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Article

Determinants of productivity growth: Science and technology policies and the contribution of R&D

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ABSTRACT

This paper provides an update of the paper «From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?» (Guellec and van Pottelsberghe 2004). We present estimates of the long-term impact of various sources of knowledge (R&D performed by the business sector, the public sector (higher education and government) and abroad) on the multifactor productivity growth of 17 major OECD countries from 1988 to 2006. The results confirm that business R&D and the R&D performed by the higher education sector significantly contribute to growth. In addition, the extent to which countries rely on triadic patents, as well as their degree of patent friendliness (enforcement mechanism and number of restrictions) affect significantly the extent to which R&D contributes to growth.

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Determinants of productivity growth: Science and technology policies and the contribution of R&D

1. Introduction

The extent to which research and development (R&D) contributes to growth has been increasingly investigated over the past twenty years. Studies at the aggregate level have regularly enriched the empirical approach, by adding new data (longer time periods or more countries), relying on improved panel data models, or introducing new variables such as the level of education or competition policy amongst the explanatory variables. This paper presents an extension of Guellec and van Pottelsberghe's paper «From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?» (GP 2004).

The paper essentially aims at estimating the long-term impact of several sources of knowledge generation on the multifactor productivity growth of 17 major OECD countries from 1988 to 2006. The sources of knowledge are the R&D performed by the business sector, by public labs, by the higher education sector and by foreign institutions. A panel dynamic OLS (DOLS) methodology is used for the econometric analysis. Several science and technology (S&T) policies are used to test whether the return to R&D activities varies across countries. The policies include the socio economic objectives of government support (civilian *versus* defence), the patent policy design related to enforcement provisions and restriction mechanisms, and the extent to which countries file triadic patents.

The results can be summarized as follows. They first confirm that Business R&D, foreign R&D and higher education R&D significantly contribute to growth. These impacts vary across countries according to their S&T policies and the extent to which high value patents are filed. Defence-related support to public R&D reduces the impact of research activities on growth. Policies that increase the power of patent holders (through easier enforcement mechanisms and through reduced provisions for loss of rights) have a negative impact on the return to business R&D at the country level. By contrast, the more high-quality patents a country's industrial sector holds, the higher is the return to its R&D activities.

2. The model and the data

The model aims at estimating the contribution of technical change to productivity growth. The following system of equations is generally referred to in order to evaluate the contribution of research to output growth:

$$\begin{aligned} Y &= MFP \cdot F(L, K) \\ MFP &= G(R, O) \\ R_t &= \sum w_h I_{t-h}^R \end{aligned}$$

where Y is the output, L and K are measures of labour and capital inputs, respectively, and MFP the current state of technology (multi-factor productivity), R the measure of accumulated R&D capital (as a proxy for the knowledge stocks generated by domestic firms, public research institutions and foreign institutions), O stands for the other forces affecting productivity (among which disembodied technical change), I^R measures the gross R&D expenditures in period t , and w_h connects the level of past R&D expenditures to the current state of knowledge.

For estimation purposes, the structure of the production function for country i is generally of the Cobb-Douglas type, which has a useful log-additive form, and O is approximated by an exponential trend (t):



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$$(1) \quad Y_i = \exp(\phi_i \cdot t + u_i) L_i^{\alpha_1} K_i^{\alpha_2} R_i^{\beta} \quad i = 1, \dots, n$$

where u is a random term, ϕ is the rate of disembodied technical change and α_1 , α_2 and β are the output elasticities of labour, capital and the R&D capital stock, respectively.¹ The estimation of these parameters may be carried out by taking the natural logarithm (L) of equation (1), as follows:

$$(2) \quad \ln Y_i = \phi_i \cdot t + \alpha_1 \cdot \ln L_i + \alpha_2 \cdot \ln K_i + \beta \cdot \ln R_i + u_i$$

It is common to derive an index of multi-factor productivity ($\ln MFP$) from equation (2):

$$(3) \quad \ln MFP_i \equiv \ln Y_i - \bar{\alpha}_1 \cdot \ln L_i - (1 - \bar{\alpha}_1) \cdot \ln K_i = \phi_i \cdot t + \beta \cdot \ln R_i + u_i$$

It requires the assumption of constant returns to scale with respect to labour and capital and payment of these traditional inputs (*i.e.* a perfect competition environment). In other words, the output elasticities with respect to labour (capital) are assumed to be equal to the labour (capital) cost share in total output and α_2 is equal to $(1 - \alpha_1)$.

Our model contains the most important sources of technical change: business R&D, higher-education R&D, government R&D and foreign R&D.

The most important sources of technical change are used in the model, namely, business R&D, foreign R&D, R&D performed in public labs and R&D performed in the higher education sector. A country specific deterministic time trend is included in the model to proxy disembodied technical change. Making the time dimension explicit, the model becomes:

$$(4) \quad \ln MFP_{i,t} = \alpha_{0i} + \alpha_{1i} t + \dots + \alpha_{qi} t^q + \beta_i \cdot \ln BRD_{i,t} + \gamma_i \cdot \ln HERD_{i,t} + \delta_i \cdot \ln GOVRD_{i,t} + \varphi_i \cdot \ln FRD_{i,t} + \varepsilon_{i,t}$$

In the previous literature on innovation and growth (*e.g.* Coe and Helpman 1995; Coe *et al.* 2009; Kao *et al.* 1999; GP 2004), those variables are found to be non stationary and cointegrated. The problem with a regression including unit root variables is that OLS estimates could lead to spurious results. An additional problem is related to the endogeneity of the right-hand side variables in the production function (2), since producers most likely decide nearly simultaneously on the levels of outputs and inputs. Kao and Chiang (2001) find that an OLS estimator in a cointegrated regression “has a non-negligible bias in finite sample” due to the endogeneity of variables. GP (2004) estimate an error correction model to deal with this issue and Coe *et al.* (2009) and Kao *et al.* (1999) estimate panel fully modified OLS (FMOLS) and panel dynamic OLS models (DOLS).

This paper relies on the DOLS estimation methodology instead of FMOLS because according to Kao and Chiang (2001), the FMOLS estimator does not improve over the OLS estimator in general and the DOLS estimator may be more promising than the OLS or FMOLS estimators (following the Monte Carlo simulations in Kao and Chiang 2001) in estimating cointegrated panel regressions. Relying on DOLS for homogeneous panel, the following equations, adapted from equation (4), are estimated:

$$(5) \quad \ln MFP_{i,t} = \alpha_{0i} + \alpha_{1i} t + \dots + \alpha_{qi} t^q + \beta_i \cdot \ln BRD_{i,t} + \gamma_i \cdot \ln HERD_{i,t} + \delta_i \cdot \ln GOVRD_{i,t} + \varphi_i \cdot \ln FRD_{i,t} + \sum_{j=-q}^q \eta_{ij} \cdot \Delta x_{i,t+j} + u_{i,t}$$

$$\text{Where } \Delta x_{i,t} = \begin{pmatrix} \Delta \ln BRD_{i,t} \\ \Delta \ln HERD_{i,t} \\ \Delta \ln GOVRD_{i,t} \\ \Delta \ln FRD_{i,t} \end{pmatrix}$$

The variables (for country i and time t) are defined as follows: $\ln MFP$ is an index of multi-factor productivity. MFP growth is computed as the difference between the output’s rate of change and input’s rate of change. The series is derived from the OECD productivity database. The four main sources of knowledge are computed as follows.

¹ In equations (1), (2) and (3), time subscripts are left out for ease of notation.

BRD is the domestic business R&D capital stock. It has been computed using the perpetual inventory method from total intramural business R&D expenditures, in constant 2000 GDP prices and US purchasing power parities (PPPs). The depreciation rate is 15 percent (sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate). The main source for the underlying R&D expenditure data is OECD Main Science and Technology Indicators (MSTI).

The higher education R&D capital stock index is HERD. It has been computed using the perpetual inventory method from total intramural higher education expenditures on R&D, in constant 2000 GDP prices and US PPPs. The depreciation rate is 15 percent (again, sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate). The basic series is taken from OECD MSTI.

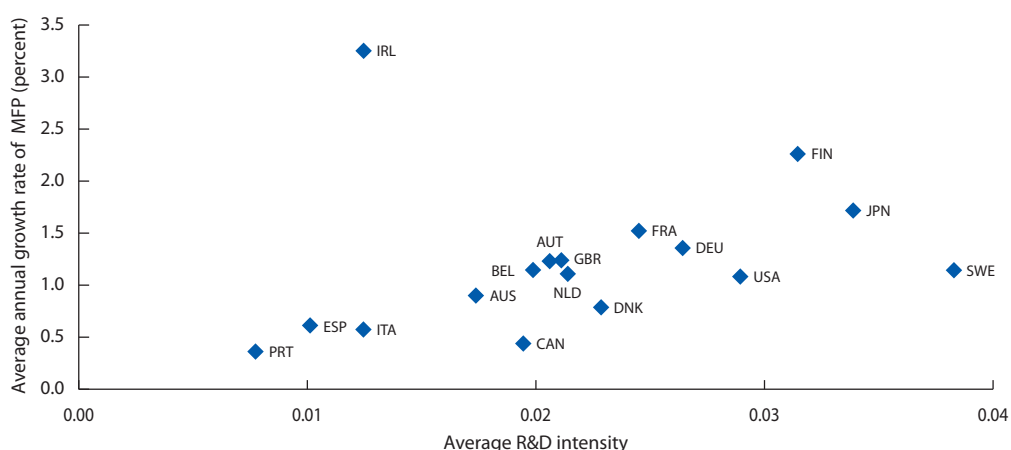
The government R&D capital stock index (GOVRD) has been computed using the perpetual inventory method from total intramural higher education expenditures on R&D, in constant 2000 GDP prices and US PPPs. The depreciation rate is 15 percent (again, sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate). The basic series is taken from OECD MSTI.

The foreign R&D capital stock index is denoted by FRD; it is the weighted sum of the domestic business R&D capital stocks of the 16 other countries of the panel. The weights correspond to the bilateral technological proximity between countries (this measure is similar to the one used by Jaffe 1988 and Park 1995). The second assumption is that a country will benefit more from foreign knowledge relating to the same technology fields it works on, than from knowledge in other fields. As we rely on an indicator of technological proximity, the stock of foreign R&D might be considered as a proxy to measure knowledge spillovers instead of rent spillovers (see Griliches 1992). However, it is very difficult to disentangle empirically rent spillovers from knowledge spillovers. Indeed, any measure of rent spillovers always incorporates to some extent knowledge spillovers, and *vice versa*.

The graphical relationship between multifactor productivity growth and business R&D is depicted in Figure 1. It clearly shows that countries with a higher average R&D-to-GDP ratio (R&D intensity) also enjoyed higher average MFP growth. However, the picture gets somewhat blurred when looking at yearly growth rates of MFP and business R&D. This is done in Figure 2. Besides a few outliers, this graph does not allow to draw clear conclusions, hence the need for an empirical model.

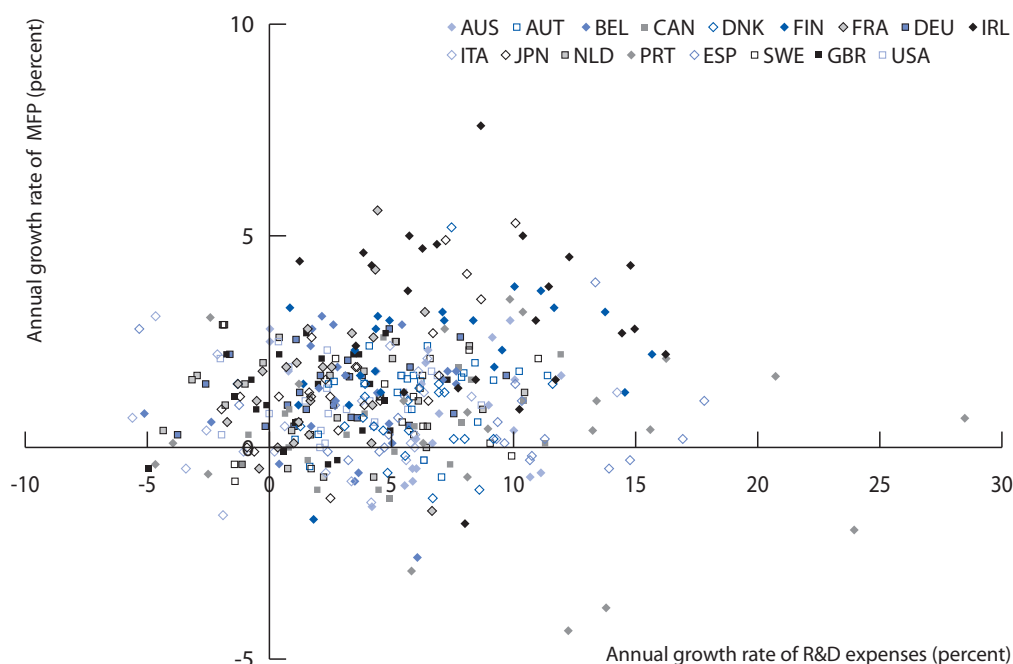
Over longer time periods, countries with higher average R&D intensity enjoy higher average MFP growth.

Figure 1. Average R&D intensity versus average growth rate of MFP (1984-2007)



The R&D-MFP nexus is less clear in year-on-year growth rates, hence the need for an empirical model.

Figure 2. Annual growth rate of R&D expenses versus annual growth rate of MFP (1984-2007)



3. Unit roots and cointegration tests

Before running DOLS estimates of equation (5), the non stationary of variables has to be tested as well as their cointegration rank. Two panel unit root tests have been performed: the one suggested by Hadri (2000) and the one by Im, Pesaran and Shin (IPS 2003). The cointegration of the variables with is investigated through the Pedroni (2004) panel cointegration test.

The Hadri (2000) test assumes that a panel data series is non stationary if the null hypothesis of stationarity is rejected or, in other words, the series is non stationary if a unit root is found for one or more countries (and not necessarily the same for each country). The IPS (2003) test assumes that a panel data series is stationary if the null hypothesis of non stationarity is rejected or, in other words, the series is stationary if at least one country has no unit root and all the other countries have a unit root and not necessarily the same for each country.

Table 1. Panel unit root tests

	IPS	Hadri
LnMFP	1.70	10.66***
LnGOVRD	1.09	9.67***
LnHERD	2.54	11.37***
LnBRD	4.57	11.72***
LnFRD	6.13	11.49***

Notes: Significance levels at the 10-, 5- and 1-percent levels for tests indicated by *, **, and ***, respectively. We reject the null hypothesis explained in the main text if the test statistic is significant.

For each variable, the IPS test does not reject the null hypothesis that the variable is non-stationary (see Table 1). The Hadri test rejects for each variable that the variable is stationary. It can therefore be concluded that the variables are non stationary with unit roots.

The Pedroni (2004) panel cointegration test considers two classes of statistics: the within dimension and the between dimension. For the within dimension, this panel cointegration test assumes, in its null hypothesis, that two or more panel data series are not cointegrated if a common unit root does

not exist for all countries of the panel. For the between-dimension, the test assumes, in its null hypothesis, that panel data series are not cointegrated, meaning that countries do not have a common unit root.

Table 2. Panel cointegration tests

Within-dimension		Between-dimension	
Panel rho-Statistic	2.85	Group rho-Statistic	4.44
Panel PP-Statistic	-6.11***	Group PP-Statistic	-11.27***
Panel ADF-Statistic	-5.41***	Group ADF-Statistic	-5.66***

Notes: Significance levels at the 10-, 5- and 1-percent levels for tests indicated by *, **, and ***, respectively. We reject the null hypothesis explained in the main text if the test statistic is significant.

The Pedroni cointegration test (see Table 2) suggests that the variables are cointegrated or in other words that there exists a linear combination of these variables with a stationary error term. Equation (5) can therefore be estimated with panel DOLS.

4. Estimation results

4.1 The direct effect of R&D performed by different types of institutions

The estimated parameters from equation (5) are presented in Table 3. The long term elasticity of MFP with respect to business R&D (BRD) is 0.14 (column 1), which is in line with the existing estimates in the literature, and very close to GP (2004) estimates. This parameter mainly captures domestic inter-firm and inter-industry spillovers, and the premium associated with business R&D activities (an “excess return” compared with the average return on regular investment).

The positive long-term business-R&D elasticity of MFP captures domestic spillovers and the ‘excess return’ on R&D compared to conventional investment.

Table 3. Estimation results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LnBRD	0.14 2.09 (***)	0.16 3.02 (***)	0.16 2.80 (***)	0.14 2.83 (***)	0.15 3.05 (***)	0.06 1.09	0.15 2.91 (***)	0.04 0.57
LnHERD	0.11 2.85 (**)	0.12 2.23 (**)	0.12 2.24 (**)		0.11 2.19 (**)	0.14 2.75 (***)	0.10 2.07 (**)	0.10 2.01 (**)
LnGOVRD	-0.10 -1.59 (*)	-0.10 -1.68 (**)	-0.10 -1.74 (**)	-0.11 -2.08 (**)		-0.12 -2.17 (**)	-0.03 -0.67 (**)	-0.08 -1.37 (*)
LnFRD	0.08 1.36 (*)	0.08 1.39 (*)	0.08 1.41 (*)	0.08 1.43 (*)	0.06 1.03	0.08 1.45 (*)	0.10 1.91 (**)	0.06 1.07
(Share of public funding of BRD) x LnBRD		-0.32 -0.93						
(Share of public funding of BRD) x (Civil share) x LnBRD			-0.28 -0.64					
(Share of public funding of BRD) x (Defence share) x LnBRD			-0.18 -0.21					
(Defence share) x LnHERD				0.13 0.91				
(Civil share) x LnHERD				0.11 2.05 (**)				
(Defence share) x LnGOVRD					-0.39 -1.12			
(Civil share) x LnGOVRD					-0.06 -1.01			
(Triadic patents per researcher) x LnBRD						3.70 2.98 (***)		
(Enforcement) x LnBRD							-0.10 -2.20 (**)	
(Loss of rights) x LnBRD								0.22 2.78 (***)

Notes: *t*-statistics are indicated in italics and significance levels at the 10%, 5%, and 1% levels for tests are indicated by (*), (**), and (***), respectively. Country-specific intercepts are not reported but are available upon request.

The research performed in academia (HERD) has a high and positive and significant impact on long term growth. The impact of HERD is even higher than the impact of business R&D, thanks probably to a more pronounced propensity to invest in basic research in academia, which is known to generate more externalities for further research or the market sector. In addition, basic research is explicitly associated with a higher risk or uncertainty, which then leads to higher returns.

Yet, performing research activities does not seem to always directly contribute to economic growth, as suggested by the negative and significant parameters associated with the R&D capital stock of public labs (GOVRD). This negative elasticity can be explained by the fact that government-performed R&D is aimed at public missions with no or little effect on economic growth (environment, defence etc.).

The elasticity of multifactor productivity with respect to Foreign R&D (FRD) is positive and significant, but lower than existing estimates in the literature. Keeping in mind that foreign R&D is accessible at a lower cost than own business R&D (absorptive capability costs *versus* own R&D and absorptive capability costs), the impact can be considered as significant. In other words, for any country, the R&D projects implemented abroad also matter for the country's own productivity growth. This result confirms that the social return to R&D is higher than the private return to R&D.

4.2 The impact of S&T policies on the return to R&D

Each domestic source of knowledge is then interacted with other policy variables in order to test whether the estimated elasticities vary across countries. Column (2) investigates whether a negative premium is associated with the subsidization rate of business R&D. The idea is to test whether subsidies have a negative impact on firms' return to own business R&D. The negative but non-significant parameter suggests that this is not the case. And even if these subsidies are split according to the main objectives of government support, the conclusion does not change (see column 3). However, the socio-economic objective of government support seems to affect the effectiveness of academic research in contributing to economic growth. Whereas defence-related government support has no impact on the social return to academic (higher education) research, civilian objectives seem to improve the social rate of return to R&D.

Productivity effects of business R&D are greater in countries that rely more on high-quality patents and favour patent holders less.

Finally, intellectual property protection is taken into account in two different ways. First, the impact of the stock of business R&D is interacted with that of the number of triadic patents per researcher in a country. Triadic patents are patents filed simultaneously in three countries: the US Patent Office, the Japanese Patent Office and the European Patent Office, which induces high costs and witnesses a clear international strategy of the firm. The idea is to test whether higher-quality intellectual property boosts productivity more. The fixed term of the business R&D capital stock shrinks and ceases to be significant (column 6), but the interaction term is highly positive and significant, suggesting a strong complementarity between R&D and valuable patents.

An alternative method is to rely on the design of patent systems to assess their role on the effectiveness of R&D. Two patent design indicators are used. They are built by Ginarte and Park (1997) and Park (2008) for many countries and every five years. Two subcomponents are used: enforcement mechanisms and loss of rights provisions. The first one increases with the power given to patent holders to enforce their rights, whatever the validity of the patent. The second one increases with the number of provisions that allow reducing the rights of patent holders (*i.e.* compulsory licensing and other policies that are less patent-friendly). The estimated interaction terms show that the social return to R&D drops with patent-friendly policies (columns 7 and 8). In other words, the more a patent system favours patent holders, the smaller the return to R&D. This result is compatible with the triadic-patent numbers, which precisely capture a small number of high value patents that are potentially granted in many countries.

5. Conclusions and policy implications

The objective of this paper has been to provide an update of Guellec and van Pottelsberghe (2004). It presents estimates of the long-term impact of various sources of knowledge (R&D performed by the business sector, the public sector (higher education and government) and foreign sector) on the multifactor productivity growth of 17 major OECD countries over the period 1988-2006. A panel dynamic OLS methodology (Kao and Chiang 2001) is used to estimate the model that includes non-stationary and cointegrated variables.

The results confirm that business R&D and the R&D performed by the higher-education sector significantly contribute to growth. In addition, the extent to which countries rely on triadic patents, as well as their degree of patent friendliness (enforcement mechanism and number of restrictions) affect significantly the extent to which R&D contributes to growth. The more a country files triadic patents (assumed to be high-value patents), the higher is the output elasticity of business R&D. At the opposite, the more a country has a patent-friendly policy (improved enforcement mechanisms and few restrictions on patent holders), the smaller is the impact of business R&D on growth.

The policy implications are the following. First, doing R&D is important for productivity and economic growth; and governments should keep these types of activities as a prime target when designing sustainable policies. Second, public laboratories seem to have a small or negative impact, suggesting that their objective is not to contribute to growth but might have pervasive effects, at the opposite of higher-education research activities. The reason why public labs are less important for economic growth might be related to their weak reactivity to technological evolution, as opposed to university labs that are constantly evolving at the scientific edge. Third, subsidies to R&D do not seem to reduce the return to business R&D, suggesting that policies aiming at providing support to business R&D are working well. Fourth, government funding with civilian objectives (as opposed to defence-related objectives) seem to improve the impact of academic research on economic growth. Fifth, stimulating the filing of high value patents while at the same time adopting less patent-friendly policies (not-so-easy enforcement mechanism, and restrictions when needed) is a balance that policy makers must find in order to secure actual leverage of their intellectual property policies.

Governments should give a central role to R&D in designing sustainable growth policies.

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