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INNOVATION AND ECONOMIC GROWTH IN EUROPEAN UNION PANEL DATA ANALYSIS

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ABSTRACT. This study examines the relationship between technological innovation and economic growth in European Union countries over the period 1993-2011. Using Blundell and Bond (1998) generalized method of the moments estimation technique, the study provides evidence that R&D expenditures and patent activities differ in terms of fostering economic growth between EU-15 and EU-13 countries. The main results indicate that there is no significant impact of R&D expenditures on the economic growth and that patent activities determine economic growth in EU-13 subsample and EU-28 as a whole. The study suggests that there may be no one particular recipe for growth for all EU countries and put into question whether setting common numerical targets in EU's innovation policy makes economic sense.

JEL Classification O33, O30, O47

Keywords *economic growth, innovation, R&D, patents, panel data, European Union*

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Introduction

The enlargement of the European Union has far-reaching economic consequences not only for the EU itself but also for the world economy. Measured in terms of goods and service it produces, the EU has achieved a position of the world's largest single market with a PPP GDP of $17,512.109 billion compared with $16,768.050 billion for the USA in 2013 (IMF 2014).

After the ten Central and Eastern European countries, together with Cyprus, Malta and Croatia joined the EU in 2004, 2007, and 2013, EU was transformed from a relatively homogenous organization of developed and highly developed countries to a rather heterogeneous body. Differences in GDP per capita remain still significant across European countries. This raises questions about possible measures that can be taken to close this gap.

The aim of this study is to assess the contribution of technological innovation to per capita GDP growth in a panel of EU countries. Our hypothesis is that the role of technological innovation in fostering economic growth differs between EU-15 and EU-13 countries. We expect the role of innovation in economic growth to be different in old and new member states due to their significant variation in terms of economic development.

Figures 1 and 2 show the trends in average GDP per capita growth rates and proxies of technological innovations in EU-15 and EU-13 countries since 1993. The growth rates are usually higher in EU-13 than EU-15. However, R&D intensity is much larger in case of EU-15 countries, being in the order of two to three times the average levels in EU-13. The gap in patent activity between old and new member states is even larger.

Figure 1. Avarage GDP per capita growth rates

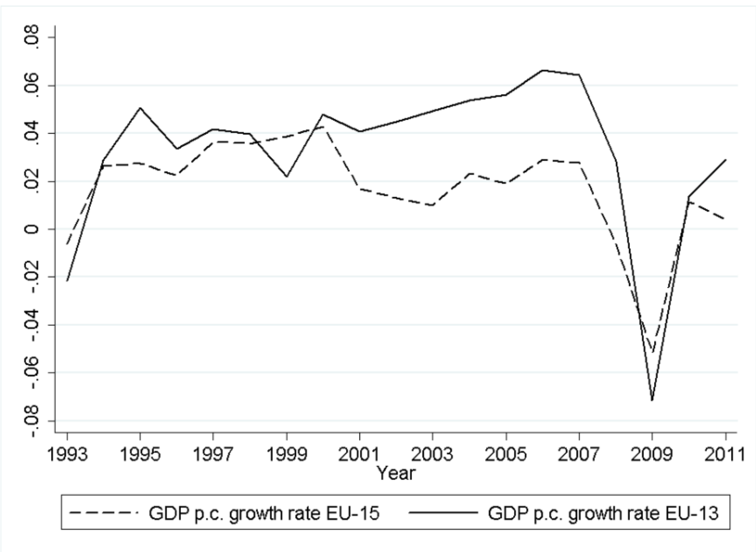
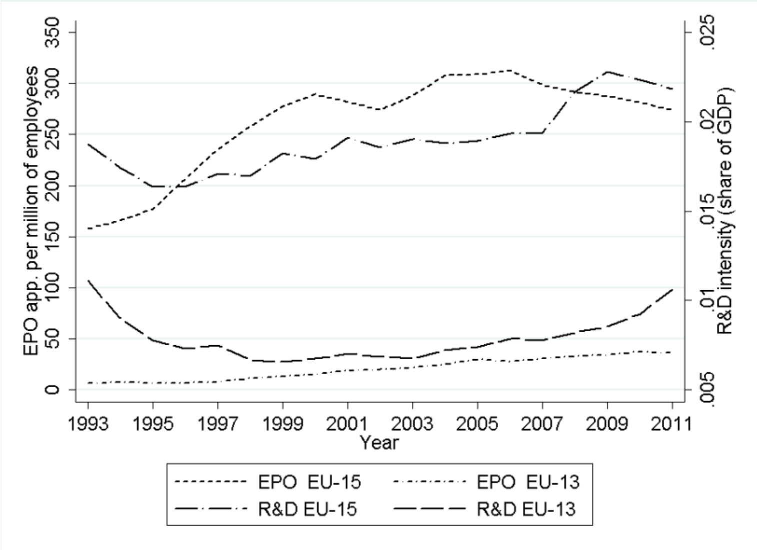


Figure 2. Avarage number of EPO applications (per million of employees) and R&D intensity



We investigate research hypothesis running separate estimates for old (EU-15) and new (EU-13) member states. Innovation is proxied by R&D outlays and patents. R&D expenditures are used as a proxy for investment in generating new knowledge. Data on patents is an indicator of the creation of new ideas. To account for the fact that knowledge builds up over time, as well as the interaction between the existing stock of knowledge and the costs of future research, we include both current and cumulative R&D and patent activity data in the regressions. In order to properly address the possible endogeneity GMM estimator was used.

There seems to be a growing consensus among economists and policy makers that investment in knowledge, which is at the center of the endogenous growth process, is a precondition for achieving permanently high economic growth thus endogenous growth models have clear implications for economic policy. Knowledge created as a result of R&D investment helps use existing physical and human capital resources more efficiently. Therefore, R&D expenditures should have a positive and persistent effect on growth. Following this line of reasoning, many policymakers and economists justify government involvement in R&D. This involvement can take the form of either direct engagement through public R&D expenditures, or indirect support for R&D by providing, e.g., tax incentives to encourage firms to invest in R&D or through the protection of intellectual property rights.

Led by the German-French alliance, EU intensifies efforts to strengthen its economic position in the global economy particularly vis-à-vis the USA and Japan. In 2000 EU adopted Lisbon strategy, a development plan, the key objective of which was to make Europe “the most dynamic and competitive knowledge-based economy in the world" (CEC 2000). One of the goals set out in the Lisbon agenda was to increase R&D expenditure to 3% of GDP. As it became obvious in 2010 that the strategy failed to meet its self-imposed targets, the "Europe 2020" - new 10-year plan was designed. The successor to the Lisbon strategy sets out economic growth based on knowledge and innovation as one of its priorities and maintains 3% objective for R&D intensity.

In the light of above-mentioned facts, we ask and try to answer a series of questions. Is there a relationship between technological innovation and economic growth in EU? Does the increase in R&D outlays contribute to economic growth in the EU? Do the role of R&D in fostering economic growth differs when R&D is differentiated by source of funding?

Whereas contribution of innovation to economic growth has been widely analyzed for OECD countries, the number of studies addressing this problem in the EU is limited. Our contribution to the existing empirical literature is twofold. First, to the best of our knowledge there are no other studies on the impact of innovative activity on the growth in the old and new EU member states. Secondly, we examine the relationship between economic growth and R&D investments differentiated by source of funding.

The study provides mixed results on the role of innovation in economic growth. We found that R&D expenditures are insignificant in both EU-15 and EU-13 countries. At the same time, the results indicate significant and positive relationship of patents with growth in the new member states and insignificant in the old EU countries. This may suggest that the impact of innovation on economic growth is of a more complex nature than previously assumed.

Brief review of the literature

After the boom of exogenous growth models in 1950s and 1960s growth theory hibernated for almost two decades, leaving the problem of sources of growth unsolved, in a "black box" of technology. The work of Romer (1986) and Lucas (1988) began a new strand of research called endogenous growth theory. In these models technological progress is not explicitly modelled and growth goes to infinity because of spillovers of knowledge and human capital externalities, which allow to escape from diminishing returns present in the exogenous growth models of the Solow type. Successive models of endogenous growth, developed in early 1990s by Romer (1990), Grossman and Helpman (1991) and Aghion and

Howitt (1992), are based on a basic growth mechanism, which operates through technological progress that is a result of purposeful R&D activity. In Romer`s model, growth is caused by an increase in the number of substitutable products (horizontal innovations) in such a way that new goods do not replace existing ones. This contrasts with the frameworks developed by Grossman and Helpman and Aghion and Howitt, which focus on vertical innovations that take place along quality ladders. However models differ with respect to the nature of innovations, they exhibit similar dynamics and put knowledge in the center of a never-ending growth process (see Helpman 2004; Acemoglu 2009 for detailed discussion).

Exogenous growth models did not address the issue of incentives to improve technology. Under the perfect competition, if capital and labor are paid their marginal products all output would go to those who supply capital and labor, and nothing would be left to compensate innovators. This problem is overcame in endogenous models by moving away from perfect competition to a monopolistically competitive market. The introduction of market power provides incentives for investment in R&D.

The next issue is the nature of knowledge, that was assumed to be both nonrival and nonexcludable in exogenous models. This naturally leads to question why rational agents would devote resources to the development of knowledge if everyone can use created knowledge freely. To avoid the problem of free-riding, it is assumed that once a design has been produced, a firm can obtain an infinitely lived patent (Romer 1990; Aghion and Howitt 1992). This means that nonrival designs are at least partially excludable. The owner of a patent gains monopoly power and monopoly profits, which provide incentives for further investment in R&D. However, no patent system can provide perfect protection, therefore some useful knowledge that results from the purposeful actions of profit-seeking firms becomes available to the public. This knowledge reduces the future costs of R&D to other innovators; hence the larger is the stock of R&D today, the cheaper it becomes to conduct R&D in the future.

Based on these models, numerous empirical analyses have been conducted. An important issue in the empirical work is how to measure innovation at macroeconomic level. R&D expenditures and data on patent statistics are often used in the empirical analysis of innovation as proxies for innovation "input" and "output", mainly due to their availability for relatively broad samples of countries.

A pioneering work was carried out by Lichtenberg (1992), who examined the relationship between R&D investment and productivity in a cross-section of 74 countries from 1964 to 1989. The effect of privately-funded R&D investment on economic growth was found to be positive. Government-sponsored R&D had a negative influence on economic growth in some specifications, however Lichtenberg indicated that his findings should be interpreted with caution and that the effect of R&D investment may depend more on its objectives than on the source of funding. The other early study on R&D was performed by Goel and Ram (1994), who explored the effect of R&D outlays on output growth from 1960 to 1985 in a cross-section of 52 countries. The authors reported estimates for the full sample and for the subsample of less developed countries. The results suggested that the R&D variable is correlated with growth only in less developed countries. The earliest panel data analyses for a relatively large number of countries was performed by Coe and Helpman (1995) – who studied 22 countries in the period 1970–1990; and Park (1995), who studied 10 OECD countries from 1970 to 1987. Park provides evidence that domestic and foreign productivity growth is positively related to domestic private investment in R&D. Coe and Helpman (1995) provide support for a positive relationship between total factor productivity (TFP) and R&D stocks, including both a country's own and that of its trade partners. Engelbrecht (1997) assessed the robustness of Coe and Helpman's results, including the human capital variable to their model. His findings are consistent with the original results, although the estimated coefficients for R&D are smaller. Guellec and de la Potterie (2004) used panel data for 16 OECD countries over the period 1980-1998 to examine whether R&D - carried out by the business sector, the public sector and foreign firms - is positively related to TFP. Their results suggest that all types of R&D are significant determinants of productivity growth, although the impact of business R&D increased while the impact of public R&D decreased over the time period analyzed. The authors also discuss the reasons why the effect of public R&D on output might be hard to capture directly in empirical analyses. Griffith et al. (2004) carried out a study using panel data of industries across 12 OECD countries for the period 1974–1990, and found R&D to stimulate growth both directly through innovation and indirectly through transfer of technology. Finally, Ang and Madsen (2011) considered the role of R&D in the growth experiences of the six Asian miracle economies from 1953 to 2006. Their results provide strong evidence that economic growth was driven by R&D intensity over the period analyzed.

Another strand of empirical literature tests whether there is relationship between patent activity and economic growth. Porter and Stern (2000) contribute to a better understanding of endogenous growth by estimating the ideas production function. Using data for 16 OECD countries, the authors examined the determinants of the flow of international patents. Those patents were measured by patents granted by USPTO (United States Patent

Office). The obtained results show that the ideas production function increases proportionally with the existing stock of knowledge and that aggregate output is positively related to patent stock. However, the worldwide knowledge stock may have a negative effect on the ideas production function since it raises the bar for producing domestic technology that is new at the international level. Ulku (2007) used data from 41 OECD and non-OECD countries and found that market size is an important determinant of the effectiveness of R&D sectors in promoting innovation. The results show that innovation, proxied by USPTO patent flows, raises per labor GDP in the high-income OECD countries only, while raising it in all non-OECD countries, except for the low-income ones. These findings suggest that developing countries benefit more from innovation than developed countries in terms of increasing per labor GDP. Madsen (2008) demonstrated that in 16 OECD countries the effect of international patent stock on growth was positive during the period 1883 to 2004. In another paper Madsen (2010) used both R&D and patents as measures of innovative activity in 21 OECD countries in different periods of time. Change in the flow and stock of patents and patenting intensity had a positive effect on productivity growth. Barcenilla-Visús et al. (2013) examined data for 15 OECD countries from 1989 to 2004 to assess the role of TFP in explaining economic growth. The results show that technology, proxied by domestic R&D stocks or alternatively by the stock of patents, stimulates the variation in technological change.

Data and methodology

The aim of the present study was to assess the contribution of patents and R&D outlays to economic growth in the EU countries. The analysis was performed at the macroeconomic level for 28 EU countries over the period 1993–2011. The countries are separated into two subsamples: EU-15 and EU-13. The time period of analysis was chosen to maximize the number of observations, given data availability. Since some of the data is not available, the panel is unbalanced and the number of observations depends on the choice of explanatory variables. Most panel data studies of economic growth use averaged data over certain time spans, usually five or ten years. Given the relatively short time dimension of our dataset (T=19 or T=16 depending on data availability), it was not possible to use averages for a panel such as ours. We use annual data instead, as it provides us with sufficient number of observations to estimate separate models for two relatively small subsamples, although we acknowledge some limitations of such approach.[1]

The standard specification in empirical literature on economic growth is the Barro-type equation[2], written in a panel variant as:

$$\Delta y_{i,t} = (\alpha - 1) y_{i,t-1} + \beta x_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

where $\Delta y_{i,t}$ is the growth rate of GDP per capita between time *t–1* and *t*, $x_{i,t}$ is a vector of control variables, η_i is a country-specific effect that allows controlling for unobserved time-invariant country heterogeneity (historical, cultural and institutional factors), and μ_t is a time-specific effect.

Rearranging equation (1) as a dynamic model with a lagged dependent variable on the right-hand side:

$$y_{i,t} = \alpha y_{i,t-1} + \beta x_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (2)$$

we obtain a convergence equation estimated in growth empirics.

The standard problem faced in empirical studies on economic growth is the choice of explanatory variables, given that the number of regressors that have been found to be significant in previous growth regressions is enormous (Sala-i-Martin et al. 2004; Doppelhofer and Weeks 2011). However, because of the relatively small sample of countries, only a limited number of determinants of economic growth were chosen. To avoid the problem of misspecification, we decided to include two variables that are robust determinants of growth even in the most restricted tests of robustness (Levine and Renelt 1992). The first base regressor is the investment rate (*INV*), and the second is the lagged level of log of GDP per capita (*GDP*(-3)).[3] In addition, we controlled for foreign trade, as imports capture technology spillovers and exports account for the effects of foreign competition on a country's innovativeness. Openness (*OPEN*)) is important in our study because of the free trade and free flow of production factors among EU member countries.

Based on a Barro-type regression we estimate the contribution of innovation to economic growth using following equation:

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[1] We also considered using three-year averages instead of the typical five-year averages, but even in this case the number of observations is extremely low and falls to less than sixty in worst cases – what cannot guarantee precise and reliable estimates.

[2] Cf. Barro 1991, 1996.

[3] Three lags were used, as a one year lagged level of GDP per capita may be too recent to explain the convergence effect. Moreover, shorter lag lengths were not enough to wipe out autocorrelation.

$$GDP_{i,t} = \alpha_1 + \alpha_2 GDP_{i,t-3} + \alpha_3 INV_{i,t} + \alpha_4 OPEN_{i,t} + \alpha_5 Z_{i,t} + \varepsilon_{i,t} \quad (3)$$

where *Z* denotes the “innovation” variable.

Technological innovation in our model is proxied by current and cumulative patents and R&D expenditures.[4] We distinguished between private and public sources of R&D funding and tried to answer the question whether private and public R&D investments differ in fostering growth.

The data on GDP, investment rate and trade openness comes from PWT 8.0 (Feenstra et al. 2013). The GDP per capita was calculated as the ratio of GDP at constant 2005 national prices (in mil. 2005 US$) to population (in mil.). Investment rate is proxied by the share of gross capital formation in GDP at current PPPs. Openness was calculated as the log of sum of exports and imports to GDP at current national prices. The data on innovation comes from the Eurostat database and contains total intramural R&D expenditures (*RD_TOT_FL*), R&D by source of funds, and patent activity. Data on patent activity includes European Patent Office applications (*EPO_FL*) and patents granted by the United States Patent and Trademark Office (*USPTO_FL*) by priority year at the national level.

Stock variables were computed using the perpetual inventory method, employing the formulae:

$$S_0 = F_1 / (r + \sigma) \quad (4)$$

$$S_{t+1} = F_{t+1} + (1 - \delta) S_t \quad (5)$$

where S_0 stands for the initial stock, F_t is the flow at time t, r is the compound annual growth rate of flow (computed for each country for the period analyzed), and δ is the depreciation rate[5] (20 per cent, as suggested in the literature).

Stock variables include R&D total stock (*RD_TOT_ST*), stock of privately/publicly funded R&D (*RD_PRIV_ST*/*RD_PUB_ST*), EPO applications stock (*EPO_ST*) and stock of patents granted by USPTO (*USPTO_ST*). The stock of private R&D was calculated using data on R&D expenditures by source of funds, and comprises business enterprises, private non-profit and abroad sectors. Stock of public R&D was calculated as the sum of government and

[4] Our indicators of innovation have some limitations. R&D expenditure is a measure of inputs and does not take into account productivity. Patents capture only some sorts of inventions, which may have very different values.
[5] Sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate (Guellec and de la Potterie 2001).

higher education sectors.[6] We also used data on gross domestic expenditure on R&D funded by the business enterprise sector (*RD_BUS_FL*), and gross domestic expenditure on R&D funded by government sector (*RD_GOV_FL*), as these are the sectors with the highest shares in total R&D. Data on R&D is expressed as a share of GDP. Table 13 lists the variables, together with their definitions and data sources.

Modelling the dynamic panel data has several advantages. The most important ones are the increase in the number of observations and the ability to control for individual unobserved heterogeneity. However, the use of such models introduces a set of problems, therefore special attention should be paid to the estimation method. We estimate equation (3) using three alternative methods to see whether the data provides support for the innovation-growth relationship.

The first is the fixed effects estimator (henceforth FE). As Durlauf et al. (2005) points out, the motivation for using this estimator in growth empirics is fact that the estimates will not be biased by any omitted variables which are constant over time. However, the use of this estimator brings with it certain costs. Measurement error is typically a problem, since the fixed effects estimator ignores the between-country variation and the reduction in bias implies higher standard errors. Moreover, Nickell (1981) proved that the FE estimator is not consistent in autoregressive panel data models with finite T, since inclusion of the lagged dependent variable leads to a correlation between regressors and the error term. Therefore dynamic panel data estimation suffers from the Nickell bias. Although this bias is a declining function of T (bias of order 1/T), we cannot guarantee that the bias was eliminated in our estimations.

For this reason the second estimator we employ is the bias-corrected LSDV estimator (henceforth LSDVC). This method, developed for unbalanced dynamic panels by Bruno (2005) helps to overcome the problem mentioned above and estimates a bootstrap variance-covariance matrix for the corrected estimator. We use the Blundell-Bond (1998) estimator to initiate bias correction and take the first order term of the approximation to the bias, which as Bruno shows, is usually capable of accounting for more than 90% of the actual bias. In order to bootstrap the estimated standard errors we undertook 100 repetitions of the procedure. The two estimation methods outlined above suffer however from one major limitation. None of them can be applied in the presence of endogenous or even weakly exogenous regressors.

[6] Due to the insufficient number of observations, stocks of privately and publicly funded R&D were computed using the compound growth rate of total R&D expenditures.

The nature of some of our regressors gives the strong potential for endogeneity. Investment is likely to be an endogenous variable as higher output may lead to higher investment. There is also similar problem with R&D: the direction of causality in R&D expenditure-growth relation is not obvious.

The most popular alternative strategy to address potential endogeneity is to use one of the class of generalized method of moments estimators. This is the third method of estimation that we employ. The GMM estimator developed by Arellano and Bond (1991) removes fixed effects, taking first differences of equation (2) in the first step. Then the differenced right-hand-side variables are instrumented with their lagged levels. A serious drawback of this estimator is that the lagged levels are likely to be weak instruments if series are highly persistent, as output and stock variables are in our case.[7]

To deal with this problem, Blundell and Bond (1998) proposed an estimator (henceforth denoted GMM) that is obtained by adding the original equation in levels to the equation in differences. Instruments in differences are used for the former and instruments in levels for the latter. This helps to solve the problem of weak identification as even persistent series may be valid instruments if their lagged first differences are used. Therefore, GMM is our preferred estimator since it is found to be more efficient for data such as ours.

Table 1 contains the descriptive statistics for all variables used in the study. Statistics are presented separately for EU-28, EU-15 and EU-13 samples for the period of 1993-2011. The Table shows several expected patterns, for example, that EU-15 countries are richer, invest more, and are more innovative in terms of R&D and patent statistics. On the other hand, EU-13 economies grow faster and trade more than the old EU members.

Empirical results

This section contains the results of regression analysis for the two samples (EU-15, EU-13) as well as for the whole group of countries (EU-28). Tables 3-12 contain the results for all alternative methods, but we concentrate on the GMM estimations as the most reliable. As a robustness check, we repeat the analysis using FE and LSDVC estimators, which take

[7] An additional important advantage of GMM estimators is that by differencing, they minimalize the risk of nonstationarity of series.

into account country specific effects.[8] All regressions follow general specification (3) and, for the purpose of comparability, include a constant set of control variables and one proxy of technological innovation at the time to minimize the risk of multicollinearity.[9]

The first set of variables is comprised of lagged GDP per capita, investment rate, and openness, as these variables are typically employed in growth regressions. The estimated coefficients of lagged GDP are statistically significant, have expected sign and are in line with the main strand of growth empirics. As expected, the share of investments in GDP is a significant and positive determinant of GDP growth. Coefficients of trade openness were significant and positive in the EU-28 and EU-15 samples, and statistically insignificant in most regressions for the EU-13.[10]

As summarized in Tables 3-8, the results demonstrate a statistically insignificant relationship between total R&D expenditures and GDP per capita growth. This holds true across all the samples analyzed and regression techniques, even when we distinguish between business and government-funded flows of R&D.

As these results may stem from the fact that current expenditures do not capture the cumulative nature of knowledge, and that its impact on economic growth cannot thus be observed when using present investments in R&D, we include in our analysis proxies for cumulative R&D effort (i.e. R&D stocks). But even when measured by accumulated R&D outlays, its impact is still insignificant using conventional levels of significance.

After discriminating between privately and publicly funded R&D stocks, the results still lack empirical evidence for the stimulating role of cumulative R&D expenditures. The stock of publicly funded R&D was statistically insignificant in all GMM specifications in each sample analyzed, and significant and negative in the case of the EU-28 countries (FE) and EU-15 (LSDVC). In turn, the stock of privately funded R&D was statistically insignificant in all specifications for EU-28 and EU-15 samples. In case of EU-13 countries,

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[8] We tested for the presence of outliers in our dataset by use of Stata *hadimvo* and *grubbs* procedures. All regression include time dummies for crisis years: 2008, 2009, 2010, and 2011. FE, LSDVC and GMM estimations carried out using *xtivreg2*, *lsdvc* and *xtabond2* Stata procedures from SSC, respectively. When the GMM estimator is applied, the second lags of endogenous variables were used and forward orthogonal deviations to minimize data loss in panel with gaps. All GMM estimations are one-step with robust standard errors.

[9] The only exceptions are models 9 in Tables 7, 8 and 11 that were re-estimated with a reduced set of control variables due to an alarming p-value of the Hansen test, which indicates a potentially excessive number of instruments. To avoid instrument proliferation, investment or investment and openness were excluded from the regressions. We found variables of interest to be statistically significant and positive in the above models irrespective of the number of other conditioning variables.

[10] The coefficients for trade openness were, however, statistically significant and positive in most of FE and LSDVC regressions for the EU-13 sample.

its impact was negative and significant using all estimation techniques.[11] Thus, returns on R&D expenditures seem to be questionable, particularly in the new member states.

When it comes to patent activity, according to the GMM results displayed in Tables 9-12, current and cumulated patents are significant determinants of GDP growth in both the new member states (EU-13) and the EU as a whole (except for an insignificant coefficient for stock of EPO applications in model 3 in Table 11), while the coefficients for the EU-15 are insignificant at a 10% level. The results for EU-13 and EU-28 are generally supported by other estimation techniques. FE and LSDVC estimators yield a positive and significant correlation between EPO application stock and GDP per capita in the whole EU. In the EU-15 sample, the coefficient is positive and significant in case of annual flows of patents and stock of USPTO patents when using the FE technique, and flows of USPTO patents in case of LSDVC estimator. However, these techniques are less reliable, as they suffer from endogeneity bias and, as a consequence, the obtained positive relationship between patent activity and GDP per capita may result from reverse causality.

Discussion

The results do not indicate the presence of a positive impact of R&D spending on GDP growth. At the same time, patent activities do matter in fostering economic growth, but only in the case of the EU-13 countries and European Union as a whole. However, effects of R&D and patents on growth are theoretically plausible, as we pointed out in the introduction. Our findings may seem surprising at a first glance, hence they require some explanation.

The results concerning R&D may indicate the possible more complex relationship between R&D expenditures and economic growth. When looking at the data, one may suppose that R&D expenditures in the EU were incapable of generating technological progress because they did not reach the critical mass, as only high R&D cumulative expenditures have a positive impact on GDP. At the theoretical level, question may be raised as to whether there is too little or too much R&D (Alvarez-Pelaez and Groth 2005).[12] This

[11] We do not take into account results obtained by model 9 (Table 7), because of alarming Hansen test p-value.

[12] The EU-13 sample is comprised mostly of countries with R&D stock below EU-28 median in 2011. The notable exceptions are the Slovenia and Estonia. On the other hand, R&D stocks in EU-15 member states are generally above EU-28 median, except for Greece, Italy and Spain.

line of reasoning also paves the way for interesting future research on the optimal level of R&D.

With respect to public R&D expenditures, they are mainly aimed at generating basic knowledge that is used in later stages by industry (the business sector) to create technological innovation. As a large part of government-funded R&D is aimed at public missions that do not directly affect productivity (health, the environment) (Guellec and de la Potterie 2001), it is highly possible that there is no direct link between public R&D and growth. Another likely explanation of the insignificant relationship between government funded R&D and economic growth may be inefficiency. It should be borne in mind that bureaucrats cannot get access to all decentralized information, therefore they are not able to behave like a benevolent social planner. As Romer (2005, 690) indicates, many people see the endogenous growth theory "as a blanket seal of approval for all of their favorite government interventions, many of which are very wrong-headed." For this reason government-funded R&D spending does not necessarily have to be effective.

Another important issue that may influence results is the heterogeneity of European countries. Comparing the old and new European member states (EU-15 and EU-13) does not fully solve the problem. The EU-15 is comprised of countries with both low R&D intensity (e.g. Greece, Portugal, Spain and Italy) as well as economies with relatively high R&D spending (e.g. Finland, Sweden, Denmark, and Germany). Moreover, heterogeneity may also reflect differences in institutions, culture and religion. However, the results may also suggest that the impact of R&D on GDP growth is indirect and hence mitigated.

As far as patent activity is concerned, the findings are quite surprising as patents have a strong commercial orientation and therefore can be expected to promote growth independently of any analyzed group of countries. We explain our results by the fact that owing to the relatively high costs of patenting, only the most economically valuable inventions are patented in the new member states, hence its impact on economic growth in EU-13 was positive. This may be related to the costs of applying for a patent in terms of actual fees as well as the relative market-size-per-unit application cost, and the different industrial structure of the new and old European countries (Arundel and Kabla 1998).[13] The reason for the lack of a correlation between the number of patents awarded and economic growth in EU-15 may be due to, inter alia, patent-trolling behavior, where patenting is purely

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[13] The differences in patenting propensity are related to, inter alia, the size of a firm, its international orientation, and the industrial sector (Arundel and Kabla 1998).

an anti-competitive strategy. This refers to situations where firms seek patents not to produce innovation, but to extort patent fees from competitors (Boldrin and Levine 2013).

The results may also be influenced by other factors. The relatively short time frame prevents us from using averages instead of annual data. Growth regressions based on annual data reflect short-run rather than long-run dynamics, although using stock variables as regressors helps to overcome this problem, at least to some extent. In fact the relationship between growth and innovation may become significant when more (longer) data becomes available.

The other potential limitation of the study is that it neglects the impact of non-technological innovations on economic growth. In substance, to obtain a complete picture of the innovativeness of a country, the concept of innovation should be extended to non-technological innovation embodied in new marketing methods or organizational change as well (OECD and Eurostat 2005). This may be an important issue for future research.

Conclusion

The aim of this paper was to provide empirical evidence in relation to the role of technological innovation in the process of economic growth in a sample of European Union countries. The main objective was to test whether the relationship between innovation and economic growth differs between the EU-15 and EU-13 countries. The impact of R&D investments, differentiated by the source of funding, on economic growth was also examined.

The estimated results show that the relation between innovation efforts and growth is not as obvious as the family of endogenous growth models predicts. We found no statistically significant relationship between total R&D outlays and economic growth. This holds true across three samples analyzed. The relationship remains insignificant also when R&D is differentiated by the source of funding. On the other hand, patents occurred to be significant determinants of GDP growth in the new member states (EU-13) and the EU as a whole (except for an insignificant coefficient for stock of EPO applications). Estimated coefficients were positive both for flows and stocks of USPTO and EPO patents.

In the light of our results, several issues concerning the European innovation policy should be addressed. First, the results raise the question whether setting common numerical targets in EU's R&D policy makes economic sense. In our setting, both the current and cumulative R&D expenditures proved to be insignificant for creating growth. It is of particular importance for building catching up strategies of new member states. Are high R&D spending indispensable for rising productivity? The Austrian “growth puzzle” shows that there are other possible ways to catch up: capital accumulation, adoption of technologies developed abroad, reforming industrial structure (OECD 2007). Setting common targets without taking into account country specific characteristics may lead to ineffective innovation policies.

Second, the paper provides mixed results about the role of patent activity in economic growth in EU-15 and EU-13 countries. This in fact raises the issue of whether the role of innovation in growth is different for economies at different stages of socio-economic development. This is certainly a topic which deserves further examination in a more comprehensive analysis.

All in all, our study suggests that there may be no one recipe for growth for all EU countries. In fact, the growth strategies may differ across European countries and should address a country’s specific settings and development challenges. This questions the practice of setting common innovation policy objectives in the EU. However, the estimated results for subsamples should be approached with caution given the relatively small time dimension of the dataset and weaknesses of our measures of innovation. A longer time frame could give more reliable estimates; therefore, our findings serve as a pilot and should be confirmed by future studies.

References

Acemoglu, D. 2009. *Introduction to Modern Economic Growth*. Princeton: Princeton University Press.

Aghion, P., P. Howitt. 1992. "A Model of Growth through Creative Destruction." *Econometrica* 60 (2): 323–351.

Alvarez-Pelaez, M. J., C. Groth. 2005. "Too Little or Too Much R&D?" *European Economic Review* 49 (2): 437-456.

Ang, J.B., J.B. Madsen. 2011. "Can Second-Generation Endogenous Growth Models Explain the Productivity Trends and Knowledge Production in the Asian Miracle Economies?" *Review of Economics and Statistics* 93 (4): 1360–1373.

Arellano, M., S. Bond. 1991. "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations." *Review of Economic Studies* 58 (2): 277–297.

Arundel, A., I. Kabla. 1998. "What Percentage of Innovations are Patented? Empirical Estimates for European Firms." *Research Policy* 27 (2): 127–141.

Barcenilla-Visús, S., J.M. Gómez-Sancho, C. López-Pueyo, M.J. Mancebón & J. Sanaú. 2013. "Technical Change, Efficiency Change and Institutions: Empirical Evidence for a Sample of OECD Countries." *Economic Record* 89 (285): 207–227.

Barro, R.J. 1991. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics* 106 (2): 407–443.

Barro, R.J. 1996. "Determinants of Economic Growth: a Cross-Country Empirical Study." NBER Working Paper 5698. National Bureau of Economics Research.

Blundell, R., S. Bond. 1998. "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models." *Journal of Econometrics* 87 (1): 115–143.

Boldrin, M., D.K. Levine. 2013. "The Case Against Patents." *Journal of Economic Perspectives* 27 (1): 3–22.

Bruno, G.S.F. 2005. "Estimation and Inference in Dynamic Unbalanced Panel-Data Models with a Small Number of Individuals." *The Stata Journal* 5 (4): 473–500.

CEC. 2000. *Presidency Conclusions of the Lisbon European Council, March 23/24*. Brussels: Commission of the European Communities.

Coe, D.T., E. Helpman. 1995. "International R&D Spillovers." *European Economic Review* 39 (5): 859–887.

Doppelhofer, G., M. Weeks. 2011. *Robust Growth Determinants*. CESifo Working Paper No. 3354.

Durlauf, S.N., P.A. Johnson, J.R.W. Temple. 2005. "Growth Econometrics." in: *Handbook of Economic Growth*, vol. 1A. ed. P. Aghion, S.N. Durlauf, 555–677. New York: Elsevier.

Engelbrecht, H.-J. 1997. "International R&D Spillovers, Human Capital and Productivity in OECD Economies: An Empirical Investigation." *European Economic Review* 41 (8): 1479–1488.

Eurostat Database. http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

Feenstra, R.C., R. Inklaar, M.P. Timmer. 2013. "The Next Generation of the Penn World Table" available for download at www.ggdc.net/pwt.

Goel, R.K., R. Ram. 1994. "Research and Development Expenditures and Economic Growth: a Cross-Country Study." *Economic Development and Cultural Change* 42 (2): 403–411.

Griffith, R., S. Redding, J. Van Reenen. 2004. "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD industries." *Review of Economics and Statistics* 86 (4): 883–895.

Grossman, G.M., E. Helpman. 1991. "Quality Ladders in the Theory of Growth." *The Review of Economic* Studies 58 (1): 43–61.

Guellec, D., B.V.P. de la Potterie. 2001. "R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries." OECD Science, Technology and Industry Working Papers 2001/3.

Guellec, D., B.V.P. de la Potterie. 2004. "From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?" *Oxford Bulletin of Economics and Statistics* 66 (3): 353–378.

Helpman, E. 2004. *The Mystery of Economic Growth*. Belknap Press of Harvard University Press.

IMF. 2014. *World Economic Outlook - Recovery Strengthens, Remains Uneven*. Washington: IMF.

Levine, R., D. Renelt. 1992. "A Sensitivity Analysis of Cross-Country Growth Regressions." *American Economic Review* 82 (4): 942–963.

Lichtenberg, F.R. 1992. "R&D Investment and International Productivity Differences." NBER Working Paper 4161. National Bureau of Economic Research.

Lucas, R.E. 1988. "On the Mechanics of Economic Development." *Journal of Monetary Economics* 22 (1): 3–42.

Madsen, J.B. 2008. "Economic Growth, TFP Convergence and the World Export of Ideas: a Century of Evidence." *The Scandinavian Journal of Economics* 110 (1): 145–167.

Madsen, J.B. 2010. "The Anatomy of Growth in the OECD since 1870." *Journal of Monetary Economics* 57 (6): 753–767.

Nickell, S. 1981. "Biases in Dynamic Models with Fixed Effects." *Econometrica: Journal of the Econometric Society* 49 (6): 1417–1426.

OECD and Eurostat. 2005. *Guidelines for Collecting and Interpreting Innovation Data - The Oslo Manual*, 3rd ed. Paris: OECD.

OECD. 2007. *OECD Economic Surveys: Austria 2007,* OECD Publishing, 2007

Park, J. 1995. "International R&D Spillovers and OECD Economic Growth." *Economic Inquiry* 33 (4): 571–590.

Porter, M.E., S. Stern. 2000. “Measuring the "Ideas" Production Function: Evidence from International Patent Output.” NBER Working Paper 7891. National Bureau of Economic Research.

Romer, P. 2005. – interview with the author in: Snowdon, B., H.R. Vane. 2005. *Modern Macroeconomics. Its Origins, Development and Current State.* Edward Elgar.

Romer, P.M. 1986. “Increasing Returns and Long-Run Growth.” *Journal of Political Economy* 94 (5): 1002–1037.

Romer, P.M. 1990. “Endogenous Technological Change.” *Journal of Political Economy* 98 (5): S71–S102.

Sala-i-Martin, X., G. Doppelhofer, R.I. Miller. 2004. “Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach.” *American Economic Review* 94 (4): 813–835.

Solow, R.M. 1956. “A Contribution to the Theory of Economic Growth.” *Quarterly Journal of Economics* 70 (1): 65–94.

Ulku, H. 2007. “R&D, Innovation and Output: Evidence from OECD and nonOECD Countries.” *Applied Economics* 39 (3): 291–307.

Table 1. Descriptive statistics

Sample	Variable	N	Mean	SD	Min.	Max.
EU-15	*GDP*	285	10.278	0.258	9.666	11.048
	GDPGR	285	0.017	0.027	-0.090	0.105
	INV	285	0.239	0.042	0.132	0.362
	OPEN	285	-0.186	0.489	-0.996	1.162
	RD_TOT_FL	256	0.019	0.008	0.005	0.041
	RD_BUS_FL	224	0.011	0.006	0.001	0.030
	RD_GOV_FL	224	0.006	0.002	0.001	0.011
	RD_TOT_ST	273	0.083	0.037	0.020	0.175
	RD_PRIV_ST	241	0.056	0.030	0.007	0.130
	RD_PUBL_ST	184	0.028	0.011	0.011	0.049
	EPO_FL	285	5.114	1.243	1.114	6.454
	USPTO_FL	240	4.527	1.377	0.019	6.303
	EPO_ST	285	6.527	1.291	2.374	7.925
	USPTO_ST	240	5.995	1.440	1.684	7.590
EU-13	*GDP*	247	9.467	0.370	8.636	10.147
	GDPGR	247	0.033	0.045	-0.174	0.124
	INV	247	0.207	0.059	0.057	0.371
	OPEN	247	0.087	0.321	-0.890	0.651
	RD_TOT_FL	214	0.008	0.004	0.002	0.025
	RD_BUS_FL	202	0.003	0.003	0.000	0.015
	RD_GOV_FL	204	0.004	0.001	0.001	0.008
	RD_TOT_ST	214	0.032	0.016	0.008	0.088
	RD_PRIV_ST	167	0.016	0.011	0.002	0.057
	RD_PUBL_ST	161	0.016	0.007	0.003	0.039
	EPO_FL	232	2.344	1.309	-1.450	4.930
	USPTO_FL	196	1.694	1.147	-1.977	3.763
	EPO_ST	152	3.565	1.439	-0.696	6.364
	USPTO_ST	144	3.224	1.151	-0.008	4.875
EU-28	*GDP*	532	9.901	0.513	8.636	11.048
	GDPGR	532	0.024	0.037	-0.174	0.124
	INV	532	0.224	0.053	0.057	0.371
	OPEN	532	-0.060	0.441	-0.996	1.162
	RD_TOT_FL	470	0.014	0.009	0.002	0.041
	RD_BUS_FL	426	0.007	0.006	0.000	0.030
	RD_GOV_FL	428	0.005	0.002	0.001	0.011
	RD_TOT_ST	487	0.060	0.039	0.008	0.175
	RD_PRIV_ST	408	0.039	0.031	0.002	0.130
	RD_PUBL_ST	345	0.023	0.011	0.003	0.049
	EPO_FL	517	3.871	1.876	-1.450	6.454
	USPTO_FL	436	3.254	1.903	-1.977	6.303
	EPO_ST	437	5.497	1.949	-0.696	7.925
	USPTO_ST	384	4.956	1.895	-0.008	7.590

Table 2. Missing values per variable (%)

Variable	Missings (%)		
	EU-28	EU-15	EU-13
	N = 532	N = 285	N = 247
RD_TOT_FL	11.7	5.5	6.2
RD_BUS_FL	19.9	11.5	8.5
RD_GOV_FL	19.5	11.5	8.1
RD_TOT_ST	8.5	2.3	6.2
RD_PRIV_ST	23.3	8.3	15.0
RD_PUB_ST	35.2	19.0	16.2
EPO_FL	2.8	-	2.8
USPTO_FL	18.0	8.5	9.6
EPO_ST	17.9	-	17.9
USPTO_ST	27.8	8.5	19.4

Table 3. R&D total expenditures and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.6947***	0.9390***	0.8831***	0.7594***	0.9199***	0.7615***	0.5019***	0.9356***	0.7233***
	(0.070)	(0.010)	(0.038)	(0.038)	(0.013)	(0.059)	(0.123)	(0.019)	(0.107)
INV	1.4397***	0.4240***	1.5396***	0.4209**	0.2687***	0.2379	2.1920***	0.5004***	2.2674***
	(0.325)	(0.044)	(0.283)	(0.165)	(0.050)	(0.246)	(0.466)	(0.055)	(0.351)
OPEN	0.2632***	0.0739***	0.1242**	0.2587***	0.0876***	0.2163***	0.2415***	0.0637***	0.0746
	(0.036)	(0.013)	(0.058)	(0.044)	(0.014)	(0.061)	(0.059)	(0.021)	(0.165)
RD_TOT_FL	0.8854	0.2860	-1.3405	1.0670	-0.4540	-2.7444	-3.0748	0.2542	1.4073
	(4.015)	(0.694)	(3.488)	(3.079)	(0.577)	(2.959)	(7.498)	(1.288)	(7.698)
C	2.7693***		0.9179***	2.4613***		2.5432***	4.3107***		2.2102**
	(0.589)		(0.328)	(0.369)		(0.589)	(1.029)		(1.010)
N	470	453	470	256	245	256	214	208	214
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.849			0.924			0.869		
Hansen test (p-value)			0.373			0.786			0.353
AR(2) test (p-value)			0.412			0.339			0.528
No. of instruments			13			13			13

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 4. Business R&D expenditures and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.7489***	0.9245***	0.8210***	0.7519***	0.9076***	0.7238***	0.6701***	0.9154***	0.6267***
	(0.028)	(0.012)	(0.040)	(0.034)	(0.013)	(0.086)	(0.046)	(0.017)	(0.085)
INV	1.0712***	0.4190***	1.3247***	0.4381**	0.2736***	0.5201***	1.5106***	0.5109***	1.7352***
	(0.154)	(0.040)	(0.212)	(0.162)	(0.053)	(0.184)	(0.156)	(0.057)	(0.184)
OPEN	0.2631***	0.0805***	0.1700***	0.2537***	0.0897***	0.2534***	0.2155***	0.0692***	0.2819***
	(0.034)	(0.014)	(0.055)	(0.040)	(0.018)	(0.067)	(0.042)	(0.019)	(0.094)
RD_BUS_FL	-2.0944	-0.1670	5.6949	1.8557	-0.3012	0.3687	-11.7126	-1.7740	1.0050
	(4.132)	(1.018)	(4.198)	(3.423)	(1.506)	(4.214)	(7.360)	(1.635)	(7.499)
C	2.3478***		1.5241***	2.5319***		2.8139***	2.9084***		3.2213***
	(0.257)		(0.371)	(0.344)		(0.881)	(0.400)		(0.779)
N	426	411	426	224	213	224	202	198	202
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.912			0.926			0.931		
Hansen test (p-value)			0.590			0.791			0.604
AR(2) test (p-value)			0.0974			0.501			0.103
No. of instruments			13			13			13

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 5. Government R&D expenditures and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.7460***	0.9239***	0.8601***	0.7610***	0.9131***	0.8057***	0.6313***	0.9144***	0.6924***
	(0.030)	(0.011)	(0.045)	(0.036)	(0.014)	(0.066)	(0.042)	(0.017)	(0.097)
INV	1.1010***	0.4211***	1.1792***	0.4284**	0.2765***	0.3108	1.5853***	0.5117***	1.7609***
	(0.156)	(0.040)	(0.205)	(0.153)	(0.054)	(0.194)	(0.164)	(0.061)	(0.167)
OPEN	0.2616***	0.0805***	0.1521**	0.2570***	0.0832***	0.1780***	0.2474***	0.0708***	0.1675
	(0.035)	(0.014)	(0.065)	(0.046)	(0.016)	(0.061)	(0.058)	(0.017)	(0.167)
RD_GOV_FL	-3.2149	1.3334	-5.6535	-6.9028	-2.7389	-9.1026	0.9984	3.3230	9.5835
	(7.894)	(1.836)	(11.739)	(6.326)	(2.466)	(6.222)	(11.177)	(3.294)	(18.193)
C	2.3694***		1.2393***	2.5033***		2.0707***	3.2114***		2.5784***
	(0.265)		(0.396)	(0.348)		(0.649)	(0.359)		(0.881)
N	428	412	428	224	213	224	204	199	204
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.911			0.927			0.924		
Hansen test (p-value)			0.614			0.437			0.844
AR(2) test (p-value)			0.274			0.910			0.125
No. of instruments			13			13			13

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 6. R&D stock and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.7259***	0.9299***	0.8618***	0.7633***	0.9236***	0.7735***	0.5662***	0.9141***	0.7170***
	(0.066)	(0.010)	(0.041)	(0.044)	(0.012)	(0.065)	(0.139)	(0.017)	(0.067)
INV	1.2488***	0.4047***	1.4147***	0.3513**	0.2538***	0.3181**	1.9132***	0.5100***	2.0690***
	(0.318)	(0.035)	(0.268)	(0.156)	(0.043)	(0.127)	(0.507)	(0.059)	(0.275)
OPEN	0.2785***	0.0868***	0.1675***	0.2564***	0.0825***	0.2091***	0.2586***	0.0848***	0.1321*
	(0.043)	(0.012)	(0.063)	(0.039)	(0.011)	(0.056)	(0.069)	(0.018)	(0.073)
RD_TOT_ST	-0.3853	-0.1149	0.1808	0.1040	-0.1157	-0.4185	-2.4417	-0.3918	-0.3836
	(0.807)	(0.148)	(0.737)	(0.599)	(0.121)	(0.711)	(1.584)	(0.354)	(2.228)
C	2.5447***		1.1332***	2.4474***		2.3819***	3.8170***		2.3277***
	(0.573)		(0.330)	(0.426)		(0.632)	(1.200)		(0.603)
N	487	472	487	273	262	273	214	210	214
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.863			0.923			0.880		
Hansen test (p-value)			0.292			0.506			0.507
AR(2) test (p-value)			0.904			0.275			0.441
No. of instruments			13			13			13

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 7. Private R&D stock and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(9a)
GDP(-3)	0.7872***	0.9379***	0.8884***	0.7765***	0.9263***	0.7624***	0.6945***	0.9223***	0.7703***	1.2566***
	(0.036)	(0.012)	(0.044)	(0.045)	(0.012)	(0.085)	(0.070)	(0.022)	(0.114)	(0.169)
INV	0.9137***	0.3769***	1.1126***	0.4215**	0.2752***	0.4209*	1.3708***	0.4810***	1.6278***	
	(0.150)	(0.035)	(0.207)	(0.164)	(0.045)	(0.233)	(0.125)	(0.056)	(0.215)	
OPEN	0.2777***	0.0778***	0.1360***	0.2576***	0.0864***	0.2729***	0.2727**	0.0723***	0.1271	
	(0.052)	(0.012)	(0.050)	(0.040)	(0.014)	(0.098)	(0.092)	(0.022)	(0.120)	
RD_PRIV_ST	-0.5120	-0.1895	-0.2507	0.1395	-0.1397	-0.6761	-3.2880*	-0.7678*	-3.4981	-10.3949**
	(0.822)	(0.153)	(0.788)	(0.684)	(0.131)	(0.870)	(1.682)	(0.439)	(2.257)	(5.208)
C	2.0244***		0.9585**	2.2995***		2.4896***	2.7087***		1.9603*	-2.1465
	(0.354)		(0.411)	(0.442)		(0.866)	(0.639)		(1.041)	(1.536)
N	408	395	408	241	231	241	167	164	167	167
No. of countries	23	23	23	13	13	13	10	10	10	10
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM	GMM
R-squared (within)	0.912			0.928			0.926			
Hansen test (p-value)			0.696			0.778			1.000	0.583
AR(2) test (p-value)			0.277			0.939			0.107	0.224
No. of instruments			13			13			13	9

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 8. Public R&D stock and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(9a)
GDP(-3)	0.7792***	0.9330***	0.8359***	0.7777***	0.9276***	0.8151***	0.6437***	0.9109***	0.7048***	0.8079***
	(0.033)	(0.012)	(0.048)	(0.039)	(0.015)	(0.059)	(0.048)	(0.021)	(0.120)	(0.119)
INV	0.9250***	0.3986***	1.1335***	0.3555*	0.2899***	0.1056	1.3542***	0.4834***	1.7715***	1.6482**
	(0.158)	(0.038)	(0.239)	(0.181)	(0.054)	(0.305)	(0.148)	(0.066)	(0.193)	(0.651)
OPEN	0.2831***	0.0819***	0.1696**	0.3307***	0.0788***	0.2884***	0.3153***	0.0922***	0.1146	
	(0.057)	(0.013)	(0.079)	(0.051)	(0.020)	(0.053)	(0.088)	(0.024)	(0.145)	
RD_PUBL_ST	-3.3523*	-0.0483	3.4816	-3.7293	-1.5197***	2.0550	-2.3842	0.6193	0.1790	0.7640
	(1.702)	(0.479)	(2.659)	(2.065)	(0.560)	(2.465)	(2.112)	(0.607)	(2.158)	(3.730)
C	2.1441***		1.3818***	2.4272***		1.9375***	3.1780***		2.4874**	1.5446
	(0.331)		(0.449)	(0.373)		(0.551)	(0.459)		(1.107)	(1.048)
N	345	335	345	184	177	184	161	158	161	161
No. of countries	20	20	20	10	10	10	10	10	10	10
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM	GMM
R-squared (within)	0.919			0.943			0.924			
Hansen test (p-value)			0.0719			0.946			0.998	0.940
AR(2) test (p-value)			0.479			0.324			0.210	0.326
No. of instruments			13			13			13	9

Notes. Standard errors in parentheses. *GDP*(-3) and *OPEN* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 9. EPO patent applications and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.6026***	0.9274***	0.7395***	0.7571***	0.9271***	0.7389***	0.4307***	0.9097***	0.5854***
	(0.076)	(0.012)	(0.053)	(0.025)	(0.013)	(0.052)	(0.093)	(0.021)	(0.173)
INV	1.0451***	0.3726***	1.2734***	0.4484**	0.2663***	0.3912***	1.5065***	0.4569***	1.8086***
	(0.171)	(0.037)	(0.166)	(0.196)	(0.046)	(0.141)	(0.268)	(0.064)	(0.259)
OPEN	0.1751***	0.0720***	0.2042***	0.2331***	0.0824***	0.2368***	0.1098**	0.0557***	-0.1710
	(0.035)	(0.011)	(0.064)	(0.043)	(0.012)	(0.047)	(0.043)	(0.018)	(0.180)
EPO_FL	0.0830***	0.0047	0.0360**	0.0377**	0.0012	0.0068	0.0994***	0.0086*	0.0991**
	(0.016)	(0.003)	(0.018)	(0.016)	(0.005)	(0.014)	(0.015)	(0.005)	(0.040)
C	3.4441***		2.2327***	2.2915***		2.6487***	4.8750***		3.3894**
	(0.672)		(0.476)	(0.281)		(0.512)	(0.803)		(1.522)
N	517	492	517	285	270	285	232	222	232
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.899			0.938			0.911		
Hansen test (p-value)			0.530			0.480			0.632
AR(2) test (p-value)			0.857			0.897			0.225
No. of instruments			13			13			13

Notes. Standard errors in parentheses. *GDP*(-3), *OPEN*, and *EPO_FL* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 10. USPTO patents granted and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.7841***	0.9516***	0.8110***	0.8086***	0.9242***	0.7787***	0.7035***	0.9504***	0.7969***
	(0.047)	(0.010)	(0.043)	(0.033)	(0.011)	(0.066)	(0.105)	(0.018)	(0.063)
INV	0.9666***	0.3093***	1.2283***	0.3458**	0.1994***	0.5360***	1.3544***	0.3730***	1.3389***
	(0.181)	(0.040)	(0.218)	(0.160)	(0.044)	(0.200)	(0.322)	(0.063)	(0.319)
OPEN	0.2409***	0.0562***	0.2006***	0.2416***	0.0796***	0.2377***	0.2047***	0.0416**	0.0132
	(0.034)	(0.011)	(0.058)	(0.046)	(0.010)	(0.071)	(0.055)	(0.017)	(0.048)
USPTO_FL	0.0442***	0.0057***	0.0443***	0.0583***	0.0099**	0.0094	0.0423***	0.0049	0.0719***
	(0.007)	(0.002)	(0.014)	(0.017)	(0.005)	(0.015)	(0.008)	(0.003)	(0.017)
C	1.8621***		1.5351***	1.7209***		2.2012***	2.5106**		1.6026***
	(0.428)		(0.397)	(0.349)		(0.632)	(0.910)		(0.551)
N	436	412	436	240	225	240	196	187	196
No. of countries	28	28	28	15	15	15	13	13	13
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.899			0.951			0.889		
Hansen test (p-value)			0.657			0.870			0.634
AR(2) test (p-value)			0.651			0.181			0.843
No. of instruments			10			10			10

Notes. Standard errors in parentheses. *GDP*(-3), *OPEN*, and *USPTO_FL* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 11. EPO patent application stock and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(9a)
GDP(-3)	0.5772***	0.9278***	0.7985***	0.7547***	0.9383***	0.7361***	0.2383***	0.8213***	0.3820***	0.3472
	(0.080)	(0.014)	(0.060)	(0.033)	(0.015)	(0.057)	(0.061)	(0.032)	(0.094)	(0.260)
INV	0.9481***	0.3619***	1.1237***	0.4331**	0.2534***	0.3683***	1.6948***	0.6094***	1.9667***	
	(0.171)	(0.033)	(0.167)	(0.196)	(0.046)	(0.135)	(0.172)	(0.086)	(0.117)	
OPEN	0.1605***	0.0607***	0.1673***	0.2419***	0.0859***	0.2369***	0.0600*	0.0282	0.1275	
	(0.033)	(0.009)	(0.045)	(0.042)	(0.012)	(0.042)	(0.031)	(0.020)	(0.156)	
EPO_ST	0.1021***	0.0067*	0.0281	0.0314	-0.0061	0.0103	0.1441***	0.0304***	0.0820***	0.2104***
	(0.020)	(0.004)	(0.021)	(0.019)	(0.006)	(0.020)	(0.013)	(0.008)	(0.030)	(0.064)
C	3.5088***		1.6826***	2.3109***		2.6506***	6.3320***		5.1526***	5.4455**
	(0.683)		(0.500)	(0.307)		(0.534)	(0.528)		(0.898)	(2.219)
N	437	414	437	285	270	285	152	144	152	152
No. of countries	23	23	23	15	15	15	8	8	8	8
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM	GMM
R-squared (within)	0.919			0.936			0.957			
Hansen test (p-value)			0.132			0.427			1	0.636
AR(2) test (p-value)			0.678			0.869			0.136	0.990
No. of instruments			13			13			13	9

Notes. Standard errors in parentheses. *GDP*(-3), *OPEN*, and *EPO_ST* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 12. USPTO patents stock and growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP(-3)	0.6586***	0.9315***	0.7746***	0.7552***	0.9262***	0.7728***	0.5222**	0.9251***	0.6219***
	(0.064)	(0.012)	(0.061)	(0.032)	(0.012)	(0.079)	(0.156)	(0.022)	(0.068)
INV	0.7433***	0.2789***	1.0174***	0.3902**	0.1805***	0.4793**	1.0825*	0.3299***	1.2345***
	(0.239)	(0.035)	(0.153)	(0.171)	(0.046)	(0.207)	(0.554)	(0.074)	(0.335)
OPEN	0.1922***	0.0441***	0.2360***	0.2247***	0.0780***	0.2409***	0.1626***	0.0170	0.1457**
	(0.031)	(0.012)	(0.059)	(0.051)	(0.010)	(0.072)	(0.040)	(0.019)	(0.062)
USPTO_ST	0.1278***	0.0197***	0.0370**	0.0761*	0.0016	0.0021	0.1364***	0.0242***	0.0808***
	(0.029)	(0.005)	(0.019)	(0.037)	(0.007)	(0.018)	(0.039)	(0.007)	(0.023)
C	2.6677***		1.9159***	2.0585***		2.3057***	3.8869**		3.1036***
	(0.533)		(0.554)	(0.314)		(0.750)	(1.322)		(0.624)
N	384	360	384	240	225	240	144	135	144
No. of countries	24	24	24	15	15	15	9	9	9
Estimation method	FE	LSDVC	GMM	FE	LSDVC	GMM	FE	LSDVC	GMM
R-squared (within)	0.898			0.947			0.881		
Hansen test (p-value)			0.0597			0.872			0.339
AR(2) test (p-value)			0.471			0.137			0.307
No. of instruments			10			10			10

Notes. Standard errors in parentheses. *GDP*(-3), *OPEN*, and *USPTO_ST* are in natural logs.
***, **, * significant at the 1, 5, and 10% respectively.

Table 13. Variables definitions and data sources

Variable	Definition	Source
GDPGR	annual growth rate of per capita GDP	PWT 8.0
GDP(-3)	log of three-year lagged level of GDP per capita	
INV	investment rate as a share of GDP	
OPEN	log of foreign trade (export + import) as a share of GDP	
RD_TOT_FL	gross domestic expenditure on R&D as a share of GDP	Eurostat database
RD_BUS_FL	gross domestic expenditure on R&D funded by business enterprise sector as a share of GDP	
RD_GOV_FL	gross domestic expenditure on R&D funded by government sector as a share of GDP	
RD_TOT_ST	stock of gross domestic expenditure on R&D as a share of GDP	
RD_PRIV_ST	stock of R&D expenditures funded by business enterprise, private non-profit and abroad sectors as a share of GDP	
RD_PUBL_ST	stock of R&D expenditures funded by government and higher education sectors as a share of GDP	
EPO_FL	log of EPO patent applications per employment	
USPTO_FL	log of patents granted by USPTO per employment	
EPO_ST	log of EPO patent applications stock per employment	
USPTO_ST	log of patents granted by USPTO stock per employment	