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What drives business Research and Development (R&D) intensity across Organisation for Economic Co-operation and Development (OECD) countries?

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This paper empirically investigates the potential determinants of business-sector R&D intensity using a panel of OECD (countries for the period of 1975–2002 with data measured as five-year averages). Estimates using a system GMM estimator controlling for endogeneity show a high degree of persistence in business-sector R&D expenditures. Tax incentives for R&D have a significant and positive impact on business R&D spending regardless of the specification and estimation techniques. Furthermore, we find that expenditures for R&D performed by universities are significantly positively related to business enterprise sector expenditures on R&D indicating that public sector R&D and private R&D are complements. Direct R&D subsidies and the high-tech export share are significantly positively related to business-sector R&D intensity, but these effects are only significant using the first-differenced GMM estimator. The static fixed effects results show that countries characterised by strong patent rights appear to have higher R&D intensities, but this effect is no longer significant in the dynamic panel data model.

I. Introduction

Over the last three decades business R&D intensity (ratio of business sector R&D expenditures to GDP) has displayed considerable variation across countries and over time: R&D intensity has risen steadily in Finland, Denmark, Sweden, the United States and Japan, and stagnated in France, Germany and Italy and has slightly fallen in the UK. R&D intensity has also significantly increased in countries with a low initial level, such as Greece, Portugal, Spain and Ireland. This large variation in business-sector R&D intensity across countries and over time raises a number of questions. How much do government policies that support R&D contribute to these R&D disparities in comparison to other non-policy R&D intensity determinants? Does R&D performed by universities crowd out business-sector R&D? Would it be more effective in raising the generosity of R&D tax incentives than any direct R&D subsidies? What is the contribution of non-policy factors such as specialisation in high-tech industries? To answer these questions, we need to know how different factors influence business-sector R&D intensity.

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The knowledge regarding the sign and magnitude of the effects of policy variables on R&D intensity is also important for policy makers. In the Barcelona European Council 2002, the EU member states decided to intensify their activities in order to increase investments in research and technology development to close the growing gap between Europe and its main competitors. Specifically, the European Council decided to increase gross expenditures on R&D from 1.9% to 3.0% of the GDP in the European Union by 2010 with industry contributing two-thirds of the total amount of R&D expenditures (European Commission, 2003). For achieving these aims, European governments use different mixes of indirect and direct measures to stimulate technological activity. The direct policies include the funding of government R&D labs, universities or businesses, the investment in human capital formation as well as the extension of patent protection and fiscal incentives for R&D (European Commission, 2003; Griffith, 2000). Fiscal incentives may take on various forms such as full write-off, R&D tax credits and an accelerated depreciation of investment devoted to R&D activities (Warda, 2002). Other policies that are not directly targeted at R&D may also have a positive impact on the level of R&D expenditure. These measures include patent protection policy, university-industry spillovers and policies that foster human capital.

This paper empirically investigates the policy and non-policy factors behind the disparities in business-sector R&D intensity using a panel of OECD countries from the period 1975–2002. One main purpose of this empirical analysis is to test whether R&D in public institutions such as universities and government laboratories acts as a stimulus to private investment in R&D or whether it crowds out private activity. Another aim of this paper is to investigate whether direct R&D subsidies and tax incentives for R&D are an effective means of stimulating private investment in R&D. Furthermore, we investigate the effects of a large number of potential determinants such as investment in physical capital, patent protection, specialisation in high-tech industries and human capital. For this purpose, we follow the dynamic panel-data approach as in Lederman and Maloney (2003). The empirical analysis is carried out using periods of approximately 27 years with five-year average observations.

A number of recent empirical studies have estimated the effect of various economic variables on R&D expenditures to R&D intensity using cross-country panel data (see Guellec and van Pottelsberghe, 2003; Lederman and Maloney, 2003; Varsakelis
1 2001; Bebcuk, 2002; Kanwar and Evenson, 2003). This present work thus attempts to extend the work of Guellec and Pottelsberghe (2003) by using more recent data and a larger sample size including 21 OECD countries. The paper further extends the literature in several ways by including variables that have not been included in a dynamic model of R&D expenditures. Furthermore, the empirical analysis provides a variety of robustness checks to changes in estimation procedures and model specification. Contrary to Guellec and Van Pottelsberghe (2003), annual data are not employed. Instead, averages derived from five-year periods are used as was done by Lederman and Maloney (2003). Firstly, the rationale for doing so lies in the limited availability of annual time series for many countries. Secondly, some indicators such as patent protection and human capital indicators are only available quinquennially. Apart from this technicality, one might also argue that some variables such as fiscal incentives for R&D (measured by the B-index) and direct subsidies displays little annual variation and that only a longer period interval is suitable to capture the effects of changes in the time dimension. Furthermore, we use the system GMM estimator accounting for endogeneity that has not been considered in previous research examining the determinants of business sector R&D intensity. For comparison, we also use the fixed effects estimator for the static model as well as a dynamic panel data model estimated using the one-step first-differenced GMM estimator.

II. Determinants of R&D Intensity in Previous Empirical and Theoretical Studies

We start by discussing the key theoretical arguments that motivate our empirical investigation. A great number of factors potentially have an impact on the business sector's R&D intensity as discussed below:

Direct R&D subsidies

The government can stimulate business R&D with direct measures, either through fiscal incentives or by means of direct financial support. The empirical literature evaluating the net effects of direct R&D subsidies addresses the question of how far public R&D-assistance induces companies to spend more of their own *additional* resources on R&D than they would have spent without public R&D assistance (David *et al*., 2000). If private funds are substituted by public funds, then the net impact is arguably low (if not zero). On the contrary, if a public R&D

subsidy increases net R&D spending, then a relationship of complementarity is found (see David *et al.*, 2000). Regression analysis at the aggregate level offers two ways to test for complementarity. In a regression with total R&D spending as the dependent variable we test whether the coefficient on the R&D subsidy is significantly higher than one, whereas in a regression with net R&D spending as the dependent variable we test whether the coefficient on R&D is significantly different from zero. Microeconometric methods such as matching methods applied to firm level data allow us to control for the selection arising from the fact that participation R&D programmes are not random (see Almus and Czarnitzki, 2003).

Fiscal incentives for R&D

Fiscal incentives for R&D may take on various forms. Some EU countries provide R&D tax credits (European Commission, 2003). These are deducted from the corporate income tax and are applicable either to the level of R&D expenditures or to the increase in these expenditures with respect to a given base. In addition, some countries allow for the accelerated depreciation of investment in machinery, equipment, and buildings devoted to R&D activities. The overall generosity of R&D tax incentives can be measured by the B-index (Warda, 2002). It is a composite index that is computed as the present value of income before taxes necessary to cover the initial cost of R&D investment and to pay the corporate income tax so that it becomes profitable to perform research activities (Warda, 2002). Algebraically, the B-index is equal to the after-tax cost of a one Euro expenditure on R&D divided by one, less the corporate income tax rate. The after-tax cost is the net cost of investing in R&D, taking account of all available tax incentives (corporate income tax rates, R&D tax credits and allowances, depreciation rates). Regression analysis can be used to test whether tax incentives displace private R&D. A price elasticity (i.e. elasticity of the R&D expenditures with respect to the B-index) of one indicates that the tax incentives can increase R&D spending by an amount equal to the loss in tax revenues.

Public sector R&D

The link between public and private sector R&D has two channels. Public sector R&D can act as a substitute to the private R&D sector, as it not only uses resources for R&D but also earns exclusive property rights for the research results. This potential source of crowding out arises if there is a shortage in the most decisive factor of the R&D process, viz. if high-skilled labour is scarce. Rising demand for high-skilled human resources by universities and government research organisations reduces the availability of the same for private sector usage. In this case, R&D subsidies could drive up the wages of scientists and engineers enough to prevent significant increases in real R&D (Goolsbee, 1998). For the United States, Goolsbee (1998) finds that increases in funding for public R&D significantly raise the wages of scientists and engineers. Thus, part of the gross R&D volume increase is eventually explained by an increase in its unit price (crowding out through prices). The public sector can also act as a complement to the private sector by lowering the cost of research for the industry. This can be achieved by conducting basic research and making its results publicly available. University research has historically been an important source of external knowledge, equipment and instrumentation, as well as methodologies for industrial researchers in the development of new products and production processes.

Patent protection

The relationship between the strength of patent protection and innovation activity is not clear-cut. Patent protection and other intellectual property rights protection measures create temporary technological rights and thus tend to increase the benefits of R&D effort (Varsakelis, 2001). However, a further strengthening of the patent protection regime could hamper technological progress, in particular with respect to basic research.

Investment

Technological innovations are typically embodied in new machinery. Therefore, physical capital is expected to positively influence R&D spending.

Human capital

Investment in human capital through education and training is a key factor in the innovation process. There are a number of arguments in favour of the importance of human capital for innovation. Firstly, it is well-known that the absorptive capacity in the form of in-house R&D and innovation activities mainly depends on the availability and quality of science and technology (S&T) workers. Secondly, skilled and trained workers are also important for the successful transfer of new technologies to firms (Bartel and Lichtenberg, 1987). This can be justified by the fact that they have a comparative advantage with respect to learning and implementing new technologies due to their ability to solve problems and adapt to changes in the work environment. Furthermore, based on a theoretical model, Acemoglu (1998) shows that a high proportion of skilled workers in the economy encourages high-skill biased technological change. More recently, Acemoglu and Zilibotti (2001) find that a country with a high share of less skilled workers would have greater difficulties in effectively implementing new technologies because of the derived lack of absorptive capacity.

Industry structure

Theoretical considerations show that a high R&D intensity may reflect either high R&D intensity within each individual industry or an industrial structure characterised by a high share of industries with a high R&D intensity. If a country is specialised in industries typically characterised by a high degree of R&D intensity, the aggregate business R&D intensity will generally be high even if the R&D intensity is equal in every industry. We use the country's share of high-tech manufacturing exports in total manufacturing exports as a measure of specialisation in high-tech industries.

Persistence of R&D

Another distinct feature of innovation is the persistence of innovation input such as R&D expenditures. The persistence of R&D expenditures can be explained by the fact that scientists and technology workers cannot be fired and rehired without a substantial loss of firm-specific human capital. Due to their high degree of specialisation, resources employed in R&D activities cannot simply be used in other activities such as marketing or production (Harhoff, 1998).

Openness

Given that OECD countries mainly export human capital and physical capital-intensive goods we expect that R&D intensity is positively related with openness. Empirical work supports the hypothesis that innovation is an important factor in trade performance (Wakelin, 1998).

GDP per capita

GDP per capita is a measure of the living standard. Lederman and Maloney (2003) suggest that rich countries invest more in R&D than poor countries.

Table 1 summarises the potential determinants of R&D intensity and lists their expected signs according to economic theory. In order to provide an overview of the empirical evidence related to each of the R&D determinants, the last column of Table 1 lists the qualitative results of recent studies using aggregate cross-country data. Note that there has also been an increase in literature investigating the impact of R&D subsidies on R&D investment at the firm level using microeconometric methods (see David, Hall and Toole, 2000 for recent reviews of econometric studies). A full review of this microeconometric literature is beyond the scope of this paper; but, in general, the evidence is overwhelming that public subsidies for R&D are complementary to private R&D expenditures.

Using aggregate data for 17 OECD countries for the period 1981–1996, Guellec and Van Pottelsberghe (2003) find that government funding stimulates business R&D expenditure (BERD) if the government research is contracted to the business sector, but tends to partially crowd out BERD when performed in government laboratories. The authors quantify the average stimulatory effect of direct government funding of private R&D as a 0.70 marginal increase in business funded R&D for each dollar of direct non-defence government funding. There is no impact of university research expenditures on business enterprise R&D expenditures. The authors also find that tax incentives are effective in stimulating BERD.

Lederman and Maloney (2003) examine the potential determinants of total R&D intensity for a panel of 40 countries over the period 1960–2000. Using the system GMM estimator controlling for endogeneity and the country fixed effects on five-year average data, the authors find that financial depth, GDP per capita, protection of intellectual property rights, government capacity to mobilise resources, quality of research institutions and public/private collaboration are all significantly positively related to the total R&D intensity. Furthermore, R&D intensity increases more than proportionally with the level of GDP per capita.

Using a cross-country analysis based on total R&D expenditures Varsakelis (2001) has shown that countries with strong patent protection have higher R&D intensity. Based on cross-country and industry level data, Bassanini and Ernst (2002) also find that the strength of intellectual property right protection tends to be positively associated with business enterprise R&D intensity. Using cross-country data covering 88 countries and two periods (averages over the 1990s and the 1980s), Bebcuk (2002) finds that the investment rate has a strong, but negative

Table 1. Overview of previous empirical studies at the aggregate level

Variable category	Specific variable	Expected sign	Empirical findings
Lagged R&D intensity	Log of R&D intensity	+	+ and high degree of persistence: Lederman and Maloney (2003)
	Log of business-funded and performed R&D	+	0 or low degree of persistence: Guellec and Pottelsberghe (2003)
Direct R&D subsidies	Government funded BERD, % GDP	Ambiguous	
	Government funded BERD, % total BERD	Ambiguous	+ (long term elasticity = 0.08 and marginal effect = 0.70) Guellec and Pottelsberghe (2003) 0 Bassanini and Ernst (2001)
R&D tax incentives	R&D user costs of capital	−	− Bloom *et al.* 2002.
	B-index	−	− Guellec and Pottelsberghe (2003),
Public sector R&D	HERD, % GDP	Ambiguous	0 Guellec and Pottelsberghe (2003),
	GOVERD, % GDP	Ambiguous	− Guellec and Pottelsberghe (2003)
Specialisation in high tech industries	High-tech export share		
GDP	Real GDP in constant ppp Real GDP growth rate	+	+ Guellec and Pottelsberghe (2003), 0 Bebczuk (2002), 0 Lederman and Maloney (2003), 0 Kanwar and Evanson (2003),
	GDP per capita in constant ppp	+	+ Lederman and Maloney (2003)
Protection of property rights	Ginarte-Park index of patent rights	Ambiguous	+ Varsakelis (2001), + Lederman and Maloney (2003), + Kanwar and Evanson (2003), + Bassanini and Ernst (2001), 3
	Kaufmann *et al.* Rule of Law Index	Ambiguous	+ Bebczuk (2002)
Human capital	Average years of schooling in population over 15 years	+	0 Kanwar and Evanson (2003)
	Total literacy rate in population over 15	+	+ Kanwar and Evanson (2003)
	Tertiary school enrolment	+	0 Bebczuk (2002)
	Share of university graduates	+	
Openness	Exports and imports as percentage of GDP	+/0	− Bebczuk (2002)
Investment	Investment ratio	+	− Bebcuk (2002)
Firm size	Employment share of large firms	+	+ Bassanini and Ernst (2001)
Collaboration	Index of collaboration between enterprises and universities		+ Lederman and Maloney (2003)
Quality of research institutions	Index of quality of academic research institutions		+ Lederman and Maloney (2003)
	OECD Indicator	−	+ Bassanini and Ernst (2001)

Notes: The last columns summarise significant signs of the R&D determinants of a number of studies. Significant signs are identified by a plus or a minus, and a zero indicates an insignificant coefficient.

relationship on R&D indicating that R&D and general capital are substitutes. Furthermore, the author finds that protection of property rights, proxied by the Kaufmann rule of law index is significantly positively related to R&D intensity. Openness (measured by the sum of exports and imports to GDP) reduces national R&D. More recently, Kanwar and Evenson (2003) estimate the determinants of R&D intensity (measured as gross R&D expenditures as a percentage of GNP) based on the time periods (averages for 1981–1985 and 1986–1990) covering 32 countries. Using a static random effects model, the authors find that the Ginarte and Park index of IPRs have a positive and significant impact on R&D investment. Furthermore, they find that either human capital measured as the literacy level or the average number of schooling years has significant and positive effects on R&D intensity. Using bilateral trade data for several OECD countries, Wakelin (1998) finds that R&D

intensity is significantly positively related to trade performance.

The empirical studies at the aggregate level differ widely in terms of the sample period, country coverage as well as empirical specification and estimation technique. Some of these studies can be criticised because they use small samples and suffer from inconsistent estimates due to their inability to deal with country-specific effects and the endogeneity of the explanation. Most studies comprise industrial and developing countries. They also differ widely in another dimension, as they are based on different time periods, frequency (i.e. annual vs. five year averages), as well as on different model specification and estimation techniques. Only a few determinants of R&D expenditures/intensity appear to be consistent and with their expected sign according to theory. They include patent protection, fiscal incentives for R&D, level of GDP per capita and to some extent R&D subsidies for businesses. The results for the impact of university R&D (i.e. HERD) and human capital is not consistent across empirical studies.

III. Empirical Model and Hypotheses

The determinants of R&D intensity in the business sector are specified using a modified version of the model specified by Guellec and Van Pottelsberghe (2003) and Lederman and Maloney (2003):

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$$\begin{aligned} BERDXGDP_{it} = f(&SUBXGDP_{it}, BINDEX_{it}, \\ &HERDXGDP_{it}, GOVERDXGDP_{it}, \\ &GDPPCAP_{it}, HIGHTECHEX_{it}, \\ &SCHOOL_{it}, PATPROT_{it}, \\ &OPENNESS_{it}, INV_{it}), \end{aligned} \tag{1}$$

where subscript i denotes the ith country (i = 1, ..., 21), and the subscript t denotes the tth period (t = 1, ..., 7) where each period is measured as five-year averages (i.e. 1970–1974, 1975–1979, 1980–1984, 1985–1989, 1990–1994, 1995–1999 and for 2000–2002). $BERDXGDP_{it}$ denotes total expenditures on R&D in the business sector as a percentage of GDP. $SUBXGDP_{it}$ denotes government-financed R&D expenditures (i.e. direct support in the form of grants, loans etc.) as a percentage of GDP. $BINDEX_{it}$ is a measure of the generosity of the tax system for R&D. $HERDXGDP_{it}$ denotes R&D expenditures within the higher education sector as a percentage of GDP and $GOVERDXGDP_{it}$ denotes R&D expenditures in the government sector as a percentage of GDP. In addition, the share of high-technology exports in total manufacturing exports ($HIGHTECHEX_{it}$), the level of GDP per capita in PPP-$ ($GDPPCAP_{it}$), average years of schooling ($SCHOOL_{it}$), index for patent protection ($PATPROT_{it}$) and the investment rate (INV_{it}) into the regression.

Following Lederman and Maloney (2003) and Guellec and Van Pottelsberghe (2003) we assume that R&D intensity is determined by a partial adjustment model. This can be justified by the fact that firms do not change their R&D expenditures immediately following changes in direct or indirect support for R&D or changes in the other variables. The optimal demand for R&D is specified as:

$$\begin{aligned} \ln BERDXGDP^*_{it} = \alpha^* + \beta^*_1 \ln SUBXGDP_{it} \\ + \beta^*_2 \ln BINDEX_{it} \\ + \beta^*_3 \ln HERDXGDP_{it} \\ + \beta^*_4 \ln GOVERDXGDP_{it} \\ + \beta^{*'}_5 \ln GDPPCAP_{it} \\ + \beta^*_6 \ln HIGHTECHEX_{it} \\ + \beta^*_7 \ln SCHOOL_{it} \\ + \beta^*_8 \ln PATPROT_{it} \\ + \beta^*_9 \ln OPENNESS_{it} \\ + \beta^*_{10} \ln INV_{it} + e_{it}, \end{aligned}$$

where $\ln BERDXGDP^*_{it}$ denotes the expected or desired business enterprise R&D intensity that is unobservable to us. The relationship between the desired and actual R&D intensity is characterised by a partial adjustment behaviour as follows:

$$\begin{aligned} &\ln BERDXGDP_{it} - \ln BERDXGDP_{i,t-1} \\ &\quad = \theta\left(\ln BERDXGDP^*_{it} - \ln BERDXGDP_{i,t-1}\right), \end{aligned}$$

that is:

$$\begin{aligned} \ln BERDXGDP_{it} = (1-\theta) \ln BERDXGDP_{i,t-1} \\ + \theta \ln BERDXGDP^*_{it}, \end{aligned} \tag{2}$$

where $BERDXGDP_{i,t-1}$ previous (one time period lagged) actual R&D intensity and θ is the adjustment parameter with $0 \leq \theta \leq 1$ and is referred to as the coefficient of adjustment. The partial adjustment mechanism states that the actual change occurring in one period is just a part of the change between the desired R&D intensity in the current period and the actual R&D intensity in the previous period.

If the adjustment parameter is equal to one, then the entire adjustment is made within one period (see also Chambers, 1996).

Inserting the equation of $\ln BERDXGDP^{*}_{it}$ derived from equation (3) in (2) and rearranging the yields, our log linear partial adjustment model is:

$$\begin{aligned} \ln BERDXGDP_{it} = {} & \alpha + (1-\delta)\ln BERDXGDP_{i,t-1} \\ & + \beta_1 \ln SUBXGDP_{it} \\ & + \beta_2 \ln BINDEX_{it} \\ & + \beta_3 \ln HERDXGDP_{it} \\ & + \beta_4 \ln GOVERDXGDP_{it} \\ & + \beta_5 \ln GDPPCAP_{it} \\ & + \beta_6 \ln HIGHTECHEX_{it} \\ & + \beta_7 \ln SCHOOL_{it} \\ & + \beta_8 \ln PATPROT_{it} \\ & + \beta_9 \ln OPENNESS_{it} \\ & + \beta_{10} \ln INV_{it} + u_{it}, \end{aligned} \tag{3}$$

where $\alpha = \delta\alpha^{*}$, $\beta_j = \delta\beta^{*}_j$ for j = 1, 2, 3.

In order to account for individual and time-specific effects, the R&D equation is specified as a two-way fixed effects model:

$$\begin{aligned} \ln BERDXGDP_{it} = {} & \alpha_i + \gamma \ln BERDXGDP_{i,t-1} \\ & + \beta_1 \ln SUBXGDP_{it} \\ & + \beta_2 \ln BINDEX_{it} \\ & + \beta_3 \ln HERDXGDP_{it} \\ & + \beta_4 \ln GOVERDXGDP_{it} \\ & + \beta_5 \ln GDPPCAP_{it} \\ & + \beta_6 \ln HIGHTECHEX_{it} \\ & + \beta_7 \ln SCHOOL_{it} \\ & + \beta_8 \ln PATPROT_{it} \\ & + \beta_9 \ln OPENNESS_{it} \\ & + \beta_{10} \ln INV_{it} + \lambda_t + \varepsilon_{it}. \end{aligned} \tag{4}$$

with $\gamma = 1 - \theta$. The terms α_i and λ_t are country-specific and period specific effects respectively and ε_{it} is white noise. We assume that the time-period effects are fixed parameters to be estimated as coefficients of period dummies for each five-year interval in the sample. The long-run effects can be easily recovered by dividing β_j by $1-\gamma$. Here γ should be equal to zero for full adjustment within one time-period. The R&D equation is a dynamic panel data model and can be estimated using the first-differenced GMM and system GMM estimator. Using the first difference transformation to eliminate the country fixed effects, the estimation equation becomes:

$$\begin{aligned} \Delta \ln BERDXGDP_{it} = {} & \alpha_i + \tilde{\gamma}\Delta \ln BERDXGDP_{i,t-1} \\ & + \tilde{\beta}_1 \Delta \ln SUBXGDP_{it} \\ & + \tilde{\beta}_2 \Delta \ln BINDEX_{it} \\ & + \tilde{\beta}_3 \Delta \ln HERDXGDP_{it} \\ & + \tilde{\beta}_4 \Delta \ln GOVERDXGDP_{it} \\ & + \tilde{\beta}_5 \Delta \ln GDPPCAP_{it} \\ & + \tilde{\beta}_6 \Delta \ln HIGHTECHEX_{it} \\ & + \tilde{\beta}_7 \Delta \ln SCHOOL_{it} \\ & + \tilde{\beta}_8 \Delta PATPROT_{it} \\ & + \tilde{\beta}_9 \Delta \ln OPENNESS_{it} \\ & + \tilde{\beta}_{10} \Delta \ln INV_{it} + \lambda_t + \Delta\varepsilon_{it}. \end{aligned}$$

where Δ is the difference operator. Using lagged levels as instruments, we apply the GMM estimator to the R&D equation. However, the first-differenced GMM estimator is shown to behave poorly when the time-series are persistent and the number of time-series is small, which is also the case in our sample of OECD countries. Unreported results show that total business R&D intensity, government funded business R&D as a percentage of GDP, B-index and high-tech export share are characterised by high AR(1) coefficient ranging between 0.83 and 0.91. Blundell and Bond (1998) show that the estimation problems of the first-differenced GMM estimator are related to the weak correlation between the current differences of the regressors and the lagged levels of the instruments. Blundell and Bond (1998) show that the efficiency of the first-differenced GMM estimator is improved by using an extended system GMM estimator. This technique uses lagged differences as instruments for an equation in levels in addition to lagged levels of the instruments for equations in first differences. In order to control for potential endogeneity, all of the variables are treated as if they were predetermined. In particular, the instruments used for equations in first differences are all levels dated (t−2) and earlier in addition to BERDGDP dated (t−2) and earlier. For the system GMM estimator, we add the observations in first differences dated (t−1) for the level equation. We also report results for the static fixed effects model.

The first question to be examined is whether public sector R&D is a complement or a substitute for private R&D, meaning that it either induces private R&D or crowds out private R&D. Overall, one can expect positive spillover effects to dominate the potentially negative impacts discussed above so that the net effect of public sector R&D on business sector R&D is positive. Should, on the other hand, public sector R&D generally crowd out private R&D, then the sign on GOVERD, % GDP and HERD, % GDP would be negative. A second aim of this section is to investigate the impact of the direct support measures on business sector R&D. Again, our prime interest refers to the question of whether government-funded R&D performed by the business sector is a substitute or a complement for private R&D.

If the marginal effect is less than 1.0, then publicly funded R&D is a substitute for private R&D (at least to some extent).[1] A marginal effect of exactly 1.0 signifies a neutral effect, and effects of above 1.0 would indicate the case of complementarity. Furthermore, another aim is to obtain some insight into the triggering role of tax credits on R&D. Decreases in the B-index mean that fiscal incentives for R&D have been increased, or, equivalently, that the cost of R&D-activities at the enterprise level has fallen. Accordingly, if fiscal incentives are effective in raising BERD, the estimated coefficient $\tilde{\beta}_2$ should be significantly negative. For the reasons that were mentioned above, the coefficients $\tilde{\beta}_5$, $\tilde{\beta}_6$, $\tilde{\beta}_7$, $\tilde{\beta}_9$ and $\tilde{\beta}_{10}$ are expected to be positive.

IV. Data and Descriptive Statistics

Data on the variables were collected from several sources (see Appendix). The main data source is the OECD MSTI database that can be downloaded from www.sourceoecd.org. R&D disaggregated by the performance sector. Since data for business-sector R&D intensity are not available prior to 1981, we also use data from the OECD ANBERD database covering the period 1973–2000. The B-index is provided by the OECD. The high-tech export share is taken from OECD MSTI and OECD STAN and includes pharmaceuticals (ISIC Rev. 3 code is 2423), office, accounting and computing machinery (30), radio, television and communication equipment (32), aircraft and spacecraft (353) and medical, precision and optical instruments (33). These data are available from the OECD STAN database.[2] The Ginarte-Park index of patent rights is provided by W. Park and is available quinquennially (i.e. 1970, 1965, 1970, 1976, 1980, 1985, 1990, 1995 and 2000). The data for 2000 can be drawn from Park and Wagh (2002). This protection index uses a 0–5 scale, and is based on several features, extent of coverage, membership in international agreements, loss of protection, as well as the enforcement and duration of protection (see Ginarte and Park, 1997). Average number of schooling years is taken form de la Fuente and Domench **2**
(2001) and available quinquennially (i.e. 1970, 1965, 1970, 1976, 1980, 1985, 1990 and 1995). Data for 2000 are obtained by interpolating the data from an education database at a glance. Data for openness, GDP per capita in constant ppp and investment is drawn from the OECD economics outlook database.

Following Lederman and Maloney (2003), we use five-year averages. This leaves us between five and seven data points for each country, viz. averages for the period 1970–1974, 1975–1979, 1980–1984, for 1985–1989, 1990–1994, 1995–1999 and for 2000–2002. For some variables (e.g. the average years of schooling and patent protection index) we do not have averages but the data refers to a single year, i.e. 1975, 1980, 1985, 1990, 1995 and 2000. The major constraining factor for the sample period was the short time series for the B-index, government funded R&D in the business sector and public sector R&D with five data points (five-year averages and one three-year average) for the period 1980–2002. Furthermore, we do not include Korea, Mexico, Czech Republic, or Hungary because they joined the OECD only recently.

The data are shown in Table 2 and Table 3. Table 2 shows that the average business–sector R&D intensity is 1% with a maximum of 3.3% in Sweden for the period 2000–2002 and a minimum of 0.04% in Greece for the period of 1980–1984. The ratio of public sector expenditures on R&D as a percentage of GDP range is on average between 0.6% with a maximum of 0.97% in Finland for the period 2000–2002 (averages) and 0.14% in Greece for the period 1980–1984 (averages). Government funding of business-sector R&D accounts is on average 0.1% measured in terms of GDP (see Table 2). In the EU-15 countries, high-technology intensive exports accounted for 22% of total manufacturing exports based on the OECD Stan database. Differences among EU countries are substantial: The share of high-technology industries in total exports ranges from 52% in Ireland and 9% in Greece for the period 2000–2002. The share of university graduates in

[1] In this paper the dependent variable is defined as total business R&D expenditures minus R&D subsidies as a percentage of GDP. In this case the coefficient has to be interpreted in a different way.
[2] Attempts to capture the industry structure by employment figures or value added turned out to be unsuccessful. The reason is that in STAN many countries do not provide for sectoral data, but only turn in aggregate figures (total manufacturing, total services, gross total).

Table 2. Summary statistic (pooled)

Variable	obs	Mean	Std. Dev.	Min	Max
BERD, % GDP	132	0.010	0.006	0.0004	0.033
Government funded BERD, % GDP	100	0.001	0.0011	0.000003	0.006
B-index	102	0.96	0.10	0.60	1.13
HERD, % GDP	101	0.004	0.0016	0.0004	0.008
GOVERD, % GDP	101	0.003	0.0012	0.0003	0.006
HERD + GOVERD, % GDP	101	0.006	0.0019	0.0014	0.010
High-tech export share, %	105	0.13	0.09	0.01	0.48
High-tech export share (wide def.)	105	0.16	0.11	0.01	0.52
GDP per capita in const. ppp (in 1000s)	147	27.4	6.8	12.2	42.7
Ginarte-Park index of patent rights (0–5 scale)	145	3.50	0.64	2.0	5.0
Average years of schooling (years)	147	10.2	2.0	4.9	13.4
Share of university graduates, %	121	0.157	0.095	0.019	0.480
Openness, %	147	0.618	0.301	0.126	1.779
Investment ratio, %	147	0.228	0.036	0.163	0.356
Private investment ratio, %	140	0.198	0.038	0.131	0.300

Source: See Table A1 in Appendix.

Table 3. Summary statistics. Evolution over time

	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2002
BERD, % GDP	0.008	0.008	0.008	0.010	0.011	0.012	0.014
Government funded BERD, % GDP			0.0012	0.0013	0.0010	0.0008	0.0009
B-index			0.979	0.961	0.966	0.957	0.934
HERD, % GDP			0.0030	0.0034	0.0040	0.0043	0.0045
GOVERD, % GDP			0.0027	0.0026	0.0026	0.0023	0.0023
HERD + GOVERD, % GDP			0.0057	0.0060	0.0066	0.0066	0.0068
High-tech export share			0.084	0.105	0.122	0.152	0.182
High-tech export share (wide def.)			0.111	0.134	0.153	0.185	0.219
GDP per capita, const. ppp (in 1000s)	20.9	23.0	24.4	26.9	29.0	32.0	35.4
Ginarte-Park index of patent rights	3.0	3.0	3.4	3.5	3.5	3.9	4.2
Average years of schooling	9.0	9.4	9.9	10.3	10.6	11.0	11.4
Share of university graduates	9.7	12.1	14.5	16.8	19.1	23.6	
Openness	0.501	0.549	0.621	0.604	0.600	0.682	0.770
Investment ratio	0.260	0.249	0.233	0.226	0.211	0.207	0.210
Private investment ratio	0.239	0.223	0.202	0.198	0.179	0.174	0.172

Source: See Table A1 in Appendix.

the working age population is on average 15.7%. The average number of years of schooling is about 10. The average investment ratio is 23%, while the private investment ratio is slightly lower at 20%.

Sample statistics for the evolution over time reported in Table 3. Average business enterprise R&D intensity increased continuously over the sample period (from 0.8% in second half of 1970s to 1.4% for the period average 2000–2002). In most OECD countries the ratio of government-funded business R&D to GDP has constantly decreased in the 1980s and 1990s, especially during the first half of the 1990s. On the contrary, there has been a significant increase in generosity of R&D tax incentives in the large company category between the first half of 1990s and in the first three years of the 2000s. Furthermore, there was an increase in generosity of R&D tax incentives between the period 1985–1989 and 1980–1984. Government sector expenditures on R&D as a percentage of GDP dropped from 0.26% to 0.23% between the first half of the 1990s and 2000s, with the majority of this fall occurring during the 1990s. In contrast, R&D performed by higher education (HERD) increased steadily, relative to GDP over the 1980s and 1990s. High-technology exports as a proportion of total exports have grown rapidly in all of the countries, particularly in Finland, Ireland, the Netherlands and United Kingdom. Between 1991 and 2001 Finnish high-technology exports as a percentage of total manufacturing exports grew faster than in any OECD country. Openness has also increased steadily over the sample period. The ratio of investment to GDP has fallen from 26% in the first half of 1970s to 21%

in the first three years of the 2000s. The Ginarte-Park index of patent rights protection increased steadily over the sample period indicating an increase in patent protection.

To obtain a first insight into the relation between R&D intensity and their potential determinants we regress the logarithm of total business R&D intensity on the logarithm of each relevant variable separately based on theoretical considerations and controlling for country and time fixed effects. The data set consists of an unbalanced panel of $N = 21$ OECD countries with T ranging between 4 and 7 time intervals, resulting in 99 to 132 observations. The results show that 9 out of 14 potential determinants are significantly different at the 5% significance level when entering the regression equation separately (see Table A2 in the Appendix). In particular, we find that direct and indirect government support for R&D (i.e. expenditures on government funded BERD % GDP and the B-index) are each significantly positively related to business-sector R&D intensity. Furthermore, the share of government and university R&D expenditures, both measured as percentages of GDP, the share of high-technology exports in total manufacturing and the strength of intellectual property rights protection are also positively and significantly associated with business sector R&D. The bivariate analysis shows no significance for GDP per capita, average years of schooling, share of university graduates, or openness and the investment ratio.

V. Estimation Results

Table 4 presents the main results of the determinants of business enterprise R&D intensity. The middle panel presents the system GMM results, while the lower panel presents the results using the first-differenced GMM estimator. Coefficients are generated using a one-step GMM estimator with asymptotic standard errors robust to cross-section and time-series heteroskedasticity in parentheses. Levels of the right-hand variables dated $(t-2)$, $(t-3)$ and $(t-4)$ are used as instruments for the equation in first differences. For system GMM we use the same level of instruments plus the first differences of the variables lagged one period in the level equations.[3] A complete set of period dummies is included in all of the specifications to control for the effects that are common over time. In order to investigate whether our model is correctly specified we use the Sargan/Hansen J test and the difference Sargan test. The tests fail to reject the null hypothesis that the instruments are exogenous. The consistency of the GMM estimates depends on the absence of the second-order serial correlation and presence of first-order serial correlations. We thus test for the first and second order correlations. Since the p-values are not in the critical region, we fail to reject the null hypothesis of the second order correlation. Unreported results show that there is some evidence of a first-order correlation. In order to compare the results with previous studies using a static model the fixed effects estimates are also presented (see the upper panel). The panel data set is unbalanced consisting of up to 21 OECD countries with a maximum of five time periods, resulting in approximately 73 to 99 observations.

Our preferred estimation method employs the system GMM estimator presented in the row labeled "System GMM estimator". The first specification in the middle panel provides estimates of the impact of HERD and B-index. In the following specifications, we add the high-tech export share, GDP per capita and the share of publicly financed business R&D as a share of GDP. Average years of schooling, the share of university graduates and openness are neither significant at the conventional levels for both GMM estimators and are therefore not included in the final estimation equations.

We find that fiscal incentives for R&D as measured by the B-index significantly affect the demand for R&D in the business sector in all of the specifications. However, in some cases the impact of the B-index is only significant at a 10% level. The short-run elasticity of approximately -0.22 indicates that a 1% reduction in the B-index (increase in generosity of tax incentives for R&D) leads to a 0.22% increase in the business-sector R&D intensity. The long-run elasticity equals -0.84.[4] This finding is consistent with prior evidence of the triggering effect of tax incentives. Bloom *et al.* (2002), for instance, find a long-run price elasticity of industry-financed and – performed R&D with respect to the price of R&D of approximately -1.0. Their estimates are based on panel data for eight OECD countries for the period 1979–1997. The European Commission (2003) suggests, in its recent report, a median price

[3] Estimates not controlling for endogeneity reveal only minor differences in results.
[4] Long-run effects are calculated as the ratio between short-run effects (i.e. estimated beta-coefficients) and the partial adjustment coefficient. The partial adjustment coefficient is defined as (1 minus the coefficient on the lagged endogenous variable).

Table 4. Determinants of Business R&D intensity: Static and dynamic panel estimates

		Lagged business R&D intensity	Government funded BERD, % GDP	B-index	HERD, % GDP	High-tech export share (wide def.)	GDP per capita in constant ppp	GDP per capita in constant ppp sq.	Log patent protection index	Openness	Sargan/ Hansen test	AR(1)	AR(2)	# of obs	R^2
Fixed Effects model															
(1)	c.			−0.62*	0.52**									99	0.68
	t			−1.98	5.49										
(2)	c.			−0.58*	0.52**		0.43							99	0.69
	t			−1.86	5.49		1.37								
(3)	c.			−0.48*	0.47**	0.48**								99	0.79
	t			−1.87	5.98	5.94									
(4)	c.		0.13**	−0.46*	0.32**	0.45**								99	0.80
	t		2.69	−1.86	3.41	5.79									
(5)	c.		0.14**	−0.41*	0.31*	0.45**	0.57**							99	0.82
	t		2.98	−1.68	3.34	6.05	2.36								
(6)	c.		0.15**	−0.43	0.29**	1.76**	0.01		0.59**					95	0.83
	t		2.82	−1.57	2.89	2.52	0.04		2.06						
(7)	c.		0.15**	−0.43*	0.27**	0.45**	0.50**			0.32*				99	0.83
	t		3.26	−1.79	3.01	6.05	2.07			1.88					
(8)	c.		0.17**	−0.63**	0.35**	0.40**	−3.96	0.68		0.32*				99	0.84
	t		3.65	−2.37	3.45	5.12	−1.43	1.62		1.91					
System GMM estimator[a]															
(1)	c.	0.81**		−0.23	0.28**						0.06	0.10	0.24	92	
	t	21.6		−1.57	3.59										
(2)	c.	0.76**		−0.26	0.31**		0.23				0.41	0.18	0.49	92	
	t	14.0		−1.76	3.53		1.11								
(3)	c.	0.81**		−0.28*	0.26**	0.03					0.23	0.20	0.45	92	
	t	12.4		−2.07	2.29	0.62									
(4)	c.	0.77**	0.03	−0.24*	0.27**	0.04					0.21	0.26	0.41	92	
	t	9.6	1.02	−1.87	2.81	0.91									
(5)	c.	0.74**	0.03	−0.22*	0.26**	0.05	0.17				0.29	0.20	0.41	92	
	t	7.8	0.97	−1.83	2.83	1.13	1.14								
First-differenced GMM estimator[a]															
(1)	c.	0.40**		−1.03**	0.35**						0.93	0.40	0.77	71	
	t	2.06		−3.43	1.01										
(2)	c.	0.40**		−0.82**					0.48**		0.98	0.32	0.72	71	
	t	2.74		−3.62					1.89						
(3)	c.	0.42**		−0.98**	0.37*		0.46**				0.98	0.36	0.87	71	
	t	2.19		−4.17	1.90		2.31								
(4)	c.	0.27		−1.00**	0.24	0.38**					0.99	0.32	0.48	71	
	t	1.59		−3.17	1.03	2.71									
(5)	c.	0.31*	0.01	−0.99**	0.23	0.26**					0.98	0.35	0.54	71	
	t	1.96	0.02	−3.56	0.92	2.48									
(6)	c.	0.28	0.10	−0.78**	0.15	0.28**	0.58**				0.99	0.35	0.98	71	
	t	1.48	3.03	−3.26	0.86	2.37	2.28								

Notes: ** and * denote significance at the 5% and 10% level. Dependent variable is log BERD % GDP (within transformed or in first differences). All variables are expressed in their logarithms. The dynamic panel data models are estimated using the one-step GMM estimator in first differences and the system estimator. [a]*t*-values are based on robust standard errors. Estimation period for the dynamic model estimated using first-differenced GMM is the period 1985–2002 with data derived from three five-year intervals and one three-year interval. Estimation period for the static model and system GMM is 1980–2002. Time effects are included but not reported.

elasticity of −0.81. Guellec and Van Pottelsberghe (2003), however, find the long-run elasticity of the B-index to be somewhat lower. Using OECD data for 17 countries, they derive a coefficient of about −0.31.

There is mixed evidence on the relationship between government funded R&D in the business sector and total business-sector R&D intensity. Using fixed effects and first-differenced GMM estimators, we find that government-funded R&D in the business sector has a positive and significant impact on total business enterprise R&D. This is consistent with the literature. The long-run elasticity estimates a range from between 0.27 and 0.29 using the preferred fixed effects model and 0.14 (calculated as 0.10/(1−0.28)) based on the preferred specification using the first-difference GMM estimator. However, the impact of government funded R&D in the business sector as a percentage of GDP is close to zero and insignificant using the system GMM estimator.

Turning to the impact of public sector R&D, we find that higher education expenditures on R&D as a percentage of GDP (HERD % GDP) is significantly positively related to the ratio of business enterprise R&D expenditures to GDP in all of the specifications using system GMM. However, estimates using the first-differenced GMM estimator show that the statistical significance diminishes when the high-tech export share is included as a control variable in the regression. The resulting decrease in significance could be caused by multicollinearity between the high-tech export share and HERD as a percentage of GDP. A Wald-Test of joint significance indicate that both variables are jointly significantly different from zero with a p-value of 0.0071 in the equation estimated using the first-differenced GMM estimator. The short- and long-run elasticities of the ratio of BERD to GDP with respect to the ratio of HERD to GDP are 0.24 and 1.00, respectively. This means that a 1% increase in the ratio of HERD to GDP in the long-run is associated with a 1% increase in business-sector R&D intensity. It may be useful to know how the elasticity estimates translate into marginal rates of return from public R&D. In terms of marginal impacts of public funding a dollar increase in R&D performed by universities leads to an additional industry R&D of about $0.6 in the short-run and $3.0 in the long-run.[5]

Furthermore, the share of high-technology exports in total manufacturing is positive, but not significant using the system GMM estimator. As noted earlier HERD % GDP and the high-tech export share are jointly significantly different from zero. This indicates that countries with a large share of technology driven industries also have high business R&D intensity. The results using the first-differenced GMM estimator suggest the high-tech export share is statistically significant at the 5% level.

The coefficient of the lagged dependent variable is significant at the 5% level in all of the specifications using the system GMM estimator. We interpret this as a rejection of a static model in favour of a dynamic model. The coefficients on lagged business enterprise R&D intensity range between 0.77 and 0.82 implying business-sector R&D intensity is relatively slow to adjust to its desired level. This provides a rate of adjustment in business-sector R&D intensity in a range between 18% and 23% within a five-year period. The low speed of adjustment in the level of R&D intensity implies that the long-run effects of policy and non-policy factors are between five and ten times as large as their respective short-run effects. This also indicates that there is only moderate catching-up and convergence that are observable in the level of business-sector R&D intensity across the OECD countries. Using the first-differenced GMM, we find that the coefficient on lagged of BERD as a percentage of GDP is of a magnitude of 0.41 or less and is insignificant at the 10% level in some cases. This suggests a much higher pace of adjustment. However, the coefficient of BERD may be significantly underestimated when the time series are persistent and short as it is also the case for our sample.

The coefficient of GDP per capita is positive but insignificant at the 5% level. The insignificance of the GDP per capita may be due to multicollinearity between the HERD % GDP and GDP per capita. Therefore, we conducted a Wald Test to test the joint significance and it was significant at the 5% level. The positive impact of the level of real GDP indicates that as countries become richer their R&D intensity increases. According to the estimated coefficients, an increase in GDP per capita by 10% increases R&D intensity by 1.7%. To capture a possible nonlinear relationship between business-sector R&D intensity and GDP per capita, we also include GDP per capita squared. However, GDP per capita and its squared term are not jointly significant in the GMM estimates. Fixed effects results indicate that R&D intensity increases with GDP per capita, but at a decreasing rate. This result stands in contrast to earlier work by Lederman and Maloney (2003) who reported that R&D intensity rises with GDP per capita at an increasing rate. This discrepancy might

[5] The marginal return of HERD % GDP is calculated as the product of the elasticity estimates and the ratio of BERD % GDP to HERD % GDP. The ratio of BERD % GDP to HERD % GDP is 0.010/0.004.

be explained at least in part by the use of a different sample: OECD countries vs. industrialised and developing countries.

The strength of intellectual property rights protection is positively associated with R&D. Thus, countries that provided stronger patent protection tend to have higher R&D intensity. However, the effect is only significant at the 10% level using first-difference GMM and insignificant using the system GMM estimator. Unreported results show that countries with a educated working age population seem to invest more in research in development, but the coefficient is never significant at the 10% level. This contrasts with the finding of Kanwar and Evenson (2003) who find that the average number of schooling years has significant and positive effects on R&D intensity. Openness is not statistically significant even though the sign is consistent with a priori expectations.

For the sake of comparison with earlier studies, we also discuss the results obtained from the fixed effects model. Government funded BERD % GDP, HERD % GDP, high-tech export share, GDP per capita and openness are significant at the 5% level. The effects model explains approximately 83% of the within variation in R&D intensity. For reference, the set of industry and country dummies alone explains 50% of the variation. This indicates that 30% of the (within) variance in R&D intensity can be explained by direct R&D subsidies, fiscal incentives for R&D, university expenditures on R&D as a percentage of GDP, specialisation in high-tech industries, GDP per capita and openness.

VI. Conclusions

The aim of this study is to empirically analyse the policy and non-policy factors affecting business-sector R&D intensity using a panel of OECD countries for the period of 1980–2002. The two main policy tools are to provide favourable tax treatment for firms undertaking R&D or to directly subsidise private R&D projects. Other factors affecting the countries business enterprise R&D intensity include expenditures on R&D performed by the public sector, specialisation in high-tech industries, the strength of patent protection, the level of GDP per capita, openness, indicators for human capital and physical investment.

The main results of the empirical analysis can be summarised as follows. Estimates using static fixed effects and dynamic panel data models suggest that tax incentives for R&D have a significant and positive impact on business R&D spending in OECD countries regardless of specification and estimation techniques. The long-run elasticity is approximately −0.9 indicating that a 1% reduction in the price of R&D (i.e. increase in generosity of tax incentives for R&D) leads to a 0.9% increase in the amount of R&D spending in the long-run. Furthermore, we find that expenditures on R&D performed by universities are significantly positively related to business enterprise sector expenditures on R&D indicating that public sector R&D and private R&D are complements. Direct R&D subsidies and specialisation in high-tech industries also contribute significantly to business-sector intensity, but these effects are only significant using the first-differenced GMM specification. Using a fixed effects estimator, we find that the Park index of patent rights is significantly positively related to business-sector R&D intensity, but the effect disappears when lagged R&D intensity is included in the regression. Our estimates suggest a high degree of persistence of business-sector R&D intensity.

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Appendix

Table A1. Definition of variables and data sources

	Definition of the variable	Data sources	
Government funded BERD, % GDP	Government funded expenditures on R&D in the business sector as a percentage of GDP	MSTI	
B-index	Log of B-index for the large company group	OECD unpublished data	
HERD, % GDP	Log of expenditures on R&D performed by higher education institutions as a percentage of GDP	MSTI	
GOVERD, % GDP	Log of expenditures on R&D performed by government institutions as a percentage of GDP	MSTI	
HERD + GOVERD, % GDP	Log of expenditures on R&D performed by the public sector as a percentage of GDP	MSTI	
High-tech export share	The logarithm of the share of exports of high-tech products in total exports. The category of products that is defined as being of "high-technology" includes aerospace, computers, office machinery, electronics, pharmaceuticals and electrical machinery.	OECD STAN and MSTI	
High-tech export share (wide def.)	The category of high-tech products include also scientific instruments	OECD STAN and MSTI	
GDP per capita in constant ppp	Log of GDP per working age population in constant 1000 PPP-$	OECD economic outlook data; http://new.sourceoecd.org	
Ginarte-Park index of patent rights	Log of a 0–5 scale index	Walter Park	
Average number of schooling years	Log of average number of schooling years	De la Fuente and Doménech (2001) and OECD Education at a glance	2
Share of university graduates	Log of working population with a degree in non-university tertiary + short and long term university courses	De la Fuente and Doménech (2001)	
Openness	Log of openness (sum of exports and imports of goods and services based on national accounts as a ratio of GDP at nominal market prices)	OECD economic outlook data; http://new.sourceoecd.org.	
Investment ratio	Log ratio of total fixed investment to GDP at market prices	OECD economic outlook data; http://new.sourceoecd.org	
Private investment ratio	Log ratio of private fixed investment to GDP at nominal market prices	OECD economic outlook data. http://new.sourceoecd.org	

Table A2. Fixed effects estimates (bivariate relations)

	Coeff	t-value	Time effects (p-value)	R^2	# of obs
(1) Government funded BERD, % GDP	0.27**	5.62	0.00	0.58	100
(2) B-index	−1.01**	−2.79	0.00	0.01	99
(3) HERD, % GDP	0.54**	5.78	0.00	0.62	101
(4) GOVERD, % GDP	0.32**	2.86	0.00	0.06	100
(5) HERD + GOVERD, % GDP	0.81**	5.60	0.00	0.53	100
(6) High-tech export share	0.45**	5.11	0.09	0.46	102
(7) High-tech export share (wide def.)	0.51**	5.20	0.09	0.53	102
(8) GDP per capita in constant ppp	0.02	0.07	0.00	0.06	132
(9) Ginarte-Park index of patent rights	1.26**	4.15	0.00	0.37	130
(10) Average years of schooling	0.98	1.52	0.03	0.30	132
(11) Share of university graduates	−0.25	−0.88	0.00	0.00	109
(12) Openness	0.16	0.73	0.00	0.04	132
(13) Investment ratio	−0.39	−1.41	0.00	0.08	132
(14) Private investment ratio	−0.67**	−3.29	0.00	0.15	127

5 *Notes*: ** and * denote significant at 5% and 10% level. Period dummies included. All of the variables are expressed in their logarithms.