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AUTHORS	Martin Falk
ARTICLE INFO	Martin Falk (2007). What Determines Patents per Capita in OECD Countries?. *Problems and Perspectives in Management*, *5*(2)
RELEASED ON	Tuesday, 22 May 2007
JOURNAL	"Problems and Perspectives in Management"
FOUNDER	LLC "Consulting Publishing Company "Business Perspectives"

NUMBER OF REFERENCES

0

NUMBER OF FIGURES

0

NUMBER OF TABLES

0

SECTION 1 ‖ **Macroeconomic Processes and Regional Economies Management**

What Determines Patents per Capita in OECD Countries?

Martin Falk[*]

Abstract

This paper investigates the determinants of EPO (European Patent Office) patent applications per capita using a panel of 22 OECD countries for the period of 1980-1999 with data measured as five-year averages. The patent production function is specified as a partial adjustment model and is estimated using system and first-differenced GMM (generalised method of moments) estimators. Estimates using system GMM estimators show a moderate degree of persistence in EPO patents per capita with an adjustment rate of around 25 percent between the five-year averages. Specialization in information and communication technology (ICT) patents has a significant and positive impact on EPO patents per capita. An increase in business enterprise R&D (BERD) expenditures is more effective in generating patent applications than public sector R&D with long-run elasticities of 1.04 and 0.24, respectively. The remaining variables, such as the strength of patent protection, human capital intensity and GDP per capita, are significantly positively related to EPO patents per capita in the static panel data model but are no longer significantly positive in the dynamic panel data model. Finally, we do not find any impact of the share of publicly financed industrial R&D as well as export performance of high-technology products on EPO patent applications per capita.

Key words: knowledge production function, patents, R&D, ICT patents, panel data.
JEL Classification: O30, O31, O33.

1. Introduction[1]

Patent applications at the European Patent Office (EPO) have increased steadily over time. As has been observed, increases in EPO patent applications coincide with increased patent protection, efforts to raise R&D investment in the public and private sector, overall skill upgrading, increased openness to international trade and a growing importance of information and communication technologies.

Some countries, such as Finland, Ireland, Korea, Portugal and Spain, have increased their research output – as measured by patent applications – to a greater extent than others (OECD, 2003). This variation of patent applications over time raises some interesting questions. What are the key factors influencing patent applications at the aggregate level? How much do policy factors (e.g. extent of patent protection and the amount of public sector R&D expenditures) contribute to these differences in patent applications in comparison to other structural patent determinants (e.g. structure of patents, persistence of patent applications). From the policy point of view it is also interesting to look at the size of the effects of private and public R&D expenditures on patent applications. What is more effective in raising patent applications: private or public R&D expenditures?

The aim of this paper is to examine the relationships between patent activity and policy, non-policy and other structural factors. We use patents registered at the European Patent Office by 22 inventor countries from the OECD area. Data are measured as five-year averages with the years

[*] Austrian Institute of Economic Research (WIFO), Austria.

1980-1999 being divided into four periods. To analyse the major factors behind patent activity, we estimate a patent production function that is specified as a partial adjustment model. In particular, we use various panel data model techniques including the fixed effects model for the static model and both system and first-differenced GMM estimators for the dynamic patent production function.

At present there is a growing number of empirical papers using panel data methods to investigate the sources of differences in patent activity among industrialized countries. In particular, most studies estimate patent production functions based on a panel of OECD countries using USPTO (United States Patent and Trademark Office) patents. However, with the exception of Park (2003) and Sanyal and Jaffe (2004), very little empirical work has been conducted on the determinants of EPO patent applications at the aggregate level. Scholars using applications to U.S. patents include Furman et al. (2002) who use country-level data on 17 OECD countries for the period of 1973-1996 and estimate the relationship between international patenting (i.e. number of patents granted by the US patent office to establishments from foreign countries) and observable measures of national innovative capacity. The authors find that a large part of the variation in patenting across countries is due to differences in the level of inputs devoted to innovation (R&D manpower and R&D spending). Furthermore, the authors find that the number of patents by foreign countries is significantly positively correlated (i) with the extent of intellectual property protection, (ii) with the share of research performed by the academic sector, (iii) with the share of R&D funded by the private sector, (iv) with the share of GDP spent on higher education, (v) with openness to international trade, (vi) the level of GDP per capita and (vii) patent specialization (Furman et al., 2002). Likewise, using USPTO patent data on 19 OECD countries for the period of 1981-1997, Ulku (2004) finds that a 1% increase in the R&D stock increases innovation by about 0.4% in the G7 and 0.5% in low income OECD countries, indicating diminishing returns to scale. As for the determinants of EPO patent applications, Sanyal and Jaffe (2004) find that business expenditures on R&D by the source country are significantly positively associated with patent applications. Furthermore, an increase in the percentage of government financed R&D exerts positive influence. Their study is based on a panel of 21 OECD countries for the period of 1994-2000.

This paper is an extension of the previous literature on the aggregate R&D-patent relationship in a number of ways. The main novelty of this paper is that we introduce a new variable, i.e. the share of information and communication (ICT) patents in total patents. ICT patents can be used as a proxy for the countries' specialization in information and communication technologies. Furthermore, we use different measures of R&D effort by distinguishing the different categories of R&D (by performing sectors and by sources of financing). To our knowledge, dynamic panel data methods have not been widely applied for the aggregate patent production function where patents are measured as EPO patent applications. In particular, we employ the system GMM estimator. Blundell and Bond (1998) recommend the use of system GMM rather than the more common Arellano-Bond method if the sample size is small or the time series highly persistent as is the case for R&D intensity and patents per capita. Contrary to Ulku (2004) and Sanyal and Jaffe (2004), we do not employ annual data, but rather averages derived from five-year periods. The rationale for doing so is the limited availability of annual time series for some smaller OECD countries. Furthermore, some indicators such as the patent protection index and average years of schooling are only available for five year intervals. Apart from this technicality, one might also argue that some variables such as R&D intensity display little annual variation and that only a longer period interval is suitable to capture the effects of changes in the time dimension. Another reason for using five-year averages is that patent applications at the EPO arrive at the EPO with some time lag if the applicant chooses the PCT (Patent Collaboration Treaty) route for international patents. Note that an increasing number of patent applicants opted for the PCT route in the 1990s, with lags that were as long as 30 months (Grupp and Schmoch, 1999; European Commission, 2002).

The structure of this paper is the following. Section 2 introduces the empirical model and the hypotheses. Section 3 presents the data used, while the empirical results are discussed in section 4. Some concluding remarks are provided in section 5.

2. Empirical model and hypotheses

Specification of the partial adjustment model

The impact of R&D and other factors on EPO patents per capita is estimated by means of an extended 'knowledge production function' (alternatively referred to as 'patent production function') developed by Griliches (1979) and widely used in innovation studies (Furman, Porter and Stern, 2002; Kortum and Lerner, 2000; Ulku, 2004). The extended patent production function may be written in general form as:

$$\ln y_{it}^* = \alpha \ln x_{it} + \beta \ln z_{it} + \eta_t + u_i + \varepsilon_{it}, \text{ i=1 ...N and t=1...T (averages for 1980-1984, 1985-1989,}$$
1990-1994 and 1995-1999),

where y_{it}^* is the desired output of the knowledge production function in country i in time t; x_{it} is research input, and z_{it} includes other variables affecting innovation output. u_i is the country effect controlling the unobserved characteristics, and η_t captures the time effects. ε_{it} is the usual error term and assumed to be identically and independently distributed with a zero mean and constant variance, i.e. $\varepsilon_{it} \sim IID(0, \sigma^2)$ and α and β are parameters to be estimated. The relationship between the desired innovation output and actual innovation output is characterized by the partial adjustment mechanism:

$$\ln y_{it} - \ln y_{it-1} = \theta \left(\ln y_{it}^* - \ln y_{it-1} \right), \quad 0 < \theta \le 1,$$

where y_{it} is the actual output of the knowledge production function in country i and time *t*, and

y_{it-1} is previous (one five-year period lagged) output. θ is referred to as the coefficient of adjustment, indicating the proportion of the gap between the observed and desired patent applications that is closed between the five-year periods. Combining both equations yields the regression equation:

$$\ln y_{it} = \lambda \ln y_{it-1} + \tilde{\alpha} \ln x_{it} + \tilde{\beta} \ln z_{it} + v_i + \omega_t + e_{it}.$$

with $\lambda = 1 - \theta$, $\tilde{\alpha} = \theta\alpha$, $\tilde{\beta} = \theta\beta$, $v_i = \theta u_i$, $\omega_t = \theta\eta_t$ and $e_{it} = \theta\varepsilon_{it}$.

The long-run effects can be easily recovered by dividing $\tilde{\alpha}$ and $\tilde{\beta}$ by 1-λ. The adjustment speed increases with a decreasing value of λ. If the coefficient of λ equals 0, the actual output equals the desired level. If the coefficient of λ is 1, there is no convergence. The regression equation can be derived by taking first-differences to remove unobserved time-invariant country-specific effects and then instrument the lagged dependent variable in the first-differenced equations using levels of the series lagged two periods or more (Arellano and Bond, 1991). For the other explanatory variables, we use all or selected past values as instruments in the regression. Since the first-differenced GMM estimator is known to behave poorly when the time series are persistent and the number of time series is small, which is typically the case in cross-country studies, we use the system-GMM estimator implemented by Blundell and Bond (1998)[1]. The basic idea of this estimator is to use lagged first differences of the variables as instruments for the equation in levels in combination with the usual approach. Thus, the system GMM estimator combines the

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[1] Simple AR(1) regressions using the GMM system estimator show that total R&D intensity and business R&D intensity are characterized by a high AR(1) coefficient with coefficients of about 0.90.

regression in differences with a regression in levels resulting in more informative moment conditions that are valid under quite reasonable conditions.

Variables and hypotheses

We use total EPO patent applications per population of one million to measure new knowledge. Patent applications have been scaled by the population in order to adjust for the size of the economy. It is well known that patent indicators at the EPO suffer from a "home advantage bias", as European countries will apply for more patents at the EPO than in other offices (Dernis et al., 2001). Fixed effects may capture the "home advantage bias" of European countries.

A number of possible factors could affect the number of patent applications per capita. The most important determinant of patents is research input. It can be measured as R&D intensity (the ratio of R&D to GDP) or the human capital engaged in research (the share of R&D personnel in the total population). Our primary measure of research input is total R&D intensity (the ratio of gross expenditures on R&D (GERD) to GDP). We use R&D intensity rather than the level of R&D expenditures in order to control for the size of countries. The composition of R&D, share of private/public sector R&D and share of government-funded business enterprise R&D all have implications on patents per capita (see Sanyal and Jaffe, 2004). Research and development activities in OECD countries are performed primarily by three sectors: business, institutions of higher learning (primarily universities) and government institutions. In this paper, we split R&D into private and public sector R&D. The distinction between the source of the financing of industrial R&D, i.e., private versus public funding, is also considered.

Previous empirical and theoretical work suggests that patent applications are positively influenced by a number of important factors in the business environment. The factors that can affect patents per capita include patent specialization, GDP per capita, education, patent protection and the industry structure. Another important factor is the initial level of patents per capita. In the following, we advance a number of hypotheses concerning the relationship between the EPO patents per capita and the possible factors influencing patents, which we will proceed to evaluate in the following empirical work.

R&D effort: One focus of this analysis is the long-run elasticity of research output with respect to research input and the measure of returns to scale. The innovation production process exhibits diminishing returns to scale if patents per capita are less than doubled when R&D intensity is doubled. The effects of R&D on patents will also depend on the type of R&D. In particular, we expect that the difference between the impact of business R&D and public sector R&D is larger than the difference between the share of business and public R&D expenditures in GDP suggests. We also expect positive effects of publicly financed R&D in the business sector.

Persistence: It is apparent that countries with a low initial level of patents per capita, such as Portugal and Spain, have accumulated much faster than countries with a high level such as Germany. One way to capture possible catch-up effects is to include the lagged dependent variable in the model. We expect a moderate speed of adjustment.

ICT patents: ICT and biotechnology patents are among the fastest growing patent classes. ICT patents belong to the so-called leading edge technologies that are characterized by high R&D intensity (Jungmittag, Grupp and Hullmann, 1998). The share of ICT patents can be used as a proxy for the countries' specialization in information and communication technologies. In addition, we use a broader measure that also includes biotechnology patents. We expect that countries with a higher growth of ICT patents will exhibit a higher growth of total patents applications. This can be justified by the fact that general-purpose technologies such as ICTs may provide positive externalities to non-ICT patents and thereby to total patents.

Patent protection: Changes in patent policies can also affect patenting activity. Economic theory provides a number of benefits from granting temporary rights to innovators (Kanwar and Evenson, 2003). The primary economic benefit is the stimulation of private innovation. Therefore, we ex-

pect a positive impact on patents per capita. Since OECD countries already have strong patent protection regimes with relatively little variation, the effect might not be significant.

Human capital: The availability of a highly educated labour force increases innovation output. The proxy measure used here is the average years of education among the working age population (from 25 to 64 years of age) (see De la Fuente and Doménech, 2000). The impact of the average years of schooling is expected to be positive, but not always significant. It is well known that the average years of schooling are a weak indicator of human capital because it cannot account for differences in the quality of one year of education.

Share of high-technology exports: One possible reason for cross-country variation in patent applications per capita is the varying industry composition. A high level of patents per capita might reflect a specialization in research-intensive industries. We use the share of high-technology exports as a proxy of a country's specialization in high-technology activities as they are characterized by a high intensity of research and development. High-technology exports include high-technology products such as aerospace, computers, pharmaceuticals, scientific instruments and electrical machinery (see OECD, 2003).

Other factor such as openness and GDP per capita may have less direct effects on domestic innovation abilities. Finally, the inclusion of time effects may capture changes in the invention process.

3. Data and descriptive statistics

The main data source is the OECD MSTI, OECD ANBERD and the OECD patent database that can be downloaded from http://www.sourceoecd.org and http://www.oecd.org, respectively. We use patent applications at the EPO from 1978-1999. From the time period of the establishment of the EPO in 1978, we exclude the very first years and mainly work with averages for the periods of 1980-1984, 1985-1989, 1990-1994 and 1995-1999. ICT patents are obtained from the OECD patent database and include patents from any of the following classes of the International Patent Classification (IPC): computing, calculating and counting (G06); information storage (G11) and electric communication technique (H04) (OECD, 2003). Gross R&D expenditures, R&D expenditures in business enterprises, the government and the higher education sector and publicly financed R&D expenditures in the business sector (all expressed as shares of GDP) are obtained from MSTI. Note that the data on higher education R&D are not comparable across countries. Therefore, we mainly focus on total public sector R&D as a percentage of GDP. The Ginarte-Park index of patent rights is provided by Walter Park and is available every five years (i.e. 1965, 1970, 1975, 1980, 1985, 1990 and 1995). This protection index uses a 0-5 scale and is based on several features, extent of coverage, membership in international agreements, loss of protection, enforcement and duration of protection (see Ginarte and Park, 1997). Average years of schooling data are drawn from the educational attainment database developed by De la Fuente and Doménech (2000) and are available every five years (i.e. 1965, 1970, 1975, 1980, 1985, 1990 and 1995). Openness is measured as total trade (equal to exports plus imports in current prices) as a proportion of nominal GDP and is obtained from the OECD Economic Outlook database. Per capita GDP is measured as GDP per working age population in 1995 US-$ ppp (in 1,000s) and is obtained from the OECD Economic Outlook database. The share of high-technology exports is calculated using the OECD STAN database and OECD MSTI and is only available for the period of 1981-2001.

Our core data set includes 22 OECD countries for which consistent time series are available for the sample period[1]. We do not include the Czech Republic, Hungary, Iceland, Luxembourg, Mexico, Poland, the Slovak Republic and Turkey because the data needed are not available for these countries.

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[1] The countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, the Republic of Korea, Spain, Sweden, Switzerland, the United Kingdom and the United States.

Table 1 contains descriptive statistics. Across all years, the average patents/population (in millions) ratio is about 54. Of the 22 OECD countries, the largest number of EPO patents per capita is held by Switzerland (with 295 patents per million) followed by Sweden, Germany and Finland. Portugal, Greece and Spain have a very low number of patents per capita.

Table 1

Summary statistics (pooled data)

	# of obs.	Mean	Std. Dev.	Min	Max
Number of EPO patent applications per capita	108	54.15	60.73	0.03	295.07
Gross expenditures on R&D (GERD) % GDP	108	1.57	0.77	0.17	3.51
Business expenditures on R&D (BERD) % GDP	84	1.02	0.62	0.04	2.62
Privately funded BERD % GDP	84	0.92	0.57	0.04	2.41
Publicly funded BERD % GDP	84	0.11	0.12	0.00	0.61
Higher education expenditures on R&D (HERD) % GDP	84	0.37	0.16	0.04	0.80
Public sector R&D, % GDP	84	0.62	0.19	0.15	0.93
ICT patents, % EPO patents	108	19.13	10.31	0.00	50.18
ICT & Biotechnology patents, % total EPO patents	108	22.65	11.45	0.00	54.11
Patent protection index (Likert scale 1-5)	108	3.48	0.61	1.98	4.86
Average years of schooling (in years)	108	10.15	2.02	5.29	13.11
Openness in % (exports + imports of goods and services/GDP)	108	61.37	27.92	17.04	150.93
GDP per capita in constant US-$ ppp, in 1,000s	108	26.43	6.51	6.27	39.48
High technology exports, % total manufacturing exports	85	14.89	9.94	1.06	44.35

Notes: Unweighted means across countries and time.
Source: MSTI, OECD patent database, own calculations.

Table 2

Summary statistics, evolution over time

	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999
Number of EPO patent applications per capita	15.1	39.3	58.3	65.2	94.8
Gross expenditures on R&D (GERD) % GDP	1.23	1.39	1.66	1.76	1.88
Business expenditures on R&D (BERD) % GDP	0.80	0.84	1.03	1.05	1.19
Privately funded BERD % GDP	n.a	0.72	0.90	0.95	1.11
Publicly funded BERD % GDP	n.a	0.12	0.13	0.10	0.08
Higher education expenditures on R&D (HERD), % GDP	n.a	0.30	0.34	0.40	0.42
Public sector R&D, % GDP	n.a	0.57	0.60	0.66	0.66
ICT patents, % EPO patents	13.9	15.3	17.9	22.1	26.5
ICT & Biotechnology patents, % total EPO patents	15.3	17.5	21.8	26.8	32.0
Patent protection index (Likert scale 1-5)	3.0	3.4	3.5	3.6	3.9
Average years of schooling (in years)	9.3	9.7	10.2	10.6	11.0
Openness in % (exports + imports of goods and services/GDP)	55.3	62.5	60.7	59.8	68.4
GDP per capita in constant US-$ ppp, in 1000s	22.2	23.7	26.1	28.3	31.4
High technology exports, % total manufacturing exports	11.1	13.4	15.9	19.0	22.4

Notes: Unweighted means across countries.
Source: MSTI, OECD patent database, OECD economic outlook, De la Fuente and Doménech (2000), Ginarte and Park (1997), own calculations.

The share of ICT patents accounts for 19% of total patents. The inclusion of biotechnology patents leads to a share of about 23%. Differences in the share of ICT patents among OECD countries are substantial: Korea and Finland both feature the highest share of ICT patents in total patents (50%), followed by Japan (43%), the Netherlands (38%) and the United States (averages for the period of 1995-1999). Austria, Spain, Italy, Greece and Portugal feature low shares. Looking at the share of both ICT and biotechnology patents, we find a quite similar ranking. Again, Korea is the leader in the patent shares, followed by Finland and Japan. The United States ranks fourth. The ratio of public sector expenditures on R&D as a percentage of GDP is about 0.62. The average number for GERD and BERD, both as a percentage of GDP, are about 1.6% and 1%, respectively. Funding from government sources for the private sector only accounted for 0.1% of the GDP on average.

The strength of patent protection is measured using the Ginarte-Park index for patent rights. On a Likert scale between 1 and 5 (where 5 represents the strongest degree of protection), sample countries have a patent protection index of about 3.5. The average country in the sample features an average 10.5 years of schooling. Over the sample period, the GDP per capita is 26,000 US-$ in constant ppp. The sample mean of openness is 61.4%. The figures are highest in Ireland (151%), Belgium (142%) and the Netherlands (113%). Table 2 contains the development of the variables measured as five-year averages: 1975-1979, 1980-1984, 1985-1989, 1990-1994 and 1995-1999. We observe an increase in most of the variables except for publicly funded BERD as a percentage of GDP.

To get some insight into the relationship between EPO patents and the possible factors, we provide correlation coefficients based on pooled data (see Figure 1 in the Appendix). We find that high-income OECD countries have the highest, while low-income and OECD countries have the lowest number of patent applications per capita. R&D intensity, the Ginarte-Park index of patent protection and the share of ICT patents are all significantly correlated with EPO patents per capita.

Table 5 in the Appendix shows the estimated coefficients from the fixed-effects regression where each of the explanatory variables was added to the regression equation separately. In order to investigate the degree of multicollinearity, we also provide estimates for possible factors influencing patents per capita. Different measures of R&D effort (i.e. GERD, % GDP, BERD, % GDP, HERD, % GDP, public sector R&D, % GDP and government-financed BERD % GDP) are all significantly positively related to EPO patents per capita (1% significance level). ICT patents, % EPO patents as well as ICT and biotechnology patents, % patents are also positive and significant. The strength of patent protection, GDP per capita and average years of schooling are positive and significant at the 5% level. However, we do not find a significant correlation between total patents and both openness and high-tech export share. Furthermore, we find that some of the explanatory variables are highly correlated which may lead to multicollinearity problems in estimating the coefficients. Therefore, we will provide Wald-Tests of joint significance.

4. Results

The results for the dynamic panel data models are reported in Table 3. In all specifications, we include time dummies for each of the five-year intervals to control for common time effects affecting EPO patents in all countries. All of the equations are estimated using the one-step GMM method with t-values and test statistics that are asymptotically robust to general heteroscedasticity and corrected for small sample bias. We provide results using the system GMM estimator (see specifications (1) to (3)) and the first-differenced GMM estimator (specifications (4) and (5)). Specification (1) presents the results of the patent production function including GDP per capita and its squared term in addition to R&D intensity. Specification (2) presents the results of the patent production function including the logarithm of the share of ICT patents in total patents and the logarithm of the patent protection index. The system GMM results use 85 observations on 22 OECD countries, with the years of 1980-1999 being divided into 4 time periods.

Note that we assume that all explanatory variables are strictly exogenous. We also estimate the equations with the less restrictive assumption that the explanatory variables are predetermined. However, no significant differences between both sets of estimates can be found[1]. Since all of the variables are measured as first (=five-year) differences in natural logarithms, the coefficients can be interpreted as short-run elasticities. Long-run elasticities can be obtained when the coefficients are divided by 1 minus the coefficient of the lagged endogenous variable. We conduct two types of diagnostic tests for the empirical models. Firstly, we conduct tests of first- and second-order serial correlations in the residuals. The AR(2) test statistics of the residuals do not reject the specification of the error term. Secondly, looking at the Sargan and Hanson tests, we see that the p-values do not indicate a decisive rejection of the model's overidentifying restrictions.

The R^2 is higher than 0.93 in all of the models. As anticipated, total R&D intensity has a strong positive effect on patenting activity in all five specifications. Using the system GMM estimator, the long-run elasticity is between 1.27 and 1.35, whereas the short run elasticity ranges 0.33 and 0.55. This indicates that total R&D activities exhibit slightly increasing returns to scale with respect to patenting. Lagged EPO patents per capita are significant at the 1% level in all regressions. This is consistent with the prediction of convergence in the countries' level of per capita patents. The corresponding estimated adjustment coefficients range between 0.25 and 0.33, implying that between 25% and 33% of the adjustment takes place between the five-year periods.

Specification 1 shows that GDP per capita and its squared term are jointly significant with a p-value of 0.08 indicating a non-linear relationship between patents and GDP per capita. Figure 2 shows the resulting relationship between log EPO patents per capita and log GDP per capita. The coefficient of EPO per capita patents increases with increasing GDP per capita until a threshold of about 3.35 which equals 28,500 US-$ ppp per capita. For countries with higher GDP per capita, EPO patents are decreasing slightly. However, GDP per capita and its squared term are neither individually nor jointly significantly different from zero when other control variables are included in the regression. Therefore, in specifications (2), (3), (4) and (5), we do not include GDP per capita squared.

Table 3

Dynamic panel data estimates of the determinants of EPO patents per capita

| | System GMM | | | | | | First-differenced GMM | | | |
| | (1) | | (2) | | (3) | | (4) | | (5) | |
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
log EPO patents per capita (lagged)	0.67 ***	9.61	0.74 ***	14.94	0.75 ***	14.89	0.42 ***	6.75	0.40 ***	6.55
log GERD % GDP	0.55 ***	5.34	0.33 ***	4.29	0.34 ***	4.64	0.25 *	1.78	0.32 **	2.12
log ICT patents, % EPO patents			0.15 *	1.80					0.29 ***	2.86
log ICT & BIOTECH patents, % EPO patents					0.17 *	1.85	0.45 ***	4.28		
log patent protection index			0.31	1.02	0.28	0.93	0.32	1.53	0.45 **	2.17
log average years of schooling			-0.33 **	-2.11	-0.37 **	-2.21	0.82	0.92	0.49	0.56
log GDP per capita in const. ppp	2.51 **	2.24	0.23	1.17	0.18	0.93	0.38	1.48	0.34	1.15

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[1] We also conduct some other robustness checks. Among the selected OECD countries there are a number of small countries. Unreported results indicate that the inclusion and exclusion of such smaller EU countries (e.g. Ireland) do not seem to have a significant impact on the estimates.

Table 3 (continuous)

	(1)		(2)		(3)		(4)		(5)	
log GDP per capita in const. ppp squared	-0.38	** -2.16								
log openness			0.11 **	2.30	0.10 **	2.12	-0.18	-0.86	-0.12	-0.55
Period dummy variables	yes		yes		yes		yes		yes	
Constant	-0.04	-0.03	3.07 ***	2.86	3.36 ***	3.02				
Hanson J-test (p-value)	0.981		0.982		0.983		0.989		0.998	
Sargan test (p-value)	0.965		0.541		0.543		0.047		0.032	
AR(2) test (p-value)	0.911		0.878		0.978		0.686		0.983	
Wald-test joint significance of GDP and GDP squared	$F(2,78) = 2.69^*$		$F(2,73) = 1.78$							
R^2	0.98		0.98		0.98		0.93		0.93	
# of observations	86		85		85		62		62	
# of countries	22		22		22		22		22	

Notes: ***, ** and * denote significance at the 1%, 5% and 10% level. Dependent variable is total EPO patent applications per million population. All variables are expressed in their logarithms. The table gives the results of (one-step) system and first-differenced GMM estimators. t-values are robust to heteroscedasticity and are corrected for small sample bias using. Windmeijer's correction. Data are measured as five-year averages from 1980-1999 divided into four periods (i.e. 1980-1984, 1985-1989, 1990-1994 and 1995-1999). Estimates using first-differenced GMM use data for four five-year averages (i.e. 1980-1984, 1985-1989, 1990-1994 and 1995-1999).

The share of ICT patents, whether they include or exclude biotechnology patents, has a positive impact on EPO patents per capita. According to the results, a 1% increase in the share of ICT patents increases per capita patents in the long-run between 0.58% and 0.66%. The positive and significant effect of ICT patents is also robust to estimation techniques. Using first-differenced GMM, we find long-run elasticities of 0.77 and 0.49 for both different measures of ICT patents. The long-run elasticities are also quite similar to those obtained for the fixed effects model (see Tables 6 and 7 in appendix). Estimates using system GMM suggest that the change in patent structure towards ICT may have accounted for 18% of the increase in per capita EPO patent applications in OECD countries that more than doubled during the last two decades. The strength of patent protection no longer has significant effects using the system GMM estimator compared to the static fixed effects regression analysis (compare Table 3 and Table 6). Finally, openness has a positive and significant impact on EPO patent applications per capita. However, the effect is not robust to the estimation techniques.

In Table 4 we report the results for the dynamic panel data model when R&D intensity is broken down by the performance sector (i.e. business enterprise sector R&D expenditures to GDP and public sector R&D expenditures on GDP) and by the source of funding. Since business enterprise expenditures on R&D and R&D expenditures by higher education institutions are highly correlated with each other, we provide Wald-Tests of joint significance. The positive role of the expenditures of higher education institutions on R&D (HERD) as a percentage of GDP is confirmed but the effect is found to be lower than the effect of private R&D. In particular, we find that the impact of BERD % GDP is twice as much as that for the HERD % GDP. However, the effect of HERD is quite large given the fact that the share of R&D expenditures by higher education institutions is only 0.4% on average, whereas the share of BERD is 1.1% . The distinction between business enterprise R&D and R&D performed in the public sector indicates that the effect of BERD % GDP is about four times larger than that of the public sector R&D. Again, the Wald-Test of joint signifi-

cance indicates that both variables are highly significant. However, the comparison of the magnitude of elasticities of HERD and public sector R&D indicates that increases in higher education expenditures on R&D are more effective than public sector expenditures on R&D in generating more EPO patents. Turning to industrial R&D disaggregated by the source of funding, estimates suggest that both privately and publicly financed R&D are important determinants of EPO patents per capita.

Table 4

Dynamic panel data estimates of the determinants of EPO patents per capita:
Impact of private and public sector R&D

	(1)		(2)		(3)	
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
log EPO patents per capita (lagged)	0.73 ***	19.69	0.73 ***	14.56	0.73 ***	17.21
log BERD % GDP	0.21 ***	4.43	0.28 ***	4.00		
log privately financed BERD % GDP					0.31 ***	3.70
log publicly financed BERD % GDP					-0.05	-1.46
log public sector R&D			0.07	0.55		
log expenditures of higher education institutions on R&D (HERD) % GDP	0.11	1.10				
log ICT & Biotechnology patents, % EPO patents	0.13 *	1.80	0.03	0.48	0.15	1.52
Time period dummy variables	yes		yes		yes	
Constant	3.65 ***	5.52	3.51 ***	3.84	2.00 ***	9.24
Wald-tests (p-value):						
log BERD % GDP=log HERD % GDP = 0,	F (2,98) =12.50 (0.00)					
log BERD % GDP = log public sector R&D = 0			F (2,98) = 9.31 (0.00)			
log BERD % GDP = log ICT patents, % EPO patents=0	F (2,98) = 16.53 (0.00)		F (2,98) = 14.20 (0.00)			
log privately financed BERD % GDP = log ICT patents, % EPO patents=0					F(2, 74) = 12.84 (0.00)	
Wald-test of joint significance of the time dummies					F(3, 74) = 28.54 (0.00)	
Hanson J-test (p-value)					0.990	
Sargan test (p-value)					0.5493	
AR(2) test (p-value)					0.4405	
R^2	0.98		0.97		0.98	
# of observations	83		83		82	
# of countries	22		22		22	

Notes: ***, ** and * denote significance at 1%, 5% and 10% level. See Table 3.

5. Conclusions

Patent applications at the European Patent Office (EPO) per capita display large variations across OECD countries and over time. Since patent applications at the EPO are a key indicator included in the European Innovation Scoreboard it is natural to ask what are the main determinants of patent applications. This paper has investigated empirically the determinants of EPO patents based on

panel data for 22 OECD countries for the period of 1980-1999 with data measured as five-year averages.

The paper extends the previous literature in several ways. First, the country coverage and the time span is broader than those used in previous literature. Second, we introduce a new variable, i.e. the share of information and communication (ICT) patents in total patents. ICT patents can be used as a proxy for the countries' specialization in information and communication technologies. Third, we use different measures of R&D effort by distinguishing the different categories of R&D (by performing sectors and by sources of financing). Fourth, we perform extensive robustness checks to change in the estimation procedure (i.e. dynamic panel data models estimated using first difference and system GMM and static fixed effects models) and empirical specifications.

The main finding of the study is that specialization in ICT patents measured as the share of ICT patents in total EPO patents is an important factor in explaining a country's level of patents per capita. The results suggest that the share of ICT patents could be added as an additional indicator in the European Innovation Scoreboard. Furthermore, we find a high degree of persistence in EPO patents per capita with an adjustment rate of around 25 percent between the five-year averages. Turning the impact of innovation input measured as the ratio of gross expenditures on R&D to GDP we find increasing returns to scale in patent production. We also find differences in the estimated impacts of these activities according to their type and source of financing. In particular, we find that the impact of the share of business enterprise expenditures on R&D is twice as much as that for the share of R&D expenditures of higher education institutions. Note that the effect of higher education expenditures on R&D as a percentage of GDP is quite large given the fact that the GDP share of higher education expenditures on R&D is only 0.4% on average, whereas the share of BERD is 1.1%. However, there is no significant impact of publicly financed BERD on EPO patents per capita. The remaining variables such as the Ginarte-Park index of patent rights, GDP per capita and human capital intensity are significantly positively related to EPO patents per capita in the static panel data model but are no longer significantly positive in the dynamic panel data model.

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Appendix
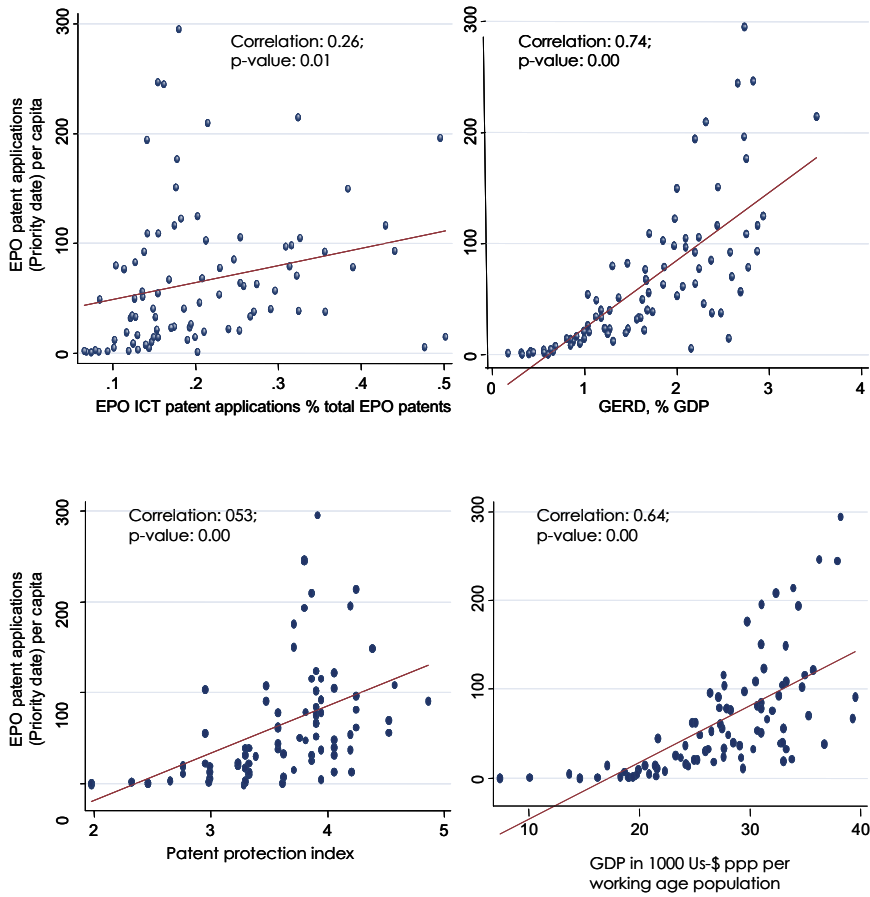
Fig. 1. Correlation coefficients between selected variables (pooled data)
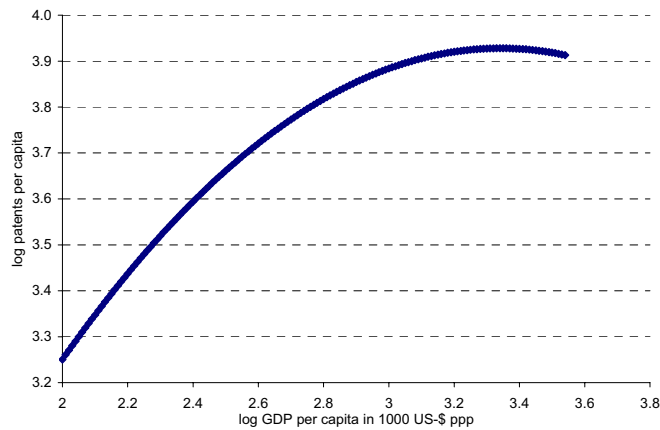
Notes: The figure shows the results of a system GMM regression analysis where log EPO patents to population is the dependent variable, and GDP per capita, GDP per capita squared, log GERD, % GDP and period dummy variables are independent variables. The coefficients of GDP per capita and GDP per capita squared are 2.51 and -0.38, respectively, with t-values of 2.24 and -2.16.

Fig. 2. Relationship between log patents per capita and log GDP per capita

Table 5

Fixed effects estimates (separate estimates for each explanatory variable)

Dependent var./ Independent var.	EPO patents per capita	GERD, % GDP	BERD, % GDP	HERD, % GDP	Public sector R&D, GDP	Government financed BERD, % GDP	ICT patents, % EPO patents	ICT & Biotechnology patents, % EPO patents	Patent protection index	GDP per capita	Openness	Average yrs. of schooling
GERD, % GDP	1.782 (0.000)	1										
BERD, % GDP	0.585 (0.000)	0.709 (0.000)	1									
HERD, % GDP	0.607 (0.000)	0.489 (0.000)	0.442 (0.000)	1								
Public sector R&D, % GDP	1.078 (0.001)	0.868 (0.000)	0.662 (0.000)	1.303 (0.000)	1							
Government financed BERD % GDP	0.362 (0.000)	0.279 (0.000)	0.247 (0.000)	0.344 (0.073)	0.248 (0.047)	1						
ICT patents, % EPO patents	1.343 (0.027)	0.572 (0.000)	0.548 (0.000)	0.379 (0.024)	0.260 (0.013)	1.035 (0.001)	1					
ICT & Biotechnology patents, % patents	1.435 (0.073)	0.651 (0.000)	0.716 (0.000)	0.579 (0.003)	0.340 (0.005)	1.061 (0.003)	1.031 (0.000)	1				
Patent protection index	2.584 (0.002)	1.172 (0.001)	0.894 (0.023)	0.685 (0.143)	0.689 (0.015)	2.160 (0.010)	1.121 (0.013)	1.292 (0.001)	1			
GDP per capita	3.948 (0.000)	1.077 (0.000)	0.254 (0.595)	-0.469 (0.403)	-0.492 (0.152)	-0.487 (0.641)	1.413 (0.000)	1.229 (0.000)	0.182 (0.089)	1		
Openness	-0.367 (0.560)	0.013 (0.962)	0.439 (0.133)	0.280 (0.418)	-0.092 (0.667)	-0.207 (0.745)	0.338 (0.320)	0.359 (0.241)	0.172 (0.068)	-0.016 (0.880)	1	
Average years of schooling	8.747 (0.000)	3.138 (0.000)	1.241 (0.180)	3.790 (0.000)	2.255 (0.000)	6.015 (0.002)	3.614 (0.009)	2.887 (0.000)	0.378 (0.078)	1.208 (0.002)	-0.010 (0.981)	1
High-Tech export share	0.079 (0.617)	0.269 (0.004)	0.498 (0.000)	0.227 (0.109)	0.132 (0.129)	0.243 (0.357)	0.360 (0.001)	0.361 (0.000)	0.047 (0.228)	-0.060 (0.070)	-0.005 (0.932)	-0.007 (0.702)

Notes: We run the regression separately for each explanatory variable using the fixed-effects estimator including time effects. All variables are transformed into logarithms. The number of observations is 85.

Table 6

Determinants of log EPO patents per capita: Fixed effects estimates

	(1)		(2)		(3)		(4)		(5)	
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
log GERD % GDP	1.12 ***	5.21	1.09 ***	4.92	0.57 ***	3.48	0.56 ***	3.35	0.71 ***	4.35
log ICT patents, % total EPO patents	0.68 ***	3.82			0.31 **	2.38				
log ICT & BIOTECH patents, % EPO patents			0.77 ***	3.84			0.38 **	2.32		
log patent protection index					0.68 **	2.01	0.57 *	1.68	0.38	1.06
log average years of schooling					2.02 **	2.36	2.49 ***	2.86	3.49 ***	3.60
log GDP per capita in constant ppp					5.37 ***	3.28	4.45 **	2.47	5.12 ***	3.04
log GDP per capita in const. ppp squared					-0.67 **	-2.43	-0.52 *	-1.73	-0.58 **	-2.03
log openness					-0.42 *	-1.73	-0.45 *	-1.82	-0.35	-1.34
Time period dummy 1980-1984									0.77 ***	8.52

Table 6 (continuous)

	(1)			(2)			(3)			(4)			(5)		
Time period dummy 1985-1989	0.22	***	2.97	0.17	**	2.24	0.13	**	1.89	0.08		1.05	0.85	***	6.72
Time period dummy 1990-1994	0.21	**	2.43	0.13		1.39	0.06		0.58	-0.03		-0.23	0.75	***	4.45
Time period dummy 1995-1999	0.46	***	4.75	0.37	***	3.42	0.21	***	1.36	0.10		0.58	0.87	***	3.71
Constant	9.17	***	12.04	9.09	***	11.81	-9.89	***	-3.81	-9.41	***	-3.51	-13.66	***	-5.81
R^2 (within)	0.90			0.90			0.96			0.96			0.96		
R^2 (within) with respect to time dummies	0.65			0.65			0.65			0.65			0.80		
Wald-test joint significance time dummies	$F(3, 58) = 8.32^{***}$			$F(3, 58) = 5.25^{***}$			$F(3, 53) = 2.94^{**}$			$F(3, 53) = 2.75^{*}$			$F(4, 76) = 28.31^{***}$		
Wald-test joint significance GDP and GDP squared							$F(2, 53)= 13.25^{***}$			$F(2, 53)= 10.44^{***}$			$F(2, 76)= 14.20^{***}$		
# of observations	85			85			85			85			108		
# of countries	22			22			22			22			22		

Notes: *** , ** and * denote significance at the 1 %, 5 % and 10 % level. Germany is excluded starting from 1990. All variables are in natural logarithms.

Table 7

Impact of public sector R&D and publicly financed BERD on EPO patents per capita: Fixed effects estimates

	(1)		(2)		(3)	
	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
log BERD % GDP	0.18	1.20	0.22	1.37		
log privately financed BERD % GDP					0.21	1.37
log publicly financed BERD % GDP					0.20 ***	2.71
log public sector R&D % GDP	0.60 ***	2.94	0.62 ***	2.94		
log ICT patents, % EPO patents	0.34 **	2.17			0.28	1.61
log ICT & BIOTECH patents, % EPO patents			0.27	1.33		
log patent protection index	0.72 *	1.84	0.66	1.62	0.76 *	1.88
Period of 1985-1989	0.33 ***	5.13	0.31 ***	4.61	0.33 ***	4.80
Period of 1990-1994	0.38 ***	5.14	0.37 ***	4.29	0.48 ***	5.62
Period of 1995-1999	0.64 ***	6.80	0.65 ***	5.97	0.75 ***	6.53
Constant	4.12 ***	4.49	4.19 ***	4.41	3.33 ***	5.17
R^2 within	0.89		0.90		0.89	
R^2 within with respect to dummies	0.81		0.81		0.81	
Wald-Test: test log BERD % GDP = log public sector R&D % GDP =0	$F(2, 54) =7.73^{***}$		$F(2, 54) = 8.12^{***}$			
Wald-test log privately financed BERD % GDP= log publicly financed BERD % GDP=0					$F(2, 53) = 6.03^{***}$	
Wald-test joint significance time dummies	$F(3, 54) = 16.52^{***}$		$F(3, 54) = 12.58^{***}$		$F(3, 53) = 14.98^{***}$	
# of observations	83		83		83	
# of countries	22		22		22	

Notes: *** , ** and * denote significance at the 1%, 5% and 10% level. Dependent variable is total EPO patent applications per million population. Germany is excluded starting from 1990. All variables are in natural logarithms. Specifications (1) to (4): Data are measured as five-year averages from 1980-1999 divided into four periods (i.e. 1980-1984, 1985-1989, 1990-1994 and 1995-1999).