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Cross-country differences in R&D productivity
Comparison of 11 European economies

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This paper examines differences in R&D productivity across a group of geographically adjacent economies. In a distribution of close to 355,000 patents across 18 industries in 11 countries, clear and systematic country patterns are found when taking into account differences in industrial structure, institutional arrangements and R&D intensity. These findings support the argument that innovation systems are important for an industry's capacity to generate new patentable knowledge.

Keywords: Patent, R&D, Innovation, international comparison, panel data

JEL code: L6, O5, O33

1. INTRODUCTION

This paper asks whether a country's innovation performance is mainly determined by the institutions that together represent its innovation system or the composition of its industry. We investigate whether there are systematic differences in R&D productivity of a group of similar countries in terms of innovation performance measured as proxied by patents granted by the U.S. Patent and Trademark Office (USPTO).

The study includes 11 European countries and 18 industrial sectors and the time-window is 1991-2005. All the investigated countries can be regarded as knowledge-based economies whose competitiveness depends largely on their ability to create, absorb, accumulate, and transform knowledge into technological development, innovation and ultimately growth.

Previous research reports large country variation in innovativeness measured as the frequency of patent application or granted patents. Some papers, for instance Furman et al. (2002), argue that the relative size of the R&D-input explains much of the differences in patenting across countries, while others stress the importance of the quality of national innovations systems (see Fu and Yang, 2009). We explore both positions by including them in two opposite hypotheses.

The first hypothesis assumes that countries have comparative advantages in their particular industrial structure, and that this is reflected in their R&D productivity regardless of the characteristics and efficiency of their innovation systems. The different countries' innovation systems are tailored to the specific structure of their industries. Thus, differences in patents per employee across countries are mainly due to their specific industrial structures.

Hypothesis 1: *For each of the 18 industries no systematic differences in patents per R&D can be expected across the countries when controlling for industry structure.*

The second hypothesis assumes that countries have comparative advantages created by their innovation systems and that this is reflected in their R&D productivity regardless of industry structure. Differences in patents per employee across countries are mainly due to the efficiency of their innovation systems.

Hypothesis 2*:* *All industries are affected by the innovation system. Better institutional conditions are reflected in a higher overall innovation performance in the various industries.*

In the next section, we will present the data, motivate the estimation strategy and introduce the estimators applied.

The remainder of this paper is constructed as follows: Section 2 reviews the relevant literature on the concept of National Innovation Systems, empirical studies on cross-country comparisons and patent statistics as innovation indicators. Section 3 discusses the dataset and the method applied. Section 4 contains the empirical results and Section 5 summarizes the main findings.

2. THEORETICAL BACKGROUND AND HYPOTHESES

2.1 Theories on Innovation systems

The concept of innovation systems dates back to Adam Smith (1776) and Friedrich List (1884). The earliest modern interpretation can be linked to Nelson and Winter 1977 and 1982, and their critique of classical political economy's inability to include institutional relationships in their models.

While capital flows easily across national borders, the institutional environment is country-specific and the result of historical developments. Institutions can be defined as “rules of the game in a society” (North, 1990), or “the formal standards that provide a framework for interaction between members of a society" (Balzat, 2002). There are a number of formal and non-formal elements such as laws and regulations, agreements and rules, as well as codes of conduct and ethical standards in relation to written and oral agreements. The institutions also include the culture of learning, generating and diffusing knowledge.

Knowledge and knowledge flows are important elements of the institutional relationships that create conditions for innovation and growth (Nelson and Winter, 1982, Dosi et al., 1988). Innovation is not a strictly linear process from research laboratory to the market through the company's production process. Instead, it is often a sophisticated process of interactions of similar or complementary businesses, suppliers, customers, consultants, universities and others, including a significant random component. This interaction takes place across industries and organizations (Achibugi et. Al 1998).

Whereas the 1980's and 1990's literature on innovation is largely focused on building a basic theoretical framework (Lundvall, 1992, Nelson 1993, Edquist, 1997), studies of the last decade have characterized more and more of the evaluation, comparison and benchmarking of national innovation.

2. 2 Empirical studies

Using patent statistics, some studies in recent years (Furman et al., 2002, Gans and Stern, 2003, Fu and Yang, 2009) attempted to investigate differences in innovation performance across countries. One conclusion from these studies is that the most successful countries are those that are best able to develop and fit their institutions to the needs of innovation (Nelson, 2008).

Furman et al. (2002) represent early attempts to integrate the national innovation systems approach in a more formal theory as a basis for international comparisons of countries' innovation capacity. Using the endogenous theory of economic growth (Romer, 1990, Jones, 1995), theories on international competitiveness (Porter, 1990) as well as insights into the literature on national innovation systems[1], Furman et al. (2002) have formulated a model in order to explain the variation in patenting among 17 OECD countries over the period 1976 – 1996.

The model describes how a country, as a political and economic entity, can persistently produce and commercialize flows of new-to-the-world technology. The authors believe that a country's national innovation is shaped by factors such as an overall innovation structure (policy-making for science and technology, the quality of education and the stock of useful knowledge) and some innovation environments such as specific industrial clusters. Expressed as a knowledge production function (Griliches, 1979), it describes how linkages of the country's innovation structure, industrial clusters, venture capital markets and universities drive the innovation capacity.

The authors' conclusion is that the differences in the relative size of R&D expenditures and number of researchers explain much of the differences in patenting across countries. Concerning other variables, there is a positive correlation between patents and (i) the share of R&D financed by business, (ii) the proportion of GDP spent on education, (iii) the per capita GDP, (iv) openness to international trade , (v) university government research grants, and (vi) the quality of IP protection. Furman et al. (2002) suggest that five OECD countries have a leading innovation capacity: the United States, Switzerland, Japan, Germany and Sweden. Denmark, Finland, Norway, France and Britain have a medium position, while Italy, Spain and New Zealand are lagging behind.

[1] These include, for example, (i) the network of institutions in the public and private sectors whose activities initiate, collect, modify and distribute new knowledge (Freeman, 1987), (ii) parties that interact in the production, dissemination and use of new and economically useful knowledge (Lundvall, 1992), (iii) a set of institutions whose interactions have a strong influence on the national firms' innovation performance, (iv) all important economic, social, political, organizational, and other factors that influence the development, diffusion and use of innovations (Edquist, 1997).

Using similar methodology, Gans and Stern (2003) conduct an empirical study of a panel of 29 OECD countries for the period 1980 to 2000 and calculate an innovation index that can be interpreted as the expected number of international patent applications per million people given a country's national policies and resources. The authors find that the 29 countries can be divided into three stable groups: leaders (the USA, Switzerland, Japan and Sweden), followers (Denmark, Finland, France and Germany) and laggards (Italy and Spain). The study by Gans and Stern has been continuously updated, and the initial results have largely been confirmed ((Gans and Hayes, 2004, 2005, 2006, 2007).

Wang and Huang (2007) use an alternative approach to measuring innovation output relative to some denominator. Applying a non-parametric Data Envelopment Analysis (DEA), they assess the patenting efficiency of 30 countries and find that fewer than half of them are fully efficient in patent production.

Comparing R&D efficiency in 21 OECD-countries with a Stochastic Frontier Analysis (SFA) for the period 1990 till 2002, Fu and Yang (2009) report that Japan, the USA, Finland, Germany, Sweden and France are at the top regarding the number of patents per million inhabitants, while Sweden, Canada, the USA, Finland and Denmark are most efficient. Looking at the covariates, Fu and Yang show that R&D productivity, measured as patents per R&D dollar, is influenced by the degree of IP protection, level of GDP per capita, share of research financed by the private sector and the scope of higher education.

While research on national innovation has provided important information about the drivers and barriers within countries, it has been criticized for the difficulty of using this information for policy measures because of the high degree of aggregation and complexity (Balzat, 2002). All the studies reviewed above represent such aggregations.

Carlsson et al. (2002) suggest a method for more effective studies of innovation systems. Since a national innovation system consists of several parts, it may be beneficial to analyze each of those parts separately, and then assemble the whole picture from separate results. They argue that measuring the performance of a system seems to be a great deal easier if the level of analysis is a product, industry or a group of industries,. We adopt this idea here by making a cross-country analysis from a 2-digit industry perspective and testing two hypotheses.

2.3 Patent statistics as innovation indicator

Patent statistics have attracted the attention of researchers since they are the only source of standardized information on new technology that is collected in a systematic way over a long time period. The availability of patent data is growing rapidly with the development of new databases and the advent of powerful computers and software. Moreover, unlike other innovation proxies, patents are directly related to inventions since patent systems require new applications to contain some degree of non-obviousness and novelty. Finally, the gradual harmonization of patenting standards across countries calls for international comparisons (Danguy et al. 2010).

Research based on patent data has also been subjected to critical questioning. Griliches (1990), for instance, claims that a patent count - which is perhaps the most common application of patents in innovation studies - by no means directly corresponds to the number of inventions:

"Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in ''quality'', in the magnitude of inventive output associated with them.''

The fact that *not all inventions are patentable* implies that some inventions do not meet the general requirements of a national patent system. For example, in order for an invention to be patentable, European patent laws require the invention to be novel, non-obvious, industrially applicable, involve an inventive step, and be of a patentable subject matter[2]. The last mentioned excludes the patenting such things as scientific theories, mathematical formulas, aesthetic creations, computer programs and business methods. Of course, this means that the use of patent-based indicators is limited to manufacturing industries, and services are left out.

The fact that *the inventions that are patented differ in quality* implies that the distribution of the economic value of patents is skewed since inventions can be significantly heterogeneous in terms of their inventive step. The lion's share of patents reflect minor technological improvements, and only a small fraction represent major scientific breakthroughs (Pakes and Schankerman, 1984, Pakes, 1986 Griliches, 1990 and others).

For years, scholars of innovation have been looking for ways to mitigate the effect of skewness. For instance, one could weight patents according to the number of times each patent is cited in subsequent patent documents, i.e., use citations as an index of the economic importance of patents (Trajtenberg et.al 1990). An alternative is to consider secondary filings, i.e. filings for renewal of existent patents and prolongation of their period of validity (examples are Schankerman and Pakes (1986) and van Pottelsberghe and van Zeebroeck (2008). The rationale here is that inventors will seek to extend only those patents that have proved to be of sufficient economic importance.

Another method is to consider only "valuable patents" by imposing an external threshold of value, i.e. filing internationally. Since patenting procedure is expensive and time-consuming, one could expect that only valuable patents will be filed at the European Patent Office (EPO, an organization that is supra-national to national patent offices in Europe), or at the United

[2] Guidelines for the examination in the EPO: http://www.epo.org/law-practice/legal-texts/html/guiex/e/index.htm

States Patent and Trademark Office (USPTO), or be triadic, i.e. filed simultaneously at the EPO, the USPTO, and the JPO (Japan Patent Office).

It should be noted, however, that international patenting indicators suffer from so-called "home bias", since the inventor's choice of patent office is influenced by her geographic location. Companies based in Europe rely more on the EPO than their non-European counterparts, while American firms favor the USPTO for obvious reasons (Danguy et al., 2010).

Triadic patents are less subject to geographical biases, but the recent strong increase in triadic patent counts may be explained purely by a greater willingness of the firms to "go triadic" and protect their inventions all over the world due to increased international competition (Danguy et al., 2010).

This paper tries to mitigate the home bias problem when comparing a set of European countries by considering their granted patent applications in the U.S., i.e., patents granted by the USPTO), and thus attempt to avoid a "home bias".

The fact that *not all inventions are patented* means that patent statistics obviously do not capture non-patented inventions, which may account for more than 50% of all inventions (de Rassenfosse, 2009). Moreover, investment protection is not the only function of patents: patent applications can be used as a tool for competitive rivalry (to exclude a competitor from a particular technological field), for communication purposes (to unveil the invention's potential to investors), or negotiations with collaborators (Pammolli and Rossi, 2005).

An extensive literature has also shown that the uses of patents vary significantly across sectors. Mansfield (1986) found that 65% of inventions in Pharmaceuticals would not have been developed in the absence of patents, while in other sectors that percentage is significantly lower due to alternative strategies of returns appropriation (such as secrecy and lead time). In a so-called "Yale survey" by Levin et al. (1987), top managers of more than 600 US firms were questioned about the importance of patents as a means of appropriation. The authors found that companies generally did not treat patents as very important instruments, except for the entities that operated in pharmaceuticals, biotechnologies, petroleum and refining. The results were confirmed more than a decade later by the "Carnegie Mellon Survey" by Cohen et al. (2000) that focused on similar, but slightly larger sample US firms.

Godinho and Rebelo (2006), applying the OECD Technology Concordance database, analyze the variance of patenting propensities across different industrial sectors in 10 countries. Using new sectoral level data, the authors confirm that there exists significant heterogeneity in patent practices across sectors and conclude that, in general, sectors that are R&D-intensive are also patent-intensive, but that there are some notable exceptions such as the aircraft or aerospace sectors, which are characterized by low R&D productivity.

However, Godinho and Rebelo (2006) also report that the inter-sectoral differences appear to be robust across countries, suggesting that the reliance on patent protection is deeply linked to the specific characteristics of the technology and research process, the nature of the market and the patterns of competition, rather than to the nature of the patent system. This finding suggests that patent studies are more appropriate when making within-industry comparisons across countries, than between industries within countries.

RESEARCH METHODOLOGY

3.1 Data

Our empirical investigation is based on a unique dataset compiled from several open data sources. First, patent data is obtained from the OECD Main Science and Technology database. Second, industrial employment and value added data are obtained from the OECD Structural Analysis (STAN) database. Third, business R&D expenditures at the industry level are obtained from the OECD Analytical Business Enterprise R&D (ANBERD) database. Fourth, variables that proxy for institutional setting are obtained from the IMD World Competitiveness Online database and the paper by Park (2008). Finally, the openness to international trade variable is calculated using the OECD MEI database.

The selection of the 11 countries for our study is motivated by two considerations. Firstly, we have endeavored to find countries that have a high degree of common ground. The 11 European countries that have been selected are relatively homogeneous (compared to the rest of the world) in terms of factors such as wealth, openness to trade and new ideas and general cultural tradition. What distinguishes the structural composition of countries' industries and the possible differences in their national innovation systems? The second consideration is to limit the study to a selection of only European countries to avoid the "home bias" in patenting frequency chosen to study patents granted in the U.S. It is also why we have not included the U.S. and Canada in the survey.

The panel dataset covers 18 industrial sectors in 11 European countries over the period 1991 to 2005. The choice of industrial sectors is determined by data availability on the different levels of aggregation: for example, the tobacco sector is merged with the food and beverages sector due to missing data for the majority of countries. The time frame is also shaped by the data constraints: 1991 is the earliest year for which industry R&D expenditures are fully presented in the ANBERD database (for obvious reasons, Germany lacks R&D expenditures data up to 1991), and 2005 is the last year for which timeline truncation of USPTO granted patents is not obvious. The choice of countries is motivated by two considerations.

3.2 Dependent variable: USPTO patents granted

We use counts of patents granted by the USPTO, instead of national filings, as our dependent variable due to the highly skewed distribution of patent value discussed earlier. There are many ways to construct a patent indicator. We follow the recommendations by the OECD (2009. Every patent document contains several dates that reflect the time of invention and the strategic behavior of the applicant (Dernis et. al 2001): the priority date, the application date, the publication date and the grant date. The OECD claims that "in order to reflect inventive performance, it is recommended to use the priority date[3] to compile patent statistics"[4] since priority date is the closest to the date of invention. Furthermore, a patent document contains information on the inventor's country of origin, applicant's country of origin, and the country where the first filing was made (priority country). The OECD recommends using the inventor's country of residence when compiling patent data in order to investigate innovation performance, and we follow this recommendation.

It should be noted that the patent data in PATSTAT is organized by International Patent Classification (IPC), while the cross-country industry comparison is based on the United Nations' International Standard Industrial Classification of All Economic Activities (ISIC, Revision 3). The matching between IPC codes and ISIC classes is made according to the concordance matrix provided by Schmoch et.al. (2003)[5][6].

In order to normalize for the size of the countries and industries, we divide patent counts in each industry by the employment statistics of that industry in a given year. The resulting dependent variable is the number of US patent counts per 1000 industrial employees.

[3] "The first date of filing of a patent application, anywhere in the world, to protect an invention

[4] OECD Patent Statistics Manual (2009), p. 62

[5] IPC codes are aggregated into 44 broader technological fields first, and these technological fields are then matched with 44 industrial sectors. Note that technological fields contribute to several industrial sectors at once, since nearly every patented technology can be applied in different industries.

[6] One should note that Schmoch's matrix is not the only way to conduct ISIC-IPC matching, and other concordance tables exist. We apply the matrix provided by Schmoch et.al. (2003) for the following reasons: it is one of the most recent; it is based on European data; it has been recently successfully applied by several prominent authors (see Danguy et al. (2010) and de Rassenfosse (2010)).

3.2 Independent variables

The set of explanatory variables consists of three blocks: variables that proxy for the research inputs at industry level; variables that proxy for the country-specific setting, and additional vectors of country and time dummies.

The most important independent variable is sectoral business R&D expenditures as a control for the industry's innovation efforts. The variable is expressed in current prices in US dollars adjusted for Purchasing Power Parity. Similarly to the dependent variable, R&D expenditures are scaled by industrial employment of the industry in order to account for size. The resulting variable is business R&D expenditure per 1000 industrial employees.

In order to account for the relative size of the industries (i.e., for the contribution of each particular industry to the total size of the national economy), we use a variable that represents the amount of Value Added produced by the industry as a share of the total Value Added produced by the entire manufacturing sector. In this case, we would like to capture possible country specialization in specific technologies; for example, Finland is known as being strongly specialized in the information technology sector.

As discussed above, the innovation performance of an industry depends not only on direct innovative inputs such as R&D expenditures, but is influenced by institutional and other system factors. These factors may amplify the innovative efforts as well as reduce their efficiency. The choice of the variables that take those factors into account is suggested by the relevant literature.

Since education can broadly affect R&D productivity in the whole economy, we include public spending on education per capita measured in current US dollars adjusted for Purchasing Power Parity as a proxy for the intensity of human capital. Following Furman et. al 2002 and Fu and Yang, 2009, we expect that the higher the level of educational expenditure, the more skilled the personnel hired by firms and other organizations across the economy, and, therefore, the more innovative the output produced.

The financial market environment is claimed to be important when it comes to funding innovation activities. Some studies use venture capital availability as an indicator of accessibility to external financing. This paper considers the whole financial market capitalization as a percentage of its own GDP, since venture capital funding is mainly associated with high-technological industries.

The degree of openness to international trade is regarded as influencing national innovative performance (Furman et al., 2002). Openness to trade may increase the incentive to innovate through "market augmentation through exporting", as a larger market will increase the opportunities to appropriate the returns from R&D. Moreover, domestic innovation activities may benefit from international knowledge spillovers (Fu and Yung, 2009). Our measure of openness to international trade is included as a country's sum of total exports and imports divided by its GDP.

Finally, we also include two variables representing the quality of legal environment that may encourage the innovation efforts of organizations. One of the variables is the index that measures the strength of the national intellectual property (IP) system developed by Ginarte and Park (1997) and later updated by Park (2008). We include this variable since countries with a higher degree of intellectual property protection are expected to have more firms opting for patent application (Danguy, 2009). The other variable is the index that is based on the IMD Executive Opinion Survey[7] and represents the degree to which the development and application of technology are supported by the legal environment. The index is measured on a 1-10 Likert scale.

[7] This is an annual survey "in which leading executives rank their perceptions of countries' circumstances along a variety of dimensions relevant to international competitiveness" (Furman et.al 2002)

3.2 The Method Applied

The objective is to analyze the patent variables with respect to country *i* and industry *j* in a regression setting, given a vector of K covariates. Since the patent variable is discrete, non-negative and noon-linear, we use a count data approach. The econometric challenge is to choose models that can account for the presence of unobserved heterogeneity, due to omitted variables, the skew distribution of patents, different distributions across industries, years, and possibly also across countries, and endogenous regressors as well.

Due to the heterogeneity in the data set, there is no optimal count-data model for all industries, for all countries and for the whole period considered. We therefore report results for the nonlinear panel data models Poisson, Negative binomial and Finite mixture models as well. We also include linear pooled ordinary least square estimates for comparisons.

The general model is a knowledge production function measuring the relationship between innovation output and innovation input specified as follows:

$$\ln USPAT_{i,j,t} = \alpha_i + \beta_1 \ln RD_{i,j,t} + \beta_2 \ln VASHARE_{i,j,t} + \beta_3 \ln OPEN_{i,j,t} + \beta_{4l} nMARK_{i,j,t} + \beta_5 \ln EDSPEND_{i,j,t}$$
$$+ \beta_6 TECH_{i,j,t} + \beta_7 GP_{i,j,t} + \beta_8 COUNTRY_j + \beta_9 YEAR_{,t}$$

where

- $lnUSPAT_{i,j,t}$ is a log of patent counts per thousand industrial employees (patent counts scaled by industrial employment) in industry *i*, country *j* and year *t*;
- $lnRD_{i,j,t}$ is a log of business R&D expenditures per thousand industrial employees (R&D expenditures scaled by industrial employment) in industry *i*, country *j* and year *t*;
- $lnVASHARE_{i,j,t}$ is a log of Value Added of industry *i* in country *j* as a share of total Value Added in country j at year *t*;
- $lnOPEN_{j,t}$ is a log of openness to international trade measure calculated as a sum of exports and imports divided by the GDP of a country *j* at year *t*;

- $lnMARK_{j,t}$ is a log of financial market capitalization of a country j as a share of its GDP at year *t;*
- $lnEDSPEND_{j,t}$ is a log of public spending on education per capita in a country j at year *t*;
- $TECH_{j,t}$ is an index that measures how the development and application of technology are supported by the legal environment in a country *j* at year *t*;
- $GP_{j,t}$ is a Ginarte-Park index of patent rights that measures the strength of the national intellectual property (IP) system in a country *j* at year *t*;
- $COUNTRY_j$ and $TIME_t$ are the corresponding vectors of country and time dummies;

All variables except indices enter the model in a log form in order to facilitate the interpretation of the index coefficients. While time dummies control for temporal effects such as the stage of the business cycle, country dummies are included in order to account for country-specific effects that institutional setting and additional variables have failed to capture. The coefficients of country dummies can thus be interpreted as an average "innovation premium" (or "innovation penalty") for locating the industry in a particular country. These coefficients are expected to answer the question: if the amount of innovation inputs as well as certain macroeconomic and institutional conditions for the industry are held constant, what will be the "residual" innovative efficiency associated with country-specific factors?

4. EMPIRICAL RESULTS

A total of 354,920 granted USPTO patents with priority dates between 1991 and 2005 are used in the analysis, see Table 1. Patent rates increased throughout the 1990s and reached a historic peak in 2000, before gradually falling back to levels seen in the early 1990s. More than 70 of the granted patents belong to companies in Germany, England and France. The Netherlands and Sweden have the most USPTO patents among the smaller countries in the study.

4.1 Summary Statistics

Tables I-III in Appendix 1 present background information for our study. In Table I there are three indexes illustrating the great difference that exists between the R & D and patenting intensity of the 18 industries in our study. The first shows that R & D expenditure per employee is 100 times higher in the pharmaceutical industry than in the textile, clothing and leather, and pulp and paper industries. The second indicates that the number of patents per employee is about 100 times as large in the industry group computers and office machineries (ISIC 30) as in the textile and wood industries. By calculating the arithmetic average of indices for R & D and patents, we have created an R & D Patents Index that is used to classify the 18 industries in 10 high-tech and 8 low-tech industries.

In line with what has been seen in previous statistics and literature, the countries in Northern Europe show higher patent intensity (e.g. WIPO, 2007) and higher R & D intensity (Mathieu and Pottelsberge 2008) compared with the countries of southern Europe. See Table II. Looking at the median value of granted USPTO per 1000 employees, the Netherlands, Sweden and Finland are at the top, while Italy and Spain have the lowest number of patents. The mean for USPTO patents is highest in Finland followed by Belgium.

Table II shows also the average R & D intensity for the 11 countries for the period 1991-2005. The median and mean give slightly different pictures of the R & D intensity. Sweden has the highest median ahead of France, Belgium and the UK. The average is the highest in the Netherlands, followed by France and Sweden.

Table III reports the comparative statistics for the indicators of the national innovation system institutions, which are among the factors that we use to explain the patent rate. It must be emphasized that we do not make any claims regarding the capture of the myriad ofdifferent factors included in an economy's institutional environment to create and commercialize new knowledge. The purpose of this article is not to evaluate the determinants of innovation, but to examine cross country differences in patent activities at the industry level.

Belgium and the Netherlands have the highest degree of transparency in international trade in relation to GDP. England has by far the most developed financial market, followed by the Netherlands, Finland and Sweden. The four Nordic countries have the highest training intensity and the most advanced technology policy. Variations in IP protection are small, which can be explained by European standardization policy. Norway, the only non-EU country among the 11 compared, differs in that it has weaker IP protection.

4.2 Regression results for all 18 industries aggregated

Tables 2 and 3 present the regressions results with various estimators and all 18 industries aggregated. In order to save space, we report the coefficient estimates only for these eight regressions, while the results for individual industries are reported only as relative differences (ranking) of the 11 countries and 18 industries (Tables 4 and 5).

In Table 2, we pool the data and estimate five different models. One model is the linear pooled OLS, while the four others are non-linear count data models. With Italy as the reference country, the coefficient estimates are fairly consistent between the negative binomial regression (nbreg), and the poisson models. The R&D productivity, measured as granted USPTP patent per R&D-dollar is highest in Belgium, followed by Finland, the Netherlands and Sweden. The results also indicate that Spain and Italy have significantly lower R&D productivity than other European countries, when controlling for industry differences. The pooled OLS reports the highest R&D-estimate for Sweden, while the mixture models of nbreg and poisson, which allow for different distributions of the dependent variable, show the largest coefficients for Belgium and Sweden.

Considering the covariates, the estimates of R&D variances between 0.025 and 0.048 are consistent with the literature, while the degree of openness somewhat surprisingly correlates negatively with patents when controlling for R&D, industry and the relative size of the different industries. The estimates also indicate that the larger the relative size of an industry compared to the economy as a whole, the lower the innovativeness. This suggests that a dominating market position reduces incentives for renewal.

Table 3 shows the nbreg and poisson estimates when controlling for time-invariant industry-specific effects as well. The results are similar to those presented in Table 2. The estimates for Belgium are highest, followed by the Netherlands and Sweden, while Italy and Spain have substantially lower estimates. The R&D-elasticities are somewhat larger when controlling for fixed effects. The size of the financial market and the quality of the governmental technology policy are both positively associated with innovation.

4.3 Ranking results for 18 individual industries

The results reported in Tables 4 and 5 are used to test the two contradictory hypotheses raised by this paper. We only report the relative position of the different countries for the 18 different industry-regressions. Since the test statistics reported in Appendix table IV suggest that the nbreg is the more appropriate model, we only report these results. Table 4 presents results for pooled estimations, while Table 5 includes the fixed effects. Panel A reports results for low technology industries, according to our definition, as shown in Appendix Table II, and Panel B shows the ranking for high technology industries.

The results test the two contradictory hypotheses raised in Section 1. Hypothesis 1 assumes that there is no systematic pattern in the ranking of the 11 countries. The reason is that countries have comparative advantages in different industries due to historical reasons and path dependency. In contrast, Hypothesis 2 states that differences in the qualities of the national innovation systems will result in systematic differences in R&D productivity.

Our methodological approach aims to answer the question of where an invested R&D dollar provides the greatest likelihood of USPTO patents, i.e. where would the outcome of R&D be best if all countries had the same industrial structure. The first hypothesis says that different comparative advantages, depending on industry structure, lead to differing relative ranking positions for different industries. The expected pattern is then that a given country has relatively many patents in certain industries, such as high technology, and relatively few in other industries that are low-tech. Still, neither Panel A nor B provides direct support for this hypothesis.

Consider first the pooled results reported in table 4. We find a systematic pattern in that Belgium, Sweden and the Netherlands typically are top-ranked for both low technology industries and high technology industries. There is also a consistent pattern in that Spain, Italy, and England are systematically ranked at the bottom of the table.

Table 5 shows the preferred fixed effects nbreg estimates. Among low technology industries Sweden is at the top, and then come Germany and the Netherlands, while England Italy and Spain are at the bottom. The most notable difference between the pooled and fixed-effects estimates is that the ranking position of Belgium changes from number 1 to number 8.

Panel B gives the fixed effects count data estimates for high technology firms. In this case the main pattern is similar to the pooled estimates in table 4. Sweden, the Netherlands and Belgium are ranked at the top, while England, Italy and Spain have the lowest rank.

The overall conclusion from both Table 4 and Table 5 is that Hypothesis 1 should be rejected. The ranking positions of the investigated countries do not change regularly among industries, showing that the individual countries have comparative advantages in particular industries. This result is robust between the two tables. Since Hypothesis 2 assumes the opposite outcome, the results show that this hypothesis cannot be rejected. Table 4 and Table 5 suggest that all industries in a country are affected positively or negatively by the quality of the innovation system. Better institutional conditions are reflected in larger R&D-productivity and better innovation performance in all industries.

5. CONCLUSION

This article is based on R & D and patent statistics in 11 European countries and 18 different industries for the period 1991-2005. In total, we have studied 355 000 granted USPTO patents. All the countries included in our study can be regarded as knowledge-based economies whose competitiveness depends largely on the ability to create, absorb, accumulate, and transform knowledge into technological development, innovation and ultimately growth.

A country's ability to create new innovation is not just dependent on how many billions it is investing in research and development, but also how effectively that money is used. Both R & D expenditures and patents vary greatly from industry to industry. R & D expenditure per employee, for example, is 100 times greater in the pharmaceutical industry than in the textile, clothing and leather, and pulp and paper industries. The number of patents per employee is about 100 times that of the industry groups computers and office machinery and textiles and wood.

The research question raised in this paper is whether the obseerved differences in granted patents per R&D dollar between the 11 European countries studied reflects their industry structures or their R&D productivity. Using a non-linear panel data approach, we find that there is a significant and systematic difference in R&D productivity in the same industries across Europe, which suggests that the most successful countries are those best able to develop and adapt their institutions to the needs of their innovation activities. These institutions can be defined as “the rules of a society”. This includes laws, regulations, codes of conduct, contracts, moral standards, quality education, labor and financial markets and corporate internal processes for interactive learning and innovation.

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Results section

TABLE SECTION

Table 1: Granted USPTO patent 1991-2005

	Ital	Belg	Dan	Finl	Fran	Tysk	Ned	Nor	Spa	Sve	Eng	TOT
1991	1279	403	227	390	3019	7116	897	139	172	791	2625	**17058**
1992	1187	482	269	453	3059	7226	920	178	162	924	2753	**17613**
1993	1420	578	339	518	3167	7844	926	158	189	1000	2863	**19002**
1994	1329	627	380	610	3376	8451	1065	193	219	1156	3126	**20532**
1995	1531	688	416	647	3730	9366	1228	213	239	1344	3496	**22898**
1996	1721	752	490	767	3986	10585	1330	252	277	1635	3732	**25527**
1997	1794	847	495	882	4326	11577	1471	299	303	1878	3921	**27793**
1998	1829	784	568	973	4456	12495	1484	292	347	1727	4312	**29267**
1999	1905	788	569	1157	4508	12597	1522	298	379	1772	4410	**29905**
2000	2048	765	589	1035	4324	12853	1751	321	391	1751	4624	**30452**
2001	1929	696	510	995	4022	12190	1534	277	430	1479	4261	**28323**
2002	1802	698	456	842	3743	11108	1554	280	361	1242	3654	**25740**
2003	1558	598	474	831	3498	10168	1469	251	306	1064	3371	**23588**
2004	1451	586	348	716	3056	9408	1261	233	302	877	2566	**20804**
2005	1174	424	273	556	2483	7405	881	210	267	727	2018	**16418**
Tot	**23957**	**9716**	**6403**	**11372**	**54753**	**150389**	**19293**	**3594**	**4344**	**19367**	**51732**	**354920**

Table 2: Regression results, all industries. Non-individual effects models

	NBREG	POISSON	OLS	MIXTURE POISSON		MIXTURE NBREG	
				LOW	HIGH	LOW	HIGH
Belgium	2.070***	2.873***	0.944***	1.045***	2.767***	1.128	2.767***
	(0.375)	(0.288)	(0.172)	(0.318)	(0.524)	(1.559)	(0.706)
Denmark	1.437***	1.679***	0.947***	1.003***	2.055***	0.998	2.055***
	(0.220)	(0.170)	(0.098)	(0.174)	(0.294)	(0.859)	(0.423)
Finland	1.789***	2.083***	1.202***	1.340***	2.037***	1.341*	2.036***
	(0.203)	(0.158)	(0.090)	(0.157)	(0.271)	(0.701)	(0.366)
France	1.257***	1.276***	0.926***	0.952***	1.505***	0.949***	1.507***
	(0.120)	(0.0964)	(0.049)	(0.0855)	(0.172)	(0.331)	(0.229)
Germany	1.483***	1.680***	1.152***	1.194***	1.778***	1.191**	1.776***
	(0.137)	(0.110)	(0.057)	(0.101)	(0.168)	(0.499)	(0.263)
Netherlands	1.782***	2.167***	1.155***	1.251***	2.056***	1.249	2.060***
	(0.304)	(0.235)	(0.136)	(0.254)	(0.407)	(1.259)	(0.573)
Norway	1.301***	1.626***	0.871***	0.850***	1.724***	0.854	1.712***
	(0.208)	(0.157)	(0.098)	(0.163)	(0.321)	(0.901)	(0.395)
Spain	-1.206***	-1.303***	-1.162***	-1.113***	-1.490***	-1.112***	-1.483***
	(0.149)	(0.136)	(0.035)	(0.0773)	(0.150)	(0.244)	(0.178)
Sweden	1.840***	2.085***	1.367***	1.385***	2.325***	1.386*	2.316***
	(0.211)	(0.162)	(0.096)	(0.172)	(0.289)	(0.752)	(0.405)
England	1.069***	1.062***	0.713***	0.820***	1.008***	0.818***	1.013***
	(0.132)	(0.105)	(0.0507)	(0.0956)	(0.166)	(0.256)	(0.249)
lnrdper1000	0.025***	0.030***	0.048***	0.000	0.026*	0.000	0.026*
	(0.008)	(0.007)	(0.006)	(0.007)	(0.013)	(0.050)	(0.013)
lnva	-0.628***	-0.676***	-0.589***	-0.392***	-0.832***	-0.394***	-0.832***
	(0.023)	(0.015)	(0.018)	(0.023)	(0.026)	(0.118)	(0.060)
lnopen	-0.524**	-1.042***	-0.066	-0.073	-1.055***	-0.072	-1.055**
	(0.260)	(0.198)	(0.118)	(0.228)	(0.362)	(1.212)	(0.487)
lnstock	0.0134	0.099***	-0.006	0.025	0.119**	0.025	0.118
	(0.050)	(0.034)	(0.022)	(0.042)	(0.046)	(0.153)	(0.081)
lned	-0.036	-0.082	0.0165	0.001	-0.301**	0.00125	-0.301*
	(0.085)	(0.064)	(0.033)	(0.062)	(0.120)	(0.360)	(0.154)
teck	0.024	0.057**	0.012	0.015	0.072	0.015	0.071
	(0.030)	(0.023)	(0.012)	(0.026)	(0.052)	(0.097)	(0.054)
gipi	0.017	0.121**	-0.015	-0.105*	0.027	-0.105	0.027
	(0.071)	(0.054)	(0.032)	(0.055)	(0.093)	(0.316)	(0.125)
Industry dummies	Included	Included	Included	Included		Included	
Year dummies	Included	Included	Included	Included		Included	
Observations	2,970	2,970	2,970	2,970		2,970	
Industries	198	198	198	198		198	

Note:

Reference country is Italy. Mixture models assume two different distributions of the dependent variable. One is for industries with a lower frequency of patents and the other for those with a higher frequency.

Standard error in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3: Regression results panel data model (individual effects). All industries

	NBREG	POISSON	RANDOM EFFECTS
Belgium	2.406***	2.480***	1.022***
	(0.312)	(0.310)	(0.250)
Denmark	1.716***	1.815***	0.951***
	(0.206)	(0.204)	(0.140)
Finland	1.748***	1.813***	1.275***
	(0.193)	(0.193)	(0.121)
France	1.111***	1.181***	0.995***
	(0.149)	(0.149)	(0.079)
Germany	1.560***	1.605***	1.205***
	(0.156)	(0.157)	(0.094)
Netherlands	2.079***	2.136***	1.200***
	(0.262)	(0.261)	(0.188)
Norway	1.521***	1.584***	0.929***
	(0.197)	(0.196)	(0.119)
Spain	-1.173***	-1.173***	-1.146***
	(0.180)	(0.181)	(0.075)
Sweden	1.882***	1.959***	1.442***
	(0.198)	(0.197)	(0.125)
England	0.749***	0.791***	0.748***
	(0.153)	(0.153)	(0.070)
lnrdper1000	0.111***	0.066***	0.000
	(0.019)	(0.013)	(0.0124)
lnva	-0.626***	-0.617***	-0.548***
	(0.019)	(0.019)	(0.079)
lnopen	-1.084***	-1.095***	-0.070
	(0.200)	(0.199)	(0.157)
lnstock	0.108***	0.104***	-0.004
	(0.034)	(0.034)	(0.0154)
lned	-0.073	-0.082	0.0139
	(0.064)	(0.064)	(0.024)
teck	0.064***	0.062***	0.011
	(0.023)	(0.023)	(0.008)
gipi	0.092*	0.098*	-0.016
	(0.055)	(0.055)	(0.023)
Industry dummies	Included	Included	Ingår
Year dummies	Included	Included	Ingår
Observations	2,970	2,970	2,970
Industries	198	198	198

Reference country is Italy.
Standard error in parentheses, *** p<0.01, ** p<0.05, * p<0

Table 4. Ranking in R&D-productivity based on granted USPTO-patents
Pooled Negative Binomial

Panel A: Low technology industries

ISIC	15-16	17-19	20-22	25	26	27	28	36	TOT
1.	Bel	Swe	Bel	Bel	Bel	Swe	Swe	Nor	Bel
2.	Den	Ned	Swe	Swe	Ned	Ned	Ger	Den	Swe
3	Ned	Ger	Fin	Ned	Swe	Fin	Nor	Fra	Ned
4.	Swe	Bel	Den	Nor	Ger	Bel	Fin	Ger	Ger
5.	Fin	Den	Ger	Ger	Fin	Ger	Ned	Fin	Fin
6.	Eng	Nor	Ned	Den	Den	Nor	Bel	Swe	Den
7.	Nor	Fin	Nor	Fin	Nor	Fra	Den	Bel	Nor
8.	Ger	Fra	Fra	Eng	Fra	Den	Fra	Eng	Fra
9.	Fra	Eng	Eng	Fra	Eng	Eng	Eng	Ned	Eng
10.	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
11.	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa

Panel B: High technology Industries

ISIC	23	24	2433	29	30	31	32	33	34	35	TOT
1.	Bel	Bel	Den	Swe	Bel	Ned	Fin	Swe	Den	Swe	Swe
2.	Ned	Ned	Bel	Ned	Fin	Swe	Swe	Ned	Ger	Ger	Ned
3	Ger	Swe	Swe	Bel	Swe	Fin	Bel	Fin	Swe	Bel	Bel
4.	Swe	Den	Fra	Fin	Ned	Ger	Ned	Bel	Fin	Fin	Fin
5.	Nor	Fin	Ned	Ger	Ger	Bel	Ger	Den	Ned	Ned	Ger
6.	Fin	Fra	Ger	Nor	Nor	Den	Fra	Ger	Nor	Nor	Den
7.	Den	Nor	Eng	Fra	Eng	Fra	Eng	Nor	Fra	Fra	Ned
8.	Eng	Ger	Nor	Den	Den	Nor	Den	Fra	Bel	Eng	Fra
9.	Fra	Eng	Fin	Eng	Fra	Eng	Nor	Eng	Eng	Den	Eng
10.	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
11.	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa

Table 5. Ranking in R&D-productivity based on granted USPTO-patents
Fixed effects Negative Binomial

Panel A: Low technology

ISIC	15-16	17-19	20-22	25	26	27	28	36	TOT
1.	Den	Swe	Swe	Ger	Ned	Fin	Swe	Fra	Swe
2.	Swe	Ger	Ger	Swe	Swe	Swe	Ger	Ger	Ger
3	Bel	Nor	Bel	Ned	Ger	Ned	Nor	Nor	Ned
4.	Ned	Ned	Fra	Fra	Fin	Ger	Fin	Fin	Fin
5.	Fin	Den	Den	Bel	Bel	Fra	Fra	Den	Fra
6.	Ger	Fin	Fin	Nor	Den	Den	Ned	Eng	Den
7.	Eng	Fra	Ned	Den	Fra	Nor	Den	Swe	Nor
8.	Fra	Eng	Eng	Fin	Nor	Eng	Bel	Bel	Bel
9.	Nor	Bel	Ita	Eng	Eng	Bel	Eng	Ita	Eng
10.	Ita	Ita	Nor	Ita	Ita	Ita	Ita	Ned	Ita
11.	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa	Spa

Panel B: High technology

ISIC	23	24	2433	29	30	31	32	33	34	35	TOT
1.	Bel	Swe	Den	Ned	Ned	Ger	Fin	Swe	Fin	Ger	Swe
2.	Ned	Den	Ned	Swe	Bel	Swe	Ger	Ned	Nor	Swe	Ned
3	Ger	Nor	Fin	Fin	Eng	Fin	Fra	Fin	Den	Bel	Fin
4.	Swe	Fin	Bel	Bel	Ger	Ned	Swe	Bel	Fra	Ned	Bel
5.	Den	Fra	Swe	Nor	Den	Fra	Bel	Den	Ger	Fra	Ger
6.	Fin	Bel	Nor	Ger	Ital	Eng	Ned	Ger	Swe	Fin	Den
7.	Eng	Ned	Fra	Fra	Fra	Den	Den	Eng	Eng	Den	Fra
8.	Nor	Ger	Ger	Eng	Swe	Nor	Eng	Nor	Ned	Eng	Nor
9.	Fra	Eng	Eng	Den	Nor	Bel	Nor	Fra	Bel	Nor	Eng
10.	Ita	Ita	Ita	Ita	Spa	Ita	Ita	Ita	Ita	Ita	Ita
11.	Spa	Spa	Spa	Spa	Fin	Spa	Spa	Spa	Spa	Spa	Spa

APPENDIX 1

Table I: R&D-Patent Index

ISIC	Index R&D	Index Patent	R&D-Patent Index
Hightechnology			
30 Office, accounting and computing	42,0	100,0	100
2423 Pharmaceuticals	100,0	38,3	98
32 Radio, television and communication	64,8	30,6	82
24 (exc. 2423) Chemicals and chemical prod	25,7	18,6	57
33 Instruments	25,5	13,1	53
23 Coke, petroleum and nuclear	16,4	15,4	48
35 Other transport equipment	25,0	5,7	45
34 Motor vehicles	18,9	8,5	44
29 Maciney and equipment	11,8	6,4	36
31 Electrical machinery	13,6	3,7	34
Low technology			
25 Rubber and platics	5,2	2,5	23
26 Other non-metallic products	2,9	1,9	19
15-16 Food, beverages and tobacco	2,7	1,0	16
27 Basic metals	0,7	3,3	16
28 Fabricated metal	1,7	1,2	14
36 Furniture, recycling	1,4	1,3	14
17-19 Textiles, apparel	1,4	0,5	12
20-22 Wood, wood products, paper	0,4	0,5	8

Note
The index in column 3 is based on an arithmetic average of the R&D-index (R & D per employee in purchasing power-adjusted U.S. dollars) and the Patents Index (patents per employee).

Table II: Granted USPTO patent 1991-2005 and R&D expenditures per 1000 employees

	Patents		R&D	
	Median	Mean	Median	Mean
11 Countries				
Italy	0.33	1.02	897	2 850
Belgium	0.62	5.90	3 354	7 405
Denmark	0.65	2.97	1 048	4 402
Finland	1.12	10.51	2 452	6 332
France	0.83	2.73	3 489	9 552
Germany	0.92	3.04	2 202	5 916
The Netherlands	1.26	3.28	1 994	10 300
Norway	0.79	4.11	1 928	4 669
Spain	0.09	0.30	1 258	2 343
Sweden	1.22	4.15	3 668	9 218
United Kingdom	0.63	1.92	3 258	6 973
18 Industries				
15-16	0.17	0.18	677	793
17-19	0.09	0.11	359	444
20-22	0.09	0.09	109	361
23	2.66	3.43	4 112	5 018
24	3.22	3.42	6 430	6 983
2423	6.61	6.41	25 000	30 100
25	0.43	0.47	1 288	1 537
26	0.33	0.38	715	801
27	0.57	0.59	165	174
28	0.20	0.22	430	494
29	1.10	1-06	2 956	3 063
30	17.27	36.94	10 500	19 700
31	0.64	0.76	3 399	3 962
32	5.28	5.23	16 200	18 600
33	2.27	2.68	6 363	6 993
34	1.46	2.07	4 716	5 546
35	0.99	1.07	6 241	7 808
36	0.22	0.22	358	490

Table III Controls

	Openess	Finance market	Education	ST-policy	IPR
Italy	29.00	35.61	1 078	4.66	4.47
Belgium	117.33	58.68	1 676	6.09	4.52
Denmark	59.46	48.18	2 806	6.97	4.52
Finland	52.40	98.77	1 756	7.85	4.29
France	37.40	61.48	1 629	6.29	4.52
Germany	43.60	39.77	1 211	5.73	4.39
The Netherlands	85.86	108.92	1 277	6.89	4.56
Norway	54.46	38.43	2 546	7.11	3.89
Spain	26.53	59.46	692	5.91	4.19
Sweden	55.93	96.38	2 251	6.93	4.41
United Kingdom	34.53	141.59	1 249	6.62	4.34
Median	48.00	60.65	1 486	6.58	4.50
Mean	54.23	71.57	1 643	6.46	4.37

Tabell IV Test statistics

Distribution of granted USPTO normalized by employment

	NORMAL	POISSON	NBREG
18 Industries	Prob>Chi 0.007	Mean: 3.63	0.075***
		St. dev: 16.7	(0.000)
Results	Non Normal	Non Poisson	Significant overdispersion