captured by the strength of patent systems. The appropriability propensity has a positive and highly significant impact and sheds new light on the variability in the patent-to-R&D ratio across industries. A few industries (computers and communication technologies) and countries (South Korea, Spain and Poland) have strongly increased their propensity to file patents. The time dummies suggest that the propensity to file patents has increased much faster for regional applications (those at the USPTO or the EPO) and for triadic patents than for priority filings, suggesting that the current patent hype observed in regional patent offices is more the result of globalization than of a particularly stronger strategic propensity to file patents.

¹ “Regional” filings are filings at either the EPO or the USPTO or a mix of both indicators as explained in Section 3.2. These two offices, indeed, attract a large number of applications from non-domestic applicants, about half the total number of filings in the two offices.

The paper is structured as follows. The next section summarizes the results of selected empirical analyses of the R&D-patent relationship and discusses the two components of the propensity to patent. Section 3 presents the empirical model, the patent indicators and the explanatory variables. The empirical results are presented and interpreted in Section 4. Section 5 concludes and puts forward policy implications.

2. A missing link in the literature?

The estimated elasticity of patents with respect to R&D has been found to be large and significant in cross-sectional studies of firms, fluctuating around 1 (see Hall *et al.* 1986, Hausman *et al.* 1984, Jaffe 1986, Duguet and Kabla 1998, Crépon *et al.* 1998, Brouwer and Kleinknecht 1999 or Cincera 1997). Similarly large estimates of the elasticity of patents with respect to R&D are observed in cross-country or cross-region estimates (see for instance de Rassenfosse and van Pottelsberghe 2009 at the country level and Bottazzi and Peri 2003 at the regional level). When within-firm time-series data are used, the estimated parameters fall sharply and become less significant (see *e.g.* Hall *et al.* 1986, Hausman *et al.* 1984 or Czarnitzki *et al.* 2009). This low elasticity questions the relevance of patent measures as indicators of innovative output.

There are several possible reasons why the estimated R&D-patent elasticity is so weak when within-firms and/or time-series dimensions are taken into account. The first is that there are decreasing returns to research activities: the additional euro of research spent would be less “productive” than previous expenses. This explanation is problematic as it is not corroborated by the theoretical literature or by the existing evidence. The second potential explanation suggests that R&D indicators encompass much more than the very activity that consists in generating new ideas and inventions. In other words, R&D might not be a good indicator of innovative efforts. A third reason is related to the great randomness in the patent series, which greatly vary in their value, with most patents having low value and a few patents having very high value. Griliches (1990: p. 1678) clearly opts for the latter two hypotheses, arguing that “...the appearance of diminishing returns... could be an artefact of the incompleteness of the underlying data rather than a reflection of the characteristics of the innovation process itself.”

Industry level analyses lead to even less conclusive insights into the R&D-patent relationship. Cross-industry differences in the patent-to-R&D ratio do not correlate with their R&D intensity or their perception of the effectiveness of patents as a protection mechanism. For instance, some R&D-intensive industries that systematically rely on the patent system such as the pharmaceutical industry show low patent-to-R&D ratios. In other words, it suggests that patent metrics do not correlate well with innovative efforts across industries.

Scholars have long argued that patent counts reflect more the propensity to patent than innovative performance or research productivity. For instance, Scherer (1983, p. 116) explicitly assumes a constant productivity of research, for the sake of simplicity. While admitting the possibility of “differential creativity of an organization’s R&D scientists and engineers”, the author does not consider it important and chooses to concentrate on other “more systematic” factors. These more “systematic” factors which drive the patenting performance of firms are of two main types: strategic behaviour and alternative protection mechanisms.

Strategic patenting has been analyzed in-depth over the past 20 years (*e.g.* Teece 1998; Rivette and Kline 2000). Applying for a patent is indeed not always driven by the desire to protect innovation rents. Many facets of strategic patenting are listed in Guellec *et al.* (2007): Patents can be used as a tool for technological negotiations with competitors or with potential collaborators, to exclude rivals from a

Why is the R&D-elasticity of patents so low over time and across industries?

Patenting is only one way to appropriate the benefits from an invention and patents are used for other strategic purposes, too.

particular technological area, for communication purposes, to increase revenues through license agreements, to ensure freedom to operate and to attract capital. These strategic considerations all influence the observed patenting performance of firms. Patents are therefore not only an indicator of innovation output and technological success but also an indicator of strategic behaviour (see Blind *et al.* 2006; Cohen *et al.* 2000; de Rassenfosse and Guellec 2009 or Hall and Ziedonis 2001 for detailed investigations in this field).

The second reason that undermines the quality of patents as indicators of technological advance is embedded in the many alternative mechanisms of appropriation, such as secrecy, lead time, complementary sales and services, complementary manufacturing facilities, barriers to entry and the importance of tacit knowledge. Although all these mechanisms may coexist with patent protection, their availability might logically lower the need to rely on patent protection. According to the Carnegie Mellon Survey by Cohen *et al.* (2000) or the survey by Arundel and Kabla (1998), patents appear to be generally the last appropriability mechanism that is used, though its importance for some industries is noticeable, as reported in Table 1. This is particularly the case for medical equipment and drugs, special purpose machinery and computers. Secrecy and lead time are ranked overall as the two most effective appropriability mechanisms being top-ranked in 17 and 13 industries, respectively. Based on survey data of R&D executives in Switzerland, Harabi (1995) shows that the ability of competitors to “invent around” patents and the perception that patent documents disclose too much information are the most important factors that reduce the willingness to file patents.

Table 1. Share of product innovations that are patented (in percent)

	Arundel and Kabla (1998)	Cohen <i>et al.</i> (2000)
Mining	28	-
Food, beverages and tobacco	26	53
Textiles, clothing	8	43
Petroleum refining	23	73
Chemicals	57	77
Pharmaceuticals	79	74
Rubber and plastic products	34	65
Glass, clay, ceramics	29	50
Basic metals	15	54
Fabricated metal products	39	77
Machinery	52	74
Office and computing equipment	57	80
Electrical equipment	44	62
Communication equipment	47	59
Precision instruments	56	70
Automobiles	30	89
Other transport equipment	31	-
Power utilities	29	41
Transport and telecom services	20	-

Note: The industry classification corresponds to that presented in Arundel and Kabla (1998). The shares are rounded to the nearest integer.

In a nutshell, beside the innovation output that requires protection, the decision to file a patent is affected by alternative mechanisms of appropriation and by the strategic role that patents can play for a firm. These elements are typically industry-specific. It is striking that despite the many sources of variation and randomness in patent data, a strong increase in the use of patent-based indicators has been observed, including for economic and strategic analyses. The objective of this paper is to reconcile the *a priori* antagonism between the intensifying use of patent data and the pessimistic appraisal of these indicators in the academic literature. This reconciliation is done by identifying key milestones when dissecting the R&D-patent relationship.

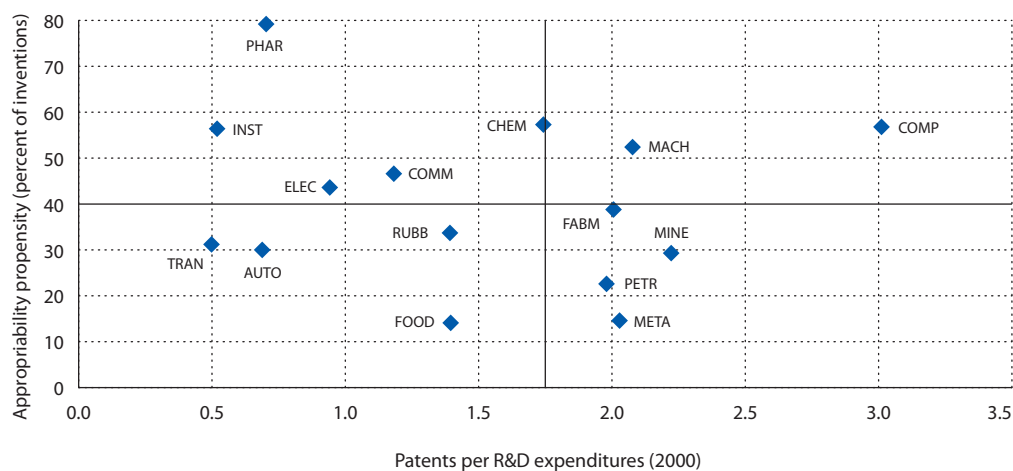
A first distinction can be made with respect to two important factors: research productivity and patent propensity. This distinction is investigated by de Rassenfosse and van Pottelsberghe (2009) who find that patent indicators reflect both research productivity and the propensity to patent. The authors exploit the cross-country variation in macroeconomic patent indicators for the year 2003. They relate the number of patents to total-economy R&D expenditure and to proxies for research productivity (e.g. the share of basic research in total R&D) and propensity to patent (e.g. the cost of filing a patent) and the strength of the patent system). Unlike the present study, however, de Rassenfosse and van Pottelsberghe (2009) have limited insights into cross-industry differences in the propensity to patent and do not investigate the time dimension, including the dynamic adjustment of patent outcomes to changes in research efforts.

The arguments made above as to why patent indicators are noisy, actually call for an additional distinction that should be made when conceptualising the R&D-patent relationship. The literature on this field has taken the implicit practice to define “patent propensity” in a (too) broad sense. We argue that it makes sense to split the propensity into two components: the “appropriability propensity” and the “strategic propensity”. The former captures the decision to protect an invention or not, and is proxied by the share of inventions that are patented, as reported in surveys like Levin *et al.* (1987), Cohen *et al.* (2000), or Arundel and Kabla (1998). The latter captures the patent-filing behaviour at a second stage. Once the decision is made to protect an invention, the applicant chooses the number of patents that are to be filed to protect it. These two dimensions surely affect the observed R&D-patent relationship. The failure to distinguish the appropriability propensity from the strategic propensity is probably what made Griliches claim that “the patent to R&D ratios appear to be dominated by what may be largely irrelevant fluctuations in the R&D numbers”. This paper argues – and provides empirical evidence of the claim – that taking into account these two dimensions provides a better understanding of the R&D-patent relationship.

‘Appropriability propensity’ refers to whether or not a firm opts for patenting at all, while ‘strategic propensity’ captures the behaviour at the filing stage.

Figure 2 illustrates somewhat the issue at stake. It depicts the appropriability propensity against the ratio of patents to R&D expenditure, with the former shown on the vertical axis and the latter on the horizontal axis. For instance, the instrument and the computer industries both have a high appropriability propensity but the latter has a much higher patent-to-R&D ratio than the former, probably due to a higher strategic propensity (patent thickets are known to be prevalent in this particular industry). Note that differences along the horizontal axis are probably not solely due to heterogeneous strategic propensities. The pharmaceutical industry has a very high appropriability propensity but a very low patent-to-R&D ratio due to the huge amount of R&D efforts devoted to a single invention. Similarly, the relatively low share of patented inventions in food and basic metals does not prevent these industries from having a relatively high number of patents per R&D. This should be borne in mind when interpreting statistics such as patents over R&D expenditures. The quantitative approach adopted in the next section aims at taking into account, and measuring, these three components of the R&D-patent relationship.

Figure 2. Appropriability propensity versus strategic propensity by industry



Source: Arundel and Kabla (1998) and own calculations
 Note: The horizontal axis corresponds to the ratio of priority filings to R&D expenditures (in million of USD PPP at constant prices).

3. Empirical framework

In analyzing the R&D-patent link, we take into account determinants of research productivity and determinants of the propensity to patent.

The aim of the empirical analysis is to investigate the link between R&D and patents at the industry level taking into account the factors that affect the propensity to patent and those that affect the productivity of research efforts. In an ideal set-up, one would be able to observe both the “raw” technology output (*i.e.* the number of inventions) and the number of patents. Yet, since the only observable measure of inventive output is the count of patents, one should be cautious in the interpretation of the parameters of the patent production function because differences in patent numbers reflect both productivity and propensity effects.

3.1 Estimation methodology

The dataset has three dimensions: time, industry and country. The estimations, however, are performed on two dimensions: the time period (*t*) and the country-industry pair (*ij*) – each “individual” is thus an industry in a country.² The patent production function is estimated in an error correction framework to differentiate short-run from long-run effects of the explanatory variables on the number of patents. More specifically, the following equation is estimated (see Box 1 for a detailed description of the model):

$$\Delta p_{ijt} = \psi_i + \psi_j + \psi_t + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha - (\lambda p_{ijt-1} - c - r_{ijt-1} \gamma - z_{ijt-1} \beta - x_{ijt-1} \alpha) + v_{ijt}$$

where *p* stands for the log of the number of patents, *r* is the log of the research efforts, *x* and *z* are vectors of variables capturing the productivity of research efforts (leading from research efforts to inventions) and the propensity to patent (leading from inventions to patents), respectively. Δ is the first difference operator, *v* is the error term, ψ_i is the vector of country dummies (*i*=1, ..., 19), ψ_j is the vector of industry dummies (*j*=1, ..., 18), and ψ_t is the vector of time dummies for the years 1987 to 2005 (*t*=1, ..., 19).

² An alternative approach would have been to estimate the parameters of a patent production function for each industry, thereby allowing for differentiated impacts across industries. The “pooled” approach is nevertheless chosen because it is based on a larger number of observations and provides averages across industries and countries. In addition, it is the very purpose of this paper to grasp cross-industry determinants of patent-to-R&D variations.

Note that since the dependent variable is the first difference of the log of patents ($\ln P_t - \ln P_{t-1}$), it is a rough approximation of the growth rate of patents.

The term in parentheses is usually referred to as the error correction term. It can be interpreted as the deviation from equilibrium in the previous period. The variables expressed in first difference (i.e. those preceded by the operator Δ) capture the short-term impact on the number of patents and indicate how a change in any explanatory variable contemporaneously affects the number of patents. The parameter λ usually fluctuates between 0 and 1 and measures the speed of adjustment to the long-term equilibrium (the closer to 1, the quicker the adjustment process). The long-run elasticities are calculated by dividing each parameter associated with the lagged variables by the adjustment parameter λ . For instance, the long-run elasticity of the productivity variable is equal to $-\alpha_j \cdot \lambda^{-1}$ (for a discussion, see Alogoskoufis and Smith 1991).

The growth-rate-of-patents equation is estimated with an error-correction model.

Box 1. Derivation of the estimation framework

Since research efforts (R) lead to inventions (I) which, in turn, may lead to patent applications (P), we can express the R&D-patent relationship for the N individuals in the sample as follows (forgetting momentarily the time dimension):

$$(B.1) \quad I = \Omega R^\gamma \quad \text{and} \quad P = \Phi I$$

where Ω and Φ are diagonal matrices of size N capturing the productivity and the propensity effects for each individual, respectively. In this framework, Φ captures both the appropriability propensity and the strategic propensity. The parameter γ is a scalar measuring the average return to R&D across individuals.¹ Φ can be expressed as a function of the two propensity components (the appropriability propensity and the strategic propensity) but this would unnecessarily clutter the notation. If we let X and Z , respectively denote the matrices of variables that affect Ω and Φ , and α and β the column vectors of parameters, we can write:

$$(B.2) \quad i = c_1 + x\alpha + r\gamma \quad \text{and} \quad p = c_2 + z\beta + i$$

where lower-case roman letters denote the log of the variables. Expanding the patent production function gives:

$$(B.3) \quad p = c + r\gamma + z\beta + x\alpha$$

where c equals $c_1 + c_2$ and is a scale parameter capturing the rate at which research efforts lead to patent applications (c_1 reflects the average productivity of research across individuals and c_2 the average propensity to file patents). It is well documented in the literature (see references in the introduction and in Section 2) that the propensity to patent has most probably constantly increased since the eighties, due to an unobservable greater reliance on the patent system for various "strategic" reasons, i.e., c_2 might have increased over time, even when accounting for the observable characteristics Z . In a similar vein, the productivity of research has also probably improved over the years (Kortum and Lerner 1999). Therefore, the extent to which the scale variable c would capture an average growth rate of the productivity of research or of the two propensity effects is unclear. It actually depends on the proxies for research productivity and the propensity to patent, respectively. As the variables used in the empirical analysis tend to better capture cross-industry and cross-country variations in the productivity of research, there are more reasons to suspect that unobserved changes are due to variation in the propensity to

1 The expression R^γ indicates that each of the N elements r_i of R is taken to the power of γ .

patent rather than in the productivity of research. It is therefore likely that the dummies would be more reflective of a change in propensity than a change in productivity. The patent production function for a given industry-country pair in a single point in time (ijt) to be estimated empirically can be written as:

$$(B.4) \quad p_{ijt} = c_{ijt} + r_{ijt} \gamma + z_{ijt} \beta + x_{ijt} \alpha + \varepsilon_{ijt}$$

where ε_{ijt} is the error term. It is good practice to estimate panel data in first-difference to avoid potential spurious-regression problems. Letting “ Δ ” denote the first-difference operator, we can write:

$$(B.5) \quad \Delta p_{ijt} = \Delta c_{ijt} + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha + \Delta \varepsilon_{ijt}$$

Assuming that c_i is constant,

$$(B.6) \quad \Delta c_{ijt} = c_{ijt} - c_{ijt-1} = (c_{1,ijt} + c_{2,ijt}) - (c_{1,ijt-1} + c_{2,ijt-1}) \approx \Delta c_{2,ijt}$$

such that we can write

$$(B.7) \quad \Delta p_{ijt} = \Delta c_{2,ijt} + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha + u_{ijt}$$

with $u_{ijt} = \Delta \varepsilon_{ijt}$. Since the variables are expressed in logs, Equation (B.7) is an approximation of the growth rate of patenting. The term $\Delta c_{2,ijt}$ is the growth rate of the propensity to patent that is not accounted for by the explanatory variables. Equation (B.7) implies that a change in any of the explanatory variable has a contemporaneous impact on the number of patents applied for. In other words, the parameters of the first-differenced variables capture the short term elasticities.

However, past R&D expenditures might also influence current patenting activity because research projects usually require quite some time before leading to a patentable invention. In order to account for a gradual adjustment, the patent production function is estimated by means of an error correction model (ECM) with a one-year lag structure. The choice of a one-year lag is motivated by de Rassenfosse and Guellec (2009) and Hall *et al.* (1986). Using firm-level survey data, de Rassenfosse and Guellec (2009) notice that the lag between initial R&D expenditures and patent applications is of the order of one year, even though it can reach as much as five years. Hall *et al.* (1986) estimate several panel data models at the microeconomic level and obtain a strong contemporaneous relationship between R&D expenditures and patenting, and a small effect of R&D history on patent applications. This is consistent with the practice of filing patents early enough in the life of a research project.

ECMs allow estimating both the short-run and the long-run impacts that exist between the endogenous and the exogenous variables. It consists in estimating the model in first difference together with previous year's deviation from equilibrium (in brackets), leading to the equation given in the main text.

$$(B.8) \quad \Delta p_{ijt} = \psi_i + \psi_j + \psi_t + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha - (\lambda p_{ijt-1} - c - r_{ijt-1} \gamma - z_{ijt-1} \beta - x_{ijt-1} \alpha) + v_{ijt}$$

Finally, remember that the individual is defined as a country-industry pair. The term $\Delta c_{2,ijt}$ of Equation (B.7) can be decomposed into a fixed country effect (ψ_i), a fixed industry effect (ψ_j) and with a common time-effect (ψ_t).

3.2 The dependent variable: patent indicators

There are many different ways of counting patents.

There exist many ways to count patents, each carrying its own meaning (see *e.g.* Dernis *et al.* 2001 and OECD 2009). It is therefore particularly important to carefully select the patent indicator that will be used to monitor countries' innovation performance so as to reduce the potential biases as much as possible. For this reason, five alternative indicators are used in the empirical analysis in order to gauge

the robustness of the results to the chosen dependent variable. These indicators are the number of national priority filings, the number of patents filed at the EPO, the number of patents filed at the USPTO, a measure combining EPO and USPTO patents, and the number of patents filed simultaneously in Japan, the US and Europe. Whereas the first indicator is composed of many patents with a much skewed distribution of value, the triadic filings are less numerous but are supposed to be of a much higher economic value. Figure 3 illustrates some of the differences between these indicators.

The patent indicators are computed from the OECD-EPO PATSTAT database (April 2009) for each manufacturing industry, following the International Standard Industry Classification scheme (ISIC, Revision 3) as indicated in Table A1 of Annex 1. Patents, however, are not characterised by the ISIC scheme, but rather by the codes of the International Patent Classification (IPC), representing different areas of technology to which they pertain. Patents have therefore been assigned to the appropriate industries using the concordance table between IPC and ISIC codes provided by Schmoch *et al.* (2003) who have estimated the empirical concordance table by investigating the patenting activity by technology-based fields (IPC) of more than 3,000 firms classified by industrial sector (ISIC). When a patent contains more than one IPC code, the industry allocation is performed on a fractional basis.³

The first indicator is the corrected count of national priority filings (NPF CORR) recently introduced by de Rassenfosse *et al.* (2009). It captures all the patents filed by the inventors based in a country, regardless of the patent office of application. The count for, say, Austria is thus equal to the number of priority filings by Austrian inventors filed at the Austrian patent office plus the priority filings from Austrian inventors directly filed at other patent offices such as the EPO, the USPTO or the German patent office.⁴ The inclusion of these priority filings abroad allows reducing the bias against small countries such as Belgium and the Netherlands which file a higher share of their patents abroad as compared with, say, France and Germany. This indicator is a very broad measure of patenting, encompassing both low-value and high-value patents. It is biased in favour of Japan and South Korea, with the share of these countries in the total of national priority filings being much higher than their share in R&D expenditures (see Figure 3). This is due to the large differences in patent systems, particularly in South Korea and Japan, where patents are much smaller but more numerous (see de Rassenfosse and van Pottelsberghe 2008). For this reason, the count for Japanese and Korean priority filings has been divided by three (for a discussion, see Kotabe 1992 and Archontopoulos *et al.* 2007).

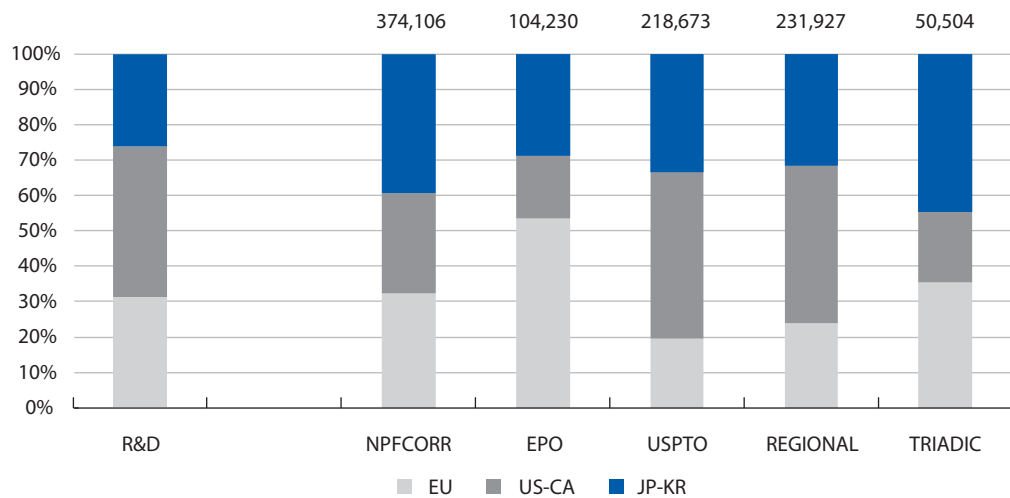
We use a corrected measure of national priority filings, applications filed at the EPO, ...

The second indicator is the count of patent applications filed at the EPO. It is composed of the patents that were filed directly at the EPO or that were later extended to the EPO as second filings. As the patenting procedure at the EPO is expensive, EPO patents are supposedly of a higher value. This indicator is nevertheless biased for two main reasons. The first is related to the home bias, which is well illustrated in Figure 3, whereby companies in Europe tend to rely more heavily on the EPO than companies from non-European countries. Second, the reliance on the EPO has increased over time, for all countries and especially European ones. De Rassenfosse and van Pottelsberghe (2007) show that a systematic bias in statistics based on European patents must be acknowledged: the share of priority filings transferred to the EPO is increasing with the age of membership to the European Patent Convention. This calls for a cautious interpretation of the evolution of the number of EPO patents over time.

3 Some patents had no IPC codes, and some IPC codes were not in the concordance table. All these “unassigned” patents were allocated to the industries according to the observed share of successfully allocated patents.

4 The nationality of filings was identified by the country of residence of inventors so as to capture all the inventive output in a given country. That is, a patent from Austrian inventors is considered as an Austrian application even if it is filed by a US assignee (or patentee). This methodology assures the best match between R&D expenditures and patent applications.

Figure 3. Research effort and patenting activity, 2004



Source: Own calculations. See Table A.1 for more details

...patents granted at the US patent office, a mixed EPO-USPTO measure and the count of triadic patent families.

The third indicator is similar to the second, except that the patent office of reference is the USPTO and that statistics are available for granted patents only. Given that a large number of countries in the sample are European countries, this indicator probably reflects the value of patents better (a European applicant will file more easily at the EPO than at the USPTO, and will seek for a US patent only for the most valuable inventions).⁵ However, this indicator is subject to an important, and logical, home bias for North American applicants (see Figure 3).

The fourth indicator (REGIONAL) is a mix between EPO and USPTO patents. Since European applicants have a higher tendency to file at the EPO and other countries preferably file at the USPTO, the indicator is composed of EPO patents for European countries and USPTO patents for other countries. The approach mitigates the home biases characterising the EPO and the USPTO indicators, with a geographical distribution that is closer to the distribution of research efforts.

The count of triadic patent families is the fifth indicator (TRIADIC). It was developed a decade ago by the OECD to select patents of a high quality standard that were comparable across countries. According to the OECD definition, the triadic patent family is defined as a set of patent applications filed simultaneously at the EPO, the JPO, and granted by the USPTO, sharing one or more priority applications (OECD 2009a, p 71). The indicator is more robust to differences in patent regulations across countries and changes in patent laws over time. Triadic patents are of high value given the high cost incurred with patent applications in the three patent offices. On average, only between 10 and 15 percent of priority filings ultimately become triadic patents. The 19 countries included in the sample have a total of 374,106 priority filings in 2004 for 50,504 triadic patent applications. The absolute count of patents and the relative shares is presented in Tables A2 and A3 of Annex 1 for countries and industries, respectively.

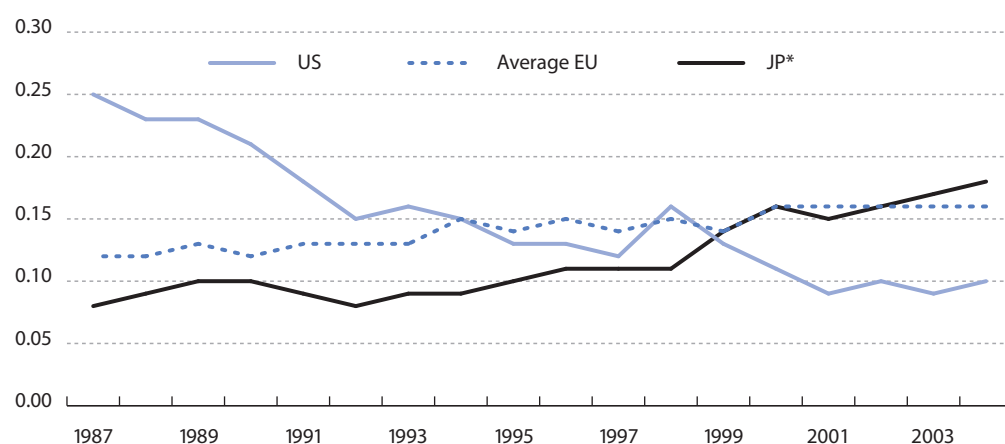
Figure 4 represents the share of priority filings that eventually became triadic patents. De Rassenfossé and van Pottelsberghe (2009) have shown that triadic patents are a good measure of research productivity and are more suited than priority filings to capture the quality of research efforts. Yet, an increase in the share of triadic patents over time does not necessarily reflect an increase in patent quality, as other factors such as the internationalisation of economic activity and a higher familiarity

⁵ To mitigate the effect of the grant lag on US patent statistics, which was especially strong in 2004 and 2005, the data are adjusted for each country-industry pair using the ratio of EPO patents to US patents for the year 2003.

with international patenting procedures possibly play a role, too. The figure shows that the share of triadic patents has been slightly increasing in Europe and Japan and decreasing in the US. The increase in Europe and Japan could be more due to a higher tendency of applicants to seek protection in foreign markets than to an increase in the average value of inventions. As for the US, it is likely that the drop in the share of triadic patents is due to a strong increase in the number of priority filings that did not lead to many triadic patent applications. According to van Pottelsberghe (2009) this is due to the very low cost of patenting in the US and a weak rigour of the examination process. Cheap patents facing a soft examination practice would logically lead to a high propensity to file low value patents, which are not later translated into triadic applications.

Triadic patents tell more about research productivity than other patent counts but their faster increase also reflects the internationalization of production.

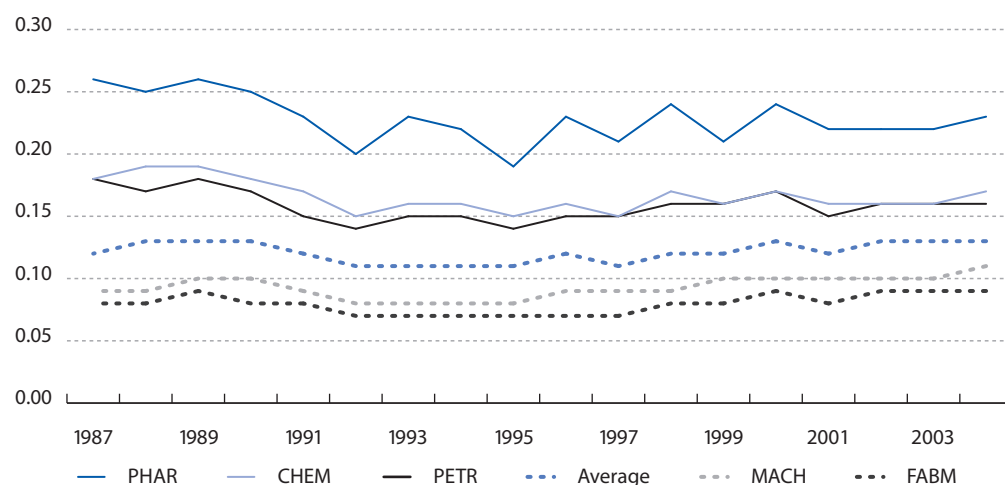
Figure 4. Share of triadic patents in total priority filings, in Europe, Japan and the USA



Source: Own calculations

Figure 5 depicts the evolution over time of the share of triadic patents for a selected number of industries. On average, 10 to 15 percent of priority filings are extended in the Triad, but some industries, in particular the pharmaceutical industry have a much higher share of triadic patents. This figure should be contrasted with the low ranking achieved by the pharmaceutical industry in Figure 2. This industry typically produces a low number of patents per unit of R&D, but these patents are of a relatively high value.

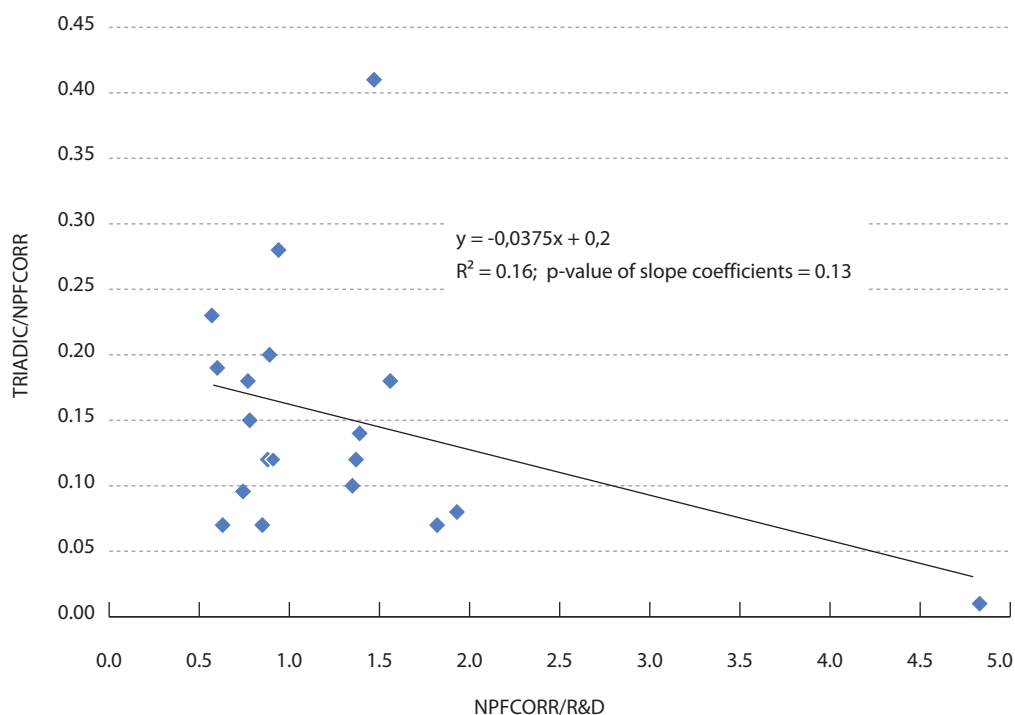
Figure 5. Share of triadic patents in total priority filings, in Europe, Japan and the USA



Source: Own calculations

To test whether a high propensity to patent is associated with a lower quality per patent, Figure 6 presents the share of triadic filings in total priority filings by country as a function of the number of priority filings per million dollars invested in R&D. There is a clear negative relationship, indicating that countries with a high propensity to patent have portfolios that are of lower average quality or economic value.

Figure 6. Quality of applications versus propensity to file, by country, (2004)



Source: Own calculations

3.3 Explanatory variables

The key explanatory variable is R&D expenditure as a measure of an industry's research efforts.

The most important explanatory variable is R&D expenditures by industry ("R&D") as a measure of the industry's research efforts. It is taken from the OECD's ANBERD database (2009), and is expressed in constant US dollars (USD) at purchasing power parity (PPP). The estimated patent elasticity with respect to R&D provides an incomplete evaluation of the research productivity. A more complete picture would be easy to draw if inventions (not patents) could be measured with accuracy and if the two types of propensity to patent were properly measured across countries and over time. Since there is no such indicator, an indirect approach such as the one developed by de Rassenfosse and van Pottelsberghe (2009) is needed. It consists in finding variables that arguably reflect (or induce) differences in the productivity of research activities and variables that arguably affect the propensity to patent.

Finding potential explanatory variables affecting the propensity and the productivity components for a large group of countries, varying over industries and available over a long period is a challenging task. Three candidates that could affect the productivity of research and two potentially affecting the propensity to patent are identified. Some vary over time and across countries and industries whereas some others vary only across countries or industries, as indicated in Table 2.

Table 2. Overview of the explanatory variables

	Component		Variation			Number of observations
	<i>Propensity (z)</i>	<i>Productivity (x)</i>	<i>Country</i>	<i>Industry</i>	<i>Year</i>	
R&D			x	x	x	4937
APPROPRIABILITY	x			x		4131
IP INDEX	x		x		x	4937
INTL COMP		x		x	x	4451
SHARE BASIC		x	x		x	1811
SHARE HIGHER EDU		x	x		x	4353

Source: OECD STAN R&D Expenditure in Industry (ISIC Rev. 3) ANBERD ed2009 for R&D; Arundel and Kabla (1998) for APPROPRIABILITY; Park (2008) for IP INDEX, with yearly data computed on the basis of a compound annual growth rate two available data points; OECD (2009b) for INTL COMP; and OECD (2009a) for SHARE BASIC and SHARE HIGHER EDU

The three variables that are supposed to affect – or correlate with – research productivity are defined and measured as follows. The variable “SHARE BASIC” is the basic-research expenditure as a percentage of gross domestic expenditure on R&D (OECD 2009a). The variable is expected to lead to a greater productivity of research efforts as basic research typically pushes forward the knowledge frontier and generates new opportunities for further development. The second productivity variable is “SHARE HIGHER EDU.” It is defined as the percentage of gross domestic expenditure on R&D performed by the higher education sector (OECD 2009a). The expected impact on the number of patents is mixed. On the one hand, the higher education sector develops and uses frontier knowledge that companies can use, suggesting a positive relationship. On the other hand, the propensity to patent is lower among universities, such that a negative impact is possible, too. The third productivity variable is “INTL COMP” and captures an industry’s exposure to international trade. It is defined for each country-industry pair as the ratio of net exports to the sum of imports and exports (OECD 2009b). The higher the variable, the more the industry exports in comparison to its imports, hence the more it is internationally competitive. A positive impact is expected as internationally competitive industries must be innovative in terms of new product performance or reduced production costs. In analyzing the determinants of patenting across a set of OECD countries, Furman *et al.* (2002, p. 899) find that “an extremely important role is played by factors associated with differences in R&D productivity [such as] openness to international trade.”

Two proxies are available for the propensity effects. As for the strategic propensity, the variable “IP INDEX” is a measure of the strength of the intellectual property (IP) system at the country level developed by Ginarte and Park (1997). We expect countries with a stronger IP regime to have a higher strategic propensity to patent as a strong protection increases the value of patent rights. This is an imperfect proxy however, as it is only published every five years.⁶ The second variable, “APPROPRIABILITY”, captures the appropriability propensity and is based on Arundel and Kabla (1998) who have surveyed the share of innovations that were patented in the French manufacturing industry. This observation allows reducing the noise in the R&D-patent relationship by directly correcting for a fundamental link between inventions and patents. This data source is preferred over others because it is the closest to the industry classification of the ANBERD database.

⁶ We compute annual data on the basis of the compound annual growth rate.

The shares of basic and/or university research and international competitiveness matter for research productivity.

It is worth mentioning that those variables that supposedly influence (or correlate with) the productivity of research are more diverse and comprehensive than the propensity variables: the exposure-to-trade variable varies across countries, industries and over time and the other two variables vary over time and across countries). By contrast, the proxy for the appropriability propensity varies only across industries, while the proxy for the strategic propensity varies essentially across countries and slightly over time. It is therefore fair to assume that the fixed effects in the regression mainly capture changes in the propensity to patent across the various dimensions of the panel (industry, country and time).

4. Empirical results

The empirical results are analyzed and interpreted in three main stages. First, the basic R&D-patent model is estimated with the alternative patent indicators. Then the productivity and propensity variables are added simultaneously to the model. The third stage consists in analyzing the various sets of dummies (industry, country and time), as they witness the remaining “dynamic” propensity to patent.

4.1. The basic R&D-patent model

The estimated parameters of the error correction model described in Equation (B.8) are presented in Table 3 for the five patent indicators. The only explanatory variable taken into account is R&D expenditure.

Table 3. Results of the error-correction model of the R&D-patent relationship

	NPFCORR	TRIADIC	EPO	USPTO	REGIONAL
$\Delta \log(\#patents)$	(1)	(2)	(3)	(4)	(5)
$\Delta \log(R\&D)$	0.009 (0.007)	0.013 (0.015)	0.009 (0.009)	-0.013 (0.010)	0.014 (0.009)
$\log(\#patents) (t-1)$	-0.119*** (0.007)	-0.290*** (0.010)	-0.155*** (0.008)	-0.145*** (0.008)	-0.149*** (0.008)
$\log(R\&D) (t-1)$	0.014*** (0.002)	0.032*** (0.005)	0.018*** (0.003)	0.017*** (0.003)	0.019*** (0.003)
Country dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Number of observations	4943	4943	4943	4943	4943
Adjusted R-squared	0.197	0.187	0.156	0.171	0.129
Long-run impact of R&D	0.118	0.110	0.116	0.123	0.128

Notes: Standard errors in parentheses; ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. The rows “country dummies”, “industry dummies” and “time dummies” report the significance level of the joint effect of these dummies. The long-run impact of R&D is computed by dividing the coefficient of $\log(R\&D) (t-1)$ by the coefficient of $\log(\#patents) (t-1)$.

On average, a 10-percent increase in R&D expenditure leads to a 1.2-percent increase in patent applications.

The short-term elasticity is not significantly different from zero (see the coefficient of $\Delta \log(R\&D)$). This result confirms that patents are a poor indicator of short-term changes in the output of inventive activity. The long-term elasticity of R&D fluctuates around 0.12, regardless of the patent indicator that is used. In other words, a 10-percent increase in R&D outlays leads to a 1.2-percent increase in patent applications, on average. These point estimates are strikingly low but compatible with estimates performed with firm-level panel data sets. The adjustment parameter λ (coefficient of variable $\log(\#patents)$) is lowest for priority filings and highest for triadic patents indicating greater inertia of

priority filings. In other words, the R&D history matters more for priority filings whereas changes in R&D expenditures have a faster impact on triadic patents.

Depending on the patent indicator that is used, R&D expenditures and the three sets of dummy variables explain between 13 and 20 percent of the growth in patent applications. The best fits are achieved with priority filings and triadic patents, *i.e.* the patent indicators that are at the opposite ends on the average-value scale: for these specifications the adjusted R-squared is 20 percent. This explanatory power is quite satisfactory given the nature of the data and the simplicity of the patent production function considered. Country, industry and time effects are all jointly significant. They are described and analyzed at the end of this section. Note that tests for autocorrelation of residuals reject the presence of correlated errors.⁷

4.2. Productivity

The low estimated elasticity of patents with respect to R&D raises the question whether other factors may help to explain industry or country variations in patent applications. This issue is investigated in Table 4 where the productivity and the two propensity components are jointly included in the model. The estimations are presented only with indicators NPFCORR, the TRIADIC and the REGIONAL as dependent variables. Regressions based on EPO and USPTO lead to similar results.

Given this low R&D-elasticity, what else drives variations in patent applications?

Table 4. Results of the full error-correction model

$\Delta \log(\#patents)$	NPFCORR	TRIADIC	REGIONAL
	(1)	(2)	(3)
APPROPRIABILITY	0.004*** (0.000)	0.012*** (0.001)	0.005*** (0.000)
IP INDEX	0.031** (0.012)	0.053** (0.023)	0.073*** (0.015)
$\Delta \log(R\&D)$	-0.003 (0.008)	-0.010 (0.016)	-0.008 (0.010)
Δ INTL COMP	-0.002 (0.016)	0.098*** (0.030)	0.052*** (0.019)
Δ SHARE HIGHER EDU	-0.010*** (0.002)	-0.002 (0.004)	-0.008*** (0.002)
$\log(\#patents)$ (t-1)	-0.142*** (0.008)	-0.279*** (0.012)	-0.137*** (0.009)
$\log(R\&D)$ (t-1)	0.014*** (0.003)	0.013** (0.006)	0.007* (0.004)
INTL COMP (t-1)	0.028*** (0.009)	0.100*** (0.017)	0.056*** (0.011)
SHARE HIGHER EDU (t-1)	0.0002 (0.001)	-0.002 (0.002)	0.005*** (0.001)
Countries dummies	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***
Number of observations	3696	3696	3696
Adjusted R-Square	0.237	0.190	0.140

Notes: Standard errors in parentheses; ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. Each of the rows "country dummies", "industry dummies" and "time dummies" report the significance level of the joint effect of the respective dummies.

⁷ Tests for autocorrelation are available upon request from the authors.

Three indicators likely to affect (or to be correlated with) research productivity are used. They include the share of higher education in total R&D expenditure, the share of basic research in total R&D expenditure and an indicator of international competitiveness. The first two indicators are not perfect because they only vary across countries and over time but not across industries. The third fluctuates in the three dimensions. The impact of the share of total R&D performed by the higher education sector (SHARE HIGHER EDU) has a positive and significant impact on the regional patent indicator only, suggesting that university-performed R&D leads to more valuable patents in the long-run. The negative short-term impact of this variable is probably due to a transitional effect caused by the diversion of resources towards less patent-minded entities. It can also be explained by longer delays in the R&D process at universities as compared with the private sector. In any case, it suggests that allocating more resources to academic research is a long-term policy aimed at securing the seeds of future innovations.

The share of basic research, an indicator of potential breakthrough inventions, is tested separately. It is not included in the main specification due to a much smaller number of data points available. The results are presented in Table A4 of Annex 1. The share of basic research has a strong productivity effect on all patent indicators, with a long-term premium of about 11 percent. In other words, the higher the share of basic research in total R&D expenditures, the higher the number of patent applications induced by an increase in the productivity of research efforts.

The exposure to international trade (INTL COMP) has a positive and significant impact on the number of patent filings, both in the short run and in the long run. This result confirms the impact on research productivity that Furman *et al.* (2002) obtain with their variable OPENNESS. Note that the effect is twice as high with international patents as with priority filings.

4.3. Propensities

The number of patents tends to be higher in countries with stringent IP protection and in industries with high appropriability propensity.

The distinction between appropriability and strategic propensities put forward in the present paper is not easy to implement empirically. The two proxies that are used to gauge these propensities are imperfect measures because they only vary across countries or across industries and are quite stable over time. Still, the appropriability propensity variable (APPROPRIABILITY) is highly significant and confirms the relevance of using information on the share of inventions that are patented in order to better understand how an increase in R&D efforts would translate into more patents. This is evidence of the key role of the appropriability propensity in the R&D-patent relationship.

The variable that aims at capturing some facets of the strategic propensity is the strength of the patent system (IP-INDEX). It turns out to be a significant determinant of the number of patents. Countries with a higher IP-INDEX are also likely to have more patent filings per unit of R&D effort. For instance, the US has a very high index because there are many patentable subject matters (as opposed to Europe where many restrictions apply) and because the enforcement system is well developed and historically supporting patented inventions.

This propensity variable is only one factor influencing the strategic propensity to patent. Despite its significant impact, which validates the intuition expressed in this paper, we recognise that “strategic propensity” is imperfectly measured since no indicator with cross-industry variations is available to the best of our knowledge. A similar criticism can be made on the appropriability variable.

4.4. Remaining “dynamic” propensity

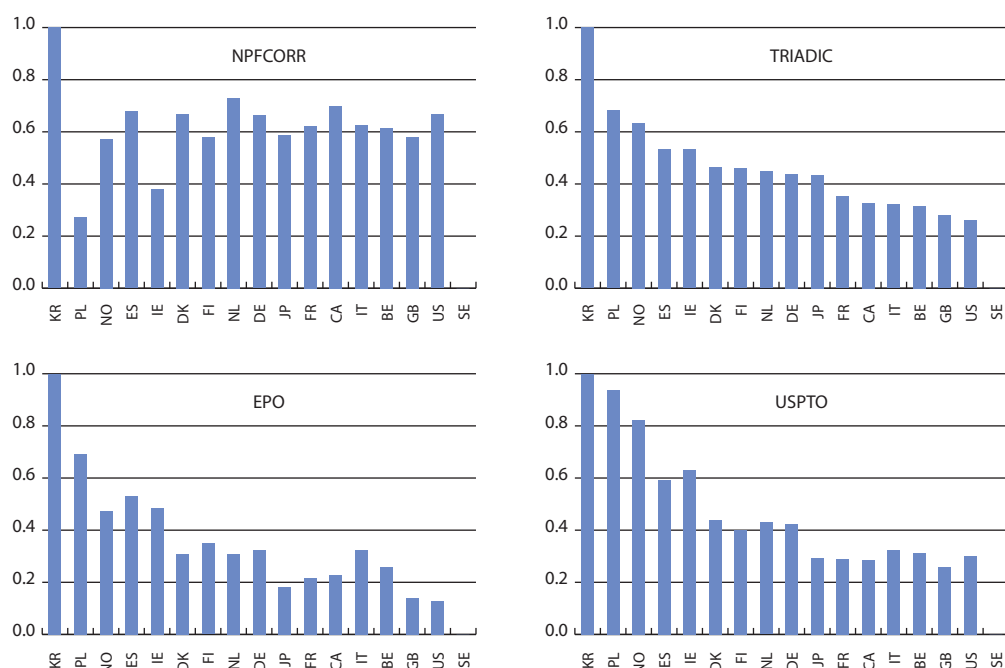
The country, industry and time effects from the full model can be used to assess the average evolution of the propensity to patent along the three dimensions (see Annex 2 for methodological details). Since

the model explains the growth rate of patent filings, the control dummies capture the increase in the propensity to patent – or the “dynamic” propensity – net of the impact of all other observable characteristics. The fixed effects probably capture unobserved changes in productivity and in the two measures of propensity. But since the R&D productivity component is definitely better measured than the two propensity components, it is fair to assume that the fixed effects capture more the propensity than the productivity components.

The remaining propensity to patent is dissected into its country, industry and time dimensions.

Figure 7 shows the normalized coefficients of the country dummies. The rankings for the international indicators (TRIADIC, EPO and USPTO) are roughly similar and clearly underline a strong catching-up effect for South Korea, Poland, Norway and Spain. Countries such as France, Canada, Great Britain and the US rank last on triadic and regional patent statistics (EPO and USPTO), suggesting that they have lost some ground in their patenting performance as measured by international indicators.

Figure 7. Dynamic propensity to patent across countries

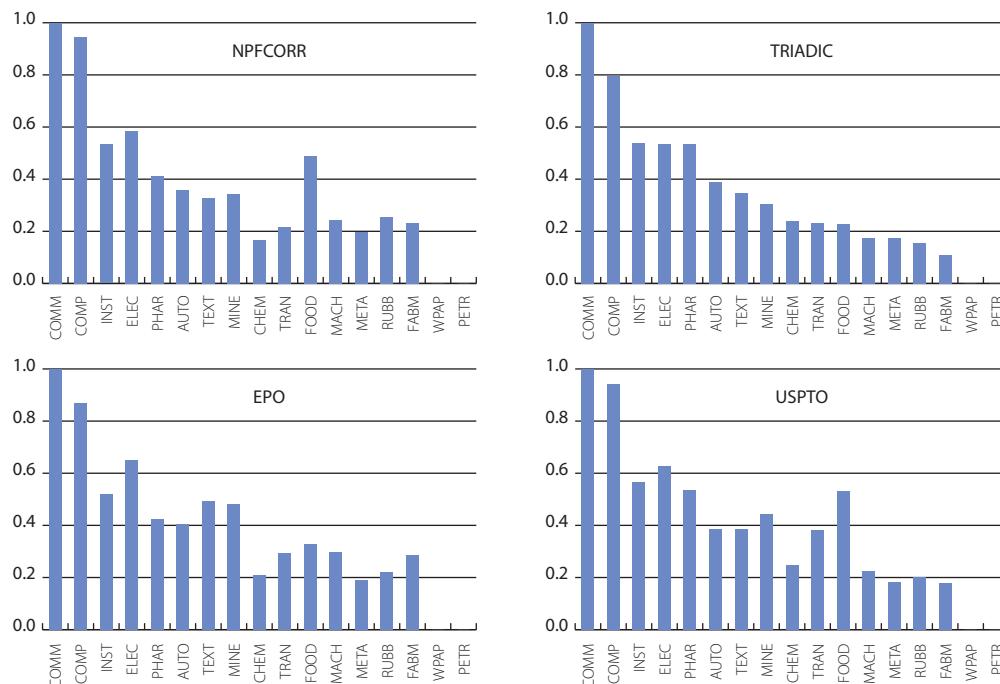


Source: Own calculations

Note: The values are coefficients of country dummies taken from the full model and are normalized from 0 to 1. They are interpreted as normalized dynamic propensity to patent. See Annex 2 for details.

The change in the propensity to patent varies as well across manufacturing industries, and to a significant extent, as illustrated in Figure 8. The industries including communication, computers and instruments are associated with the strongest increase in the propensity to patent whereas fabricated metals or rubber and plastics products had the lowest increase. There is a clear ICT (information and communication technologies) effect here. The industries in this area already scored high in at least one of the two propensity components (see Figure 2), and they have apparently further increased their willingness to patent. This observation is true for all patent indicators. Contrary to the country dummies, which illustrate a catching-up effect from newcomers, the industry dummies seem to reinforce the trends towards a higher propensity to patent. As we control for the industry-specific appropriability propensity, this effect is most probably due to a sharp increase in the strategic propensity to patent in the two industries.

Figure 8. Dynamic propensity to patent across industries

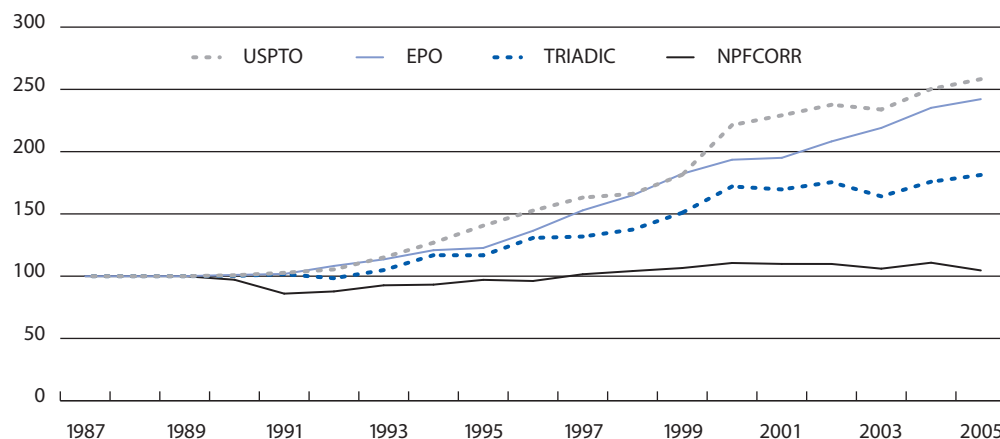


Source: Own calculations
 Note: The values are coefficients of industry dummies taken from the full model and are normalized from 0 to 1. They are interpreted as normalized dynamic propensity to patent. See Annex 2 for details.

The global 'patent warming' is mainly due to companies' willingness to extend patent protection to foreign markets.

Finally, Figure 9 depicts the evolution of the propensity to patent over time for the principal patent indicators. The most striking observation is that the propensity to file priority filings has been roughly constant over time whereas the propensity to file international/regional applications has steadily increased. Taken together, these trends lead to the conclusion that there has been no particular "burst" in the underlying inventiveness (beyond the increase in R&D efforts and beyond the improvement in research productivity measured in the empirical analysis) and that the "patent warming" observed at major patent offices is mostly due to a globalization effect: companies do not file particularly more patents, but have a higher willingness to extend them abroad. The USPTO (and to a lesser extent the EPO) is particularly intensely targeted in this respect.

Figure 9. Evolution of the propensity to patent over time



Source: Own calculations (see Annex 2 for details)

5. Concluding remarks and policy implications

The literature on the R&D-patent relationship reports a weak correlation between R&D efforts and patents in two main configurations: time-series analyses and cross-industry investigations. This weakness has not reduced the emerging hype towards the use of patent statistics for many purposes, including economic research on technological progress and knowledge diffusion. The objective of this paper is to provide further conceptual and empirical insights into the apparent failure to find a strong relationship between R&D efforts and patent applications. The empirical investigation relies on a unique panel data set composed of 18 manufacturing industries in 19 countries over the period 1987 to 2005, for which three broad patent indicators are developed. Six main methodological and policy implications summarize the main contributions of this paper.

The first is conceptual. The literature has implicitly or explicitly assumed that the patent-to-R&D ratio is driven by a research productivity stage (the extent to which additional units of R&D generate additional inventions) and a propensity-to-patent stage. This paper claims that in order to better understand how an increase in R&D expenditure translates into patent applications, the propensity to patent must be split into two main components: the “appropriability propensity” which indicates whether or not an invention is protected with patents; and the “strategic propensity” which measures the number of patents used to protect the invention. While the former component can be proxied by existing survey data on the share of inventions that are patented (e.g. Arundel and Kabla 1998) in each industrial sector, the latter can so far be gauged only with quantitative analysis. This theoretical insight has a major implication: Large-scale surveys like the Community Innovation Survey in Europe should regularly assess the two propensity components for many countries. Data on the evolution of the share of inventions that are patented as well as on the average number of patents used to protect an invention would drastically improve our understanding of the R&D-patent relationship. So far only single-country information is available for a given year or period.

Second, the econometric results based on the cross-industry, cross-country and time series dataset confirm that the patent elasticity with respect to R&D is positive and significant but small. It fluctuates around 12 percent and is very robust to the patent indicator used as dependent variable (national priority filings *versus* the more restrictive and valuable triadic patents). R&D and the various fixed effects (country, industry and time dummies) explain about 20 percent of the variance in the growth rate of patents. The results therefore confirm the existing dynamic time series estimates at the microeconomic level: The elasticity is much smaller than “hoped” for (Griliches 1990) and captures only a small share of the patent variance, which is arguably due to two important missing links unrelated to the productivity of research, namely appropriability and strategic propensities.

Third, the empirical analysis confirms that a significant productivity effect takes place and does explain part of the variations in the R&D-patent ratio, as witnessed by the positive and significant premium associated with basic research and academic research, or by the noticeable impact of the international-competitiveness variable, an indicator of ultimate innovation performance. The positive impact of basic and academic research suggests that allocating more resources to university-performed research and to basic projects is a long-term policy aimed at securing the seeds of future innovations.

Fourth, the empirical results lead to the conclusion that the appropriability propensity plays a positive and highly significant role in the patent production function, despite the fact that its measure only varies across industries. The implicit assumption that it is similar across countries and does not vary over time is probably too strong, but there is no convincing alternative to the best of our knowledge. The strategic propensity to patent is measured by one variable supposed to affect it, the strength of the patent system in the inventor country. This variable has a positive and significant impact on the propensity to patent, but probably only partially captures the strategic propensity to patent.

The number of patents depends on R&D efforts, research productivity, the wish to appropriate inventions and on strategic behaviour.

Fifth, the country and industry dummies allow to identify in some depth the origins of the increase in the propensity to file patents. This “dynamic propensity” is logically composed of an appropriability component and a strategic component. Two manufacturing industries, which were already characterized by a high patent-to-R&D ratio, communications and computers, turn out to be associated with the sharpest increase in the propensity to patent. This is precisely the technological area where a patent “paradox” was identified by Hall and Ziedonis (2001). In this respect our result shed some additional light on the R&D-patent relationship and its industry dimension. The pharmaceutical industry has a high appropriability propensity but is not associated with a particularly strong increase in its propensity to patent. The countries that are associated with the sharpest increase in their propensity to patent are South Korea, Poland and Spain, which witnesses a clear catching up effect. These results exemplify the pitfalls and advantages associated with patent data. Whereas they witness fundamental economic changes such as catching-up effects, they are also greatly impacted by nations’ industrial structure, hence the need to improve our understanding of the “propensity” components.

The global ‘patent warming’ would justify stronger coordination of national/regional patent offices if their views on patent system design converged.

Finally, the time dummies provide a broad measure of the dynamic increase in patent propensity, net of country and industry specificities, and of R&D expenditure. Here the results depend on the patent indicators that are used. The sharpest increases are associated with regional patent offices (EPO and USPTO) followed by triadic applications. As far as national priority filings are concerned, hardly any increase in the unaccounted propensity to patent is observed. In other words, the “global patent warming” that is currently taking place is essentially the result of a stronger internationalization of national patent applications, and not a consequence of increased propensity to rely on patent systems with national priority applications. Innovating firms are increasingly targeting global markets and hence have a higher tendency to seek for protection in regional patent offices, world-wide. This tendency would justify a stronger coordination of patent offices at the global level, provided their views of how a patent system should be designed converge noticeably, as suggested in van Pottelsberghe (2009).

Annex 1. Additional background tables

Table A1. Abbreviations of countries and industries

Abbr.	Country	Abbr.	ISIC Rev.3	Industry definition	Technological classification*
AT	Austria	FOOD	15-16	Manufacture of food products, beverages and tobacco products	LOTE
BE	Belgium	TEXT	17-19	Manufacture of textiles, wearing apparel; dressing and dyeing of fur; Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	LOTE
CA	Canada	WPAP	20-22	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; manufacture of paper and paper products; publishing, printing and reproduction of recorded media	LOTE
CH	Switzerland	PETR	23	Manufacture of coke, refined petroleum products and nuclear	MLTE
DE	Germany	CHEM	24 less 2423	Manufacture of chemicals and chemical products	MHTE
DK	Denmark	PHAR	2423	Pharmaceuticals and medicinal chemicals	HTE
ES	Spain	RUBB	25	Manufacture of rubber and plastics products	MLTE
FI	Finland	MINE	26	Manufacture of other non-metallic mineral products	MLTE
FR	France	META	27	Manufacture of basic metals	MLTE
GB	United Kingdom	FABM	28	Manufacture of fabricated metal products, except machinery and equipment	MLTE
IE	Ireland	MACH	29	Manufacture of machinery and equipment not elsewhere classified (n.e.c.)	MHTE
IT	Italy	COMP	30	Manufacture of office, accounting and computing machinery	HTE
JP	Japan	ELEC	31	Manufacture of electrical machinery and apparatus n.e.c.	MHTE
KR	Korea	COMM	32	Manufacture of radio, television and communication equipment and apparatus	HTE
NL	Netherlands	INST	33	Manufacture of medical, precision and optical instruments, watches and clocks	HTE
NO	Norway	AUTO	34	Manufacture of motor vehicles, trailers and semi-trailers	MHTE
PL	Poland	TRAN	35	Manufacture of other transport equipment	MHTE
SE	Sweden	MISC	36	Manufacture of furniture; manufacturing n.e.c.	MHTE
US	United States				

Note: * Based on the OECD technological classification, LOTE, MLTE, MHTE and HTE stand for low technology, medium-to-low technology, medium-to-high technology and high technology, respectively.

Table A2. Absolute and relative number of patents by country (2004)

Country	NPFCORR	%	TRIADIC	%	EPO	%	USPTO	%	REGIONAL	%
AT	2,356	0.6	284	0.6	1,259	1.2	825	0.4	1,259	0.5
BE	1,742	0.5	394	0.8	1,265	1.2	927	0.4	1,265	0.5
CA	5,569	1.5	381	0.8	1,147	1.1	3,750	1.7	3,750	1.6
CH	3,480	0.9	988	2.0	2,656	2.5	1,874	0.9	2,656	1.1
DE	49,502	13.2	6,865	13.6	24,130	23.2	17,126	7.8	24,130	10.4
DK	1,579	0.4	311	0.6	1,015	1.0	906	0.4	1,015	0.4
ES	2,525	0.7	177	0.4	886	0.9	519	0.2	886	0.4
FI	2,640	0.7	314	0.6	1,175	1.1	1,199	0.5	1,175	0.5
FR	14,635	3.9	2,675	5.3	7,839	7.5	5,541	2.5	7,839	3.4
GB	19,665	5.3	1,944	3.8	5,181	5.0	5,782	2.6	5,181	2.2
IE	559	0.1	82	0.2	237	0.2	282	0.1	237	0.1
IT	10,007	2.7	696	1.4	3,962	3.8	2,195	1.0	3,962	1.7
JP*	113,488	30.3	19,890	39.4	25,382	24.4	56,968	26.1	56,968	24.6
KR*	33,282	8.9	2,736	5.4	4,573	4.4	16,084	7.4	16,084	6.9
NL	5,742	1.5	2,329	4.6	3,879	3.7	3,362	1.5	3,879	1.7
NO	1,045	0.3	127	0.3	356	0.3	410	0.2	356	0.2
PL	2,226	0.6	13	0.0	135	0.1	99	0.0	135	0.1
SE	3,599	1.0	685	1.4	1,817	1.7	1,491	0.7	1,817	0.8
US	100,465	26.9	9,613	19.0	17,336	16.6	99,334	45.4	99,334	42.8
Total	374,106	100	50,504	100	104,230	100	218,673	100	231,927	100

Source: Own calculations

Notes: *The number of priority filings for Japan and Korea has been divided by 3. The "%columns report the share of each country in the total of each patent count, expressed in percent.

Table A3. Absolute and relative number of patents by industry (2004)

Industry	NPFCORR	%	TRIADIC	%	EPO	%	USPTO	%	REGIONAL	%
FOOD	7,939	2.1	997	2.0	2,172	2.1	4,156	1.9	4,258	1.8
TEXT	2,521	0.7	268	0.5	613	0.6	1,258	0.6	1,369	0.6
WPAP	4,698	1.3	605	1.2	1,324	1.3	2,418	1.1	2,649	1.1
PETR	4,632	1.2	739	1.5	1,496	1.4	2,497	1.1	2,664	1.1
CHEM	37,325	10.0	6,307	12.5	12,306	11.8	20,427	9.3	22,077	9.5
PHAR	21,229	5.7	4,872	9.6	8,762	8.4	13,831	6.3	14,734	6.4
RUBB	7,282	1.9	840	1.7	2,030	1.9	3,410	1.6	3,878	1.7
MINE	6,654	1.8	810	1.6	1,767	1.7	3,380	1.5	3,695	1.6
META	7,774	2.1	1,003	2.0	2,148	2.1	3,948	1.8	4,319	1.9
FABM	10,142	2.7	925	1.8	2,579	2.5	4,532	2.1	5,239	2.3
MACH	44,986	12.0	4,741	9.4	11,938	11.5	22,169	10.1	24,578	10.6
COMP	53,304	14.2	7,012	13.9	12,922	12.4	36,830	16.8	37,443	16.1
ELEC	14,209	3.8	1,794	3.6	3,736	3.6	8,527	3.9	9,016	3.9
COMM	81,450	21.8	11,453	22.7	21,622	20.7	55,051	25.2	56,313	24.3
INST	15,260	4.1	2,148	4.3	4,211	4.0	9,400	4.3	9,821	4.2
AUTO	34,274	9.2	4,088	8.1	9,983	9.6	16,838	7.7	18,995	8.2
TRAN	10,916	2.9	1,329	2.6	3,112	3.0	5,893	2.7	6,441	2.8
MISC	9,511	2.5	573	1.1	1,510	1.4	4,107	1.9	4,439	1.9
Total	374,106	100	50,504	100	104,230	100	218,673	100	231,927	100

Source: Own calculations

Note: The "%columns report the share of each country in the total of each patent count.

Table A4. Partial model with share of basic research in total R&D

$\Delta \log(\#patents)$	NPFCORR	TRIADIC	EPO	USPTO	REGIONAL
	(1)	(2)	(3)	(4)	(5)
$\Delta \log(R\&D)$	0.019 (0.013)	-0.004 (0.029)	0.007 (0.019)	-0.031* (0.019)	0.020 (0.018)
$\Delta \text{SHARE BASIC}$	0.016*** (0.003)	-0.0002 (0.007)	-0.008* (0.004)	0.028*** (0.004)	-0.005 (0.004)
$\log(\#patents) (t-1)$	-0.114*** (0.011)	-0.365*** (0.019)	-0.191*** (0.014)	-0.207*** (0.014)	-0.192*** (0.014)
$\log(R\&D) (t-1)$	0.016*** (0.005)	0.041*** (0.011)	0.020*** (0.007)	0.020*** (0.007)	0.022*** (0.007)
$\text{SHARE BASIC} (t-1)$	0.019*** (0.003)	0.029*** (0.006)	0.026*** (0.004)	0.021*** (0.004)	0.023*** (0.004)
Countries dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Number of observations	1811	1811	1811	1811	1811
Adjusted R-Square	0.331	0.241	0.192	0.245	0.170

Notes: ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. The rows "country dummies", "industry dummies" and "time dummies" report the significance level of the joint effect of these dummies.

Annex 2. Construction of the dynamic propensities

The variables presented in Figures 7, 8 and 9 are based on ψ_i , ψ_j and ψ_t in Equation (B.8) that is, the industry, country and time-effects, respectively. Since the dependent variable is the difference of the log of patent filings, the fixed effects can be interpreted as the growth rate in propensity to patent taking into account all the potential explanatory variables. We refer to these parameters as the dynamic propensities.

Note that the fixed effects cannot be recovered immediately from Equation (B.8). Indeed, the fact that that error correction term is left open in Equation (B.8) of Box 1 means that the estimated fixed effects also include the parameter c (recall from Equation (B.3) that c captures the rate at which research efforts lead to patent applications). For this reason, the fixed effects presented in Figures 7, 8 and 9 have been recovered in the following way. We have first estimated the residuals from Equation (B.4) and injected them into Equation (B.7) in lieu of the lagged long-term relationship (the expression in parentheses in Equation (B.7)). The fixed effects of this modified specification can be interpreted as the country, industry and time components of the change in the propensity to patent. Figures 7, 8 and 9, respectively, present the parameters ψ_i and ψ_j , which are normalized to lie between 0 and 1 for ease of readability. Figure 9 presents the cumulative growth of the time dummies, net of industry and country effects.

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