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Abstract

This paper investigates the determinants of EPO (European Patent Office) patent applications per capita using a panel of 22 OECD countries with data measured as five-year averages for the period 1980-1999. 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 measured as the share of ICT patents in total patents has a significant and positive impact on EPO patents per capita. Business enterprise R&D (BERD) expenditures are 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. Openness is not significantly different from zero in most of the specifications. Finally, we do not find any impact of publicly financed industrial R&D on EPO patent applications per capita.

JEL Classification: O30, O31, O33.

Keywords: knowledge production function, patents, R&D, ICT patents, panel data.

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 raises the question of the key factors influencing research output at the aggregate level. According to the endogenous growth model developed by Romer (1990), knowledge production increases with research input, in particular input in terms of human capital. The empirical literature widely approves to this point and further emphasises the importance of patent protection and regulatory environments for innovation output (Furman, Porter and Stern, 2002; Ulku, 2004; Sanyal and Jaffe, 2004; Bassanini and Ernst, 2002). Technological specialization measured as Balassa's revealed comparative advantage index also seems to be a significant factor affecting the growth in the number of patent applications (Jungmittag, Grupp, Hullmann, 1998; Furman et al., 2002).

The aim of this paper is to examine the relationships between patent activity and economic variables, particularly those under policy control. We use patents registered at the EPO by 22 inventor countries from the OECD area. Data are measured as five-year averages with the years 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.

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At present there is a growing stock 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.

Scholars using applications to the former include Furman et al. (2002) who use country-level data on 17 OECD countries for the period 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. Bond, Hoeffler and Temple (2001) 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 hypothesis

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:

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

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

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:

$$\ln y_{it} = \lambda \ln y_{it-1} + \tilde{\alpha} \ln x_{it} + \tilde{\beta} \ln X_{it} + v_t + \omega_i + e_{it}.$$

with $\lambda = 1-\theta$, $\tilde{\alpha} = \theta\alpha$, $\tilde{\alpha}_2 = \theta\alpha_2$, $\tilde{\beta} = \theta\beta$, $v_i = \theta\mu_i$, $\omega_t = \theta\lambda_t$ and $e_{it} = \theta\varepsilon_{it}$.

The long-run effects can be easily recovered by dividing $\tilde{\alpha}_1$ and $\tilde{\alpha}_2$ by 1-λ. The adjustment speed increases with a sinking 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).[2] The basic idea of this estimator is to use lagged first differences of the variables as instruments for the

[2] 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.

equation in levels in combination with the usual approach. Thus, the system GMM estimator combines the regression in differences with a regression in levels resulting in more informative moment conditions that are valid under quite reasonable conditions.

Variables and hypothesis

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 the impact of business R&D to be higher than that of public sector R&D. 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 adjustment speed.

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 expect 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 labor 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).

Others 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 W. 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.[3] 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.

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
GERD % GDP	108	1.57	0.77	0.17	3.51
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
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.

[3] 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 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
GERD % GDP	1.23	1.39	1.66	1.76	1.88
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
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 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 represent 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 7 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 F-Tests of joint significance.

4. Results

Results for the static model

Table 3 presents the regression results for the determinants of the EPO patents-population ratio using the fixed effects estimator. All specifications include time dummies to control for common time effects affecting EPO patents in all countries. Specification (1) presents the results of the patent production function including the logarithm of the share of ICT patents in total patents. In specification (2), ICT patents also include biotechnology patents. In specification (3) and (4), we include other control variables such as the log patent protection index, log average years of schooling, log GDP per capita in constant US-$ ppp and its squared term. The fixed effects analysis in specifications (1) to (4) uses 85 observations on 22 OECD countries, with the years of 1980-1999 being divided into 4 time periods. Specification (5) contains the results for the fixed effects model based on a longer time period (5 time periods and 22 OECD countries).

The results of the fixed effects model show all of the explanatory variables except openness and are positive and highly significant. The R^2 is higher than 0.90 in all of the models. As anticipated, R&D intensity has a strongly positive effect on patent activity. The results indicate that a 1% increase in total R&D intensity increases the level of EPO patents per capita by about 1.1% implying slightly increasing returns to scale. ICT patents, whether they include or exclude biotechnology patents, have a powerful and positive impact on EPO patents per capita. According to the results, a 1% increase in the share of ICT patents increases per capita patents between 0.68% and 0.77%. Together, variation in R&D intensity and the share of ICT patents explain one fourth of the variation in the logarithm of EPO patent applications per capita that are not captured by country and time effects. Specification (3) and (4) show that the inclusion of other control variables such as the log of patent protection, log of the average years of schooling, log of the GDP per capita in constant ppp and its squared term, and log of openness leads to a reduction in the coefficients on R&D intensity and the share of ICT patents by one half. Patent protection has a significantly positive impact on EPO patents per capita with coefficients of 0.57 and 0.68. The former is significant at the 10% level and the latter at the 5% level. Human capital intensity measured as average years of schooling is highly significant. In order to allow for a nonlinear relationship between patents per capita and GDP per capita, we introduce quadratic terms into the model. An F-Test rejects the hypothesis that GDP per capita and its squared term are jointly not significantly different from zero with a p-value of 0.00. The signs of the coefficients indicate that EPO per capita patents are increasing with increasing GDP per capita but with a diminishing rate until a threshold. Turning to the time effects, we find that time effects are significant and increasing over time. However, they are not significant when the share of ICT patents enters the regression equation.

Table 3: 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
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	
F-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***	
F-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.

The results of the fixed-regression analysis 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 are presented in Table 4. The distinction between business enterprise R&D and R&D performed in the public sector indicates that it is mainly the latter activity that contributes to EPO patents per capita. This is surprising, given the fact that less than 10% of total patents can be attributed to universities and government labs (European Commission, 2002). Note also that business-sector R&D expenditures are not significant at the 10% level. This loss of precision is clearly due to the complementary relation between private and public sector R&D and the resulting collinearity. Indeed, an F-Test of joint significance indicates that both variables are highly significant. 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: 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 1985-1989	0.33	***	5.13	0.31	***	4.61	0.33	***	4.80
Period 1990-1994	0.38	***	5.14	0.37	***	4.29	0.48	***	5.62
Period 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		
F-Test: test log BERD % GDP = log public sector R&D % GDP =0	$F(2, 54) = 7.73^{***}$			$F(2, 54) = 8.12^{***}$					
F-test log privately financed BERD % GDP= log publicly financed BERD % GDP=0							$F(2, 53) = 6.03^{***}$		
F-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. Specification (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).

Results for the dynamic panel data model

The results for the dynamic panel data models are reported in Table 5. 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. We provide results using the system GMM estimator (see specifications (1) to (3)) and the first-differenced GMM estimator (specification (4) and (5)). 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.[4] 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. In all specifications, we include time dummies for each of the five-year intervals. 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.

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.

Again, 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, indicating that the R&D impact is larger than those found in the static fixed effects model. This indicates that total R&D activities exhibit slightly increasing returns to scale with respect to patenting. We also find that the share of ICT patents in total patents has a significant and positive impact on EPO patents per capita in all of the equations with long-run elasticities of about 0.58 for log ICT patents, % EPO patents and 0.66 for log ICT and biotechnology patents, % EPO patents. 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. 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.

[4] 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) does not seem to have a significant impact on the estimates.

Table 5: Determinants of EPO patents per capita: Dynamic panel data estimates

	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
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	
F-test joint significance GDP and GDP squared		F(2,78) = 2.69*			F(2,73) = 1.78										
# 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. 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 three five-year averages (i.e. 1980-1984, 1985-1989, 1990-1994 and 1995-1999).

However, patent protection no longer has significant effects using the system GMM estimator compared to the static fixed effects regression analysis. In specification (1), the GDP per capita and its squared term are jointly significant with a p-value of 0.00. Figure 2 shows the resulting relationship between log EPO patents per capita and log GDP per capita. EPO per capita patents increase 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 both lagged R&D intensity and other control variables are included in the regression. Therefore, in specification (3), (4) and (5), we do not include GDP per capita squared. Finally, openness has a positive and significant impact on EPO patent applications per capita.

In Table 6 we report the results for the dynamic panel data model with both business-sector and public sector R&D, both measured as a percentage of GDP. Since both variables are highly correlated with each other, we provide F-Tests of joint significance. The positive role of both public sector R&D and higher education expenditures on R&D 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.

Table 6: Impact of public sector R&D: dynamic panel data estimates

	(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 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
F-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)		
F-test joint significance 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		
# of observations	83			83			82		
# of countries	22			22			22		

Notes: ***, ** and * denote significance at 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 the (one-step) system GMM estimator. t-values are robust to heteroscedasticity. 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). Time dummies are included.

Moreover, the impact of business sector R&D is about four times larger than that of the total public sector R&D. This is consistent with the fact that less than 10% of all patent applications in OECD countries stem from government labs or universities. Turning to industrial R&D

disaggregated by the source of funding, estimates suggest that privately financed business R&D is important while publicly financed BERD % GDP is not significant.

The share of ICT patents is only significant at the 10% level based on the first specification and is no longer significant in the second specification. This loss of precision is clearly due to the complementary relation between the share of ICT patents and both of the R&D variables. Using an F-test, we can strongly reject the hypothesis that the coefficients of the share of ICT patents and BERD % GDP are jointly zero.

5. Conclusions

This paper examines 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 patent production function is specified as a standard partial adjustment model. Compared with the other estimator, the system GMM estimator provides more intuitive results regarding the magnitude of the impact of private and public sector R&D on patents. The main finding of the study is that specialization in ICT patents measured as the share of ICT patents is an important factor in explaining a country's level of patents per capita. The econometric results also show slightly increasing returns to scale of own R&D with respect to patenting. We find differences in the estimated impacts of these activities according to their type and source of financing. Business enterprise R&D has a higher impact than public sector R&D, while no significant impact of publicly financed BERD is found. Estimates using the system GMM estimator show a high degree of persistence in EPO patents per capita with an adjustment rate of around 25 percent between the five-year averages. The remaining variables such as the Ginarte-Park index of patent rights, 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. Openness is not significantly different from zero in most of the specifications. Finally, we do not find any impact of publicly financed industrial R&D on EPO patent applications per capita.

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Appendix

Table 7: Fixed effects estimates

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

Figure 1: Correlation coefficients between selected variables (pooled data)

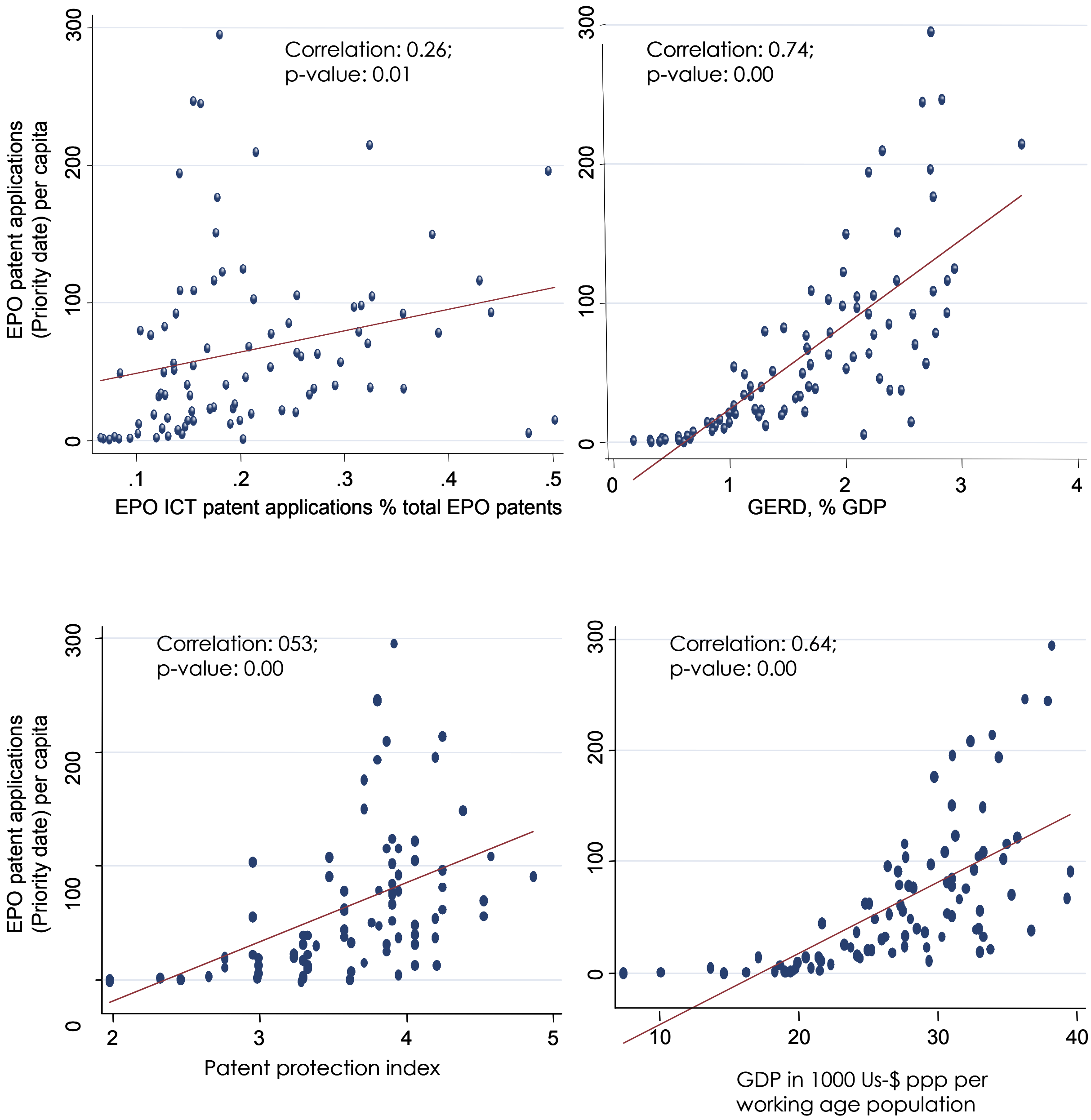
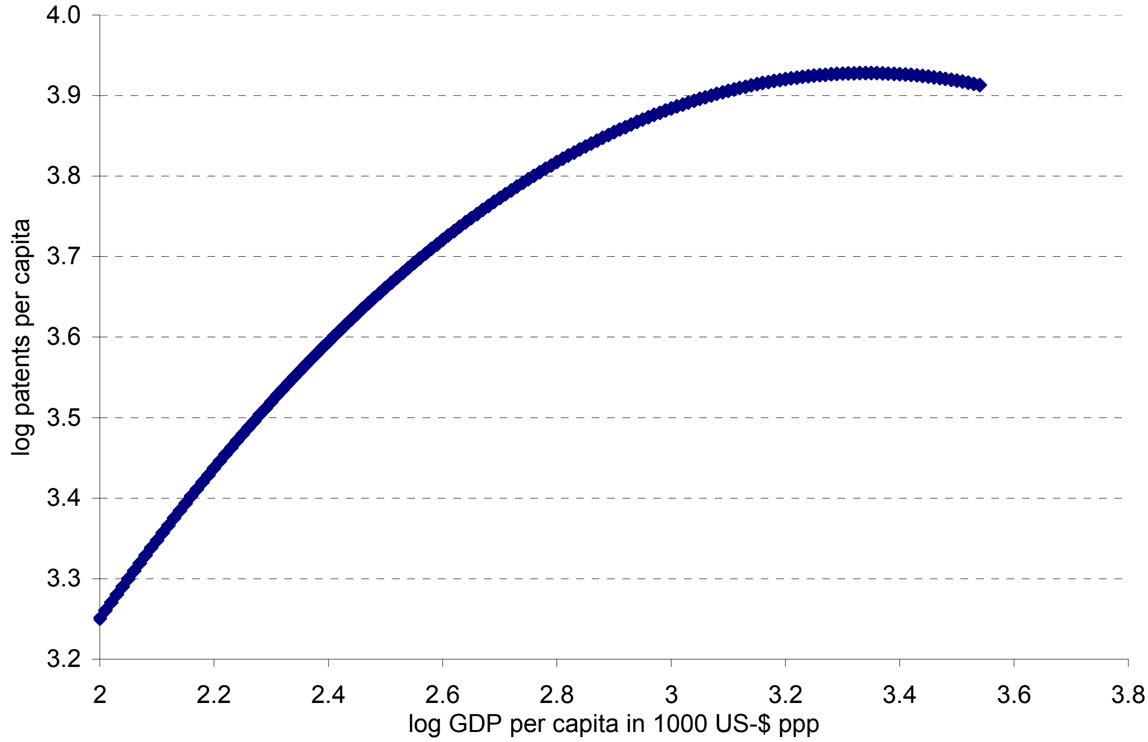


Figure 2: Relationship between log patents per capita and log GDP per capita



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.

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