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Abstract:

This paper empirically investigates the potential determinants of business-sector R&D intensity using a panel of OECD countries for the period of 1970-2002 with data measured as five-year year averages. Estimates using a system GMM estimator controlling for endogeneity show a high degree of persistence in business-sector R&D. Tax incentives for R&D have a significant and positive impact on business R&D spending regardless of specification and estimation techniques. Furthermore, we find that expenditures on R&D performed by universities are significantly positively related to the 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 intensity but these effects are only significant using the first-differenced GMM estimator. Static fixed effects results show that countries characterised by a low level mark-up ratio appear to have higher R&D intensities but this effect disappears after controlling for lagged R&D intensity. Similarly, the Ginarte-Park index of patent rights is significantly positively related to business-sector R&D intensity in the static panel data model but is no longer significant in the dynamic panel data model.

JEL: O3, O30, O57.

Keywords: Innovation, R&D, Government support, Industry structure.

1. Introduction[1]

Over the last three decades business R&D intensity (ratio of business sector R&D expenditures to GDP) displays considerable variation across countries and over time: R&D intensity has risen steadily in Finland, Denmark, Sweden, the United States and Japan, stagnated in France, Germany and Italy and 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 to 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.

The knowledge about both the sign and the 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 to increase investment 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. 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 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 not directly targeted at R&D may also have a positive impact on the level of R&D expenditure. These measures include competition policy and regulation in several sectors, including pharmaceuticals and telecommunications (Griffith, 2000).

[1] We would like to thank Heinz Hollenstein, Hannes Leo, Georg Licht, Jordi Jaumandreu and Jacques Mairesse for their helpful comments on an earlier draft of this paper. Financial support from European Commission's (DG

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 1970-2002. 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 around 30 years with five-year average observations.

The first step in the 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 both direct R&D subsidies and tax incentives 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.

We use various panel regression techniques in order to consider some of the possible influence in R&D intensity. In particular, we use the fixed effects estimator for the static model and secondly a dynamic panel data model estimated using both the one-step GMM estimator in first differences and the system GMM estimator. The data set is unique because of various features. Firstly, it covers 30 years of data. Secondly, it provides alternative measures of some of the variables. The paper further extends the literature in several ways. It uses dynamic panel data models to correct for endogeneity and heterogeneity. Furthermore, it performs a variety of robustness checks to changes in estimation procedures and model specification.

A number of recent empirical studies have estimated the effect of various economic variables using cross-country panel data. Guellec and van Pottelsberghe (2003) examine the effect of government funding on business R&D across 17 OECD countries for the period 1981-1996. The authors report 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. There is no impact of university research expenditures on business enterprise R&D expenditures. They also find that tax incentives are effective in stimulating BERD. 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. Lederman and Maloney (2003) examine

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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 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 total R&D intensity. Furthermore, R&D intensity increases more than proportionally with the level of GDP per capita. Using the first-differenced GMM estimator based on a panel of 15 OECD countries and annual data, Reinthaler and Wolff (2004) find that the log R&D subsidy ratio is significantly positively related to total business sector R&D intensity with an elasticity of 0.24 and marginal effects exceeding one. This indicates that public funded BERD is a complement to private R&D in the business sector. Furthermore, they find that the ratio of R&D expenditures performed by higher education institutions to GDP is significantly negatively related to business-sector R&D intensity suggesting that both are substitutes. Openness and real GDP have a significant positive influence on business-sector R&D intensity. Von Tunzelmann and Martin (1998) investigate the relationship between the levels of private funded R&D to public funded R&D controlling for country fixed effects. The authors find that public R&D is complementary to private R&D. Using a cross-country analysis based on total R&D expenditures Varsakelis (2001) has shown that countries with a strong patent protection have a higher R&D intensity. Using cross-country data covering 88 countries and two time periods (averages over the 1990s and the 1980s), Bebcuk (2002) finds that the investment rate has a strong, but negative relationship with 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. Based on cross-country and industry level data, Bassanini and Ernst (2001, 2002) find that evidence that strict labour market regulations decrease R&D spending in high-technology industries. Furthermore, the authors find that the strength of intellectual property right protection tends to be positively associated with business enterprise R&D intensity. Using cross-country data for the EU, Griffith and Harisson (2004) show that the competition-R&D

relationship may follow an inverted u-curve with too little competition or too much competition diminishing R&D spending.

These empirical studies 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 endogeneity of the explanatory. While most of the literature focuses on the determinants of total R&D expenditures/intensity, few studies investigate the determinants of business-sector R&D intensity. Notable exceptions are the studies by Guellec and Pottelsberghe (2003) and Reinthaler and Wolff (2004).

In this study, we empirically analyse the determinants of business-sector R&D intensity. Contrary to Guellec and Van Pottelsberghe (2003) and Reinthaler and Wolff (2004), annual data are not employed. Instead, averages derived from five-year periods are used as in 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 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.

2. 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:

(i) **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 subsidies is basically concerned with three sources of negative (side-)effects. First, studies on the so-called "input additionality" address 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 the public R&D assistance (see Garcia-Quevedo 2004; David et al., 2000). If private funds are only substituted by public funds, then the net impact is arguably low (if not zero). To get the concepts clear, it is useful to differentiate between total and net R&D spending. *Total* R&D spending is the sum of private R&D spending (financed exclusively by the company) and public R&D subsidies. *Net* R&D spending contains only the privately financed part of total R&D spending. Thus, if a public subsidy increases net R&D spending, then a relationship of **complementarity** is found. One can be confident that new R&D projects have been undertaken or that existing R&D projects have been enlarged. On the contrary, if a public subsidy reduces net R&D spending, then a relationship of **substitutability** is established (see David et al., 2000). This indicates that companies reduce their own contribution to R&D as a response to the subsidy. Regression analysis 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.

(ii) **Fiscal incentives for R&D**: Tax incentives are typically used to provide assistance to a broad range of sectors. With tax incentives, firms decide which R&D projects will be undertaken. Tax incentives can be more effective in encouraging long-term expenditures in R&D than other measures such as R&D subsidies. Furthermore, tax incentives can be less costly and less burdensome than direct R&D subsidies. 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, 1996, 2002). It is a composite index 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, 1996, 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). Alternatively, the generosity of R&D tax incentives can be measured by taking the annual cost of R&D tax credits (see Bloom et al. 2002).

(iii) **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 to 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 and methodologies for industrial researchers in the development of new products and production processes.

(iv) **Profitability**: The countries profitability ratio could indicate the competitive environment it faces. High profits may indicate a low level of competition and thus the lack of pressure to spend in innovative activities. In theory the effect of competition on the incentives to innovate is ambiguous. The standard Schumpeterian argument is that there is a negative relationship between competition and innovation. However, based on theoretical models, Aghion and Howitt (1998) predicted a positive relationship between product market competition and R&D. However, Kamien and Schwartz (1982) have concluded that profitability is a threshold factor that is necessary to some degree for R&D activity but with no functional relationship with the level of innovative activity. Furthermore, the profitability R&D relationship may be subject to a simultaneity bias as the outcome of R&D projects would be reflected in higher profit margins.

(iv) **Regulation**: Excessive regulation and administrative burdens can hinder innovation activities (Bassanini and Ernst, 2002). Improvements in the regulatory environment, therefore, can have a positive effect on the firm's capability to innovate and develop new products.

(iv) **Patent protection:** Patent protection and other intellectual property rights protection measures create temporary technological rights and thus tend to increase the benefits of R&D effort (Edquist and Johnson, 1997; Varsakelis, 2001). Therefore, patent protection is expected to positively influence R&D spending.

(iv) **Investment**: Technological innovations are typically embodied in new machinery. Therefore, physical capital is expected to positively influence R&D spending.

(iv) **Human capital**: The higher the qualification of workers, the higher the capacity of the firm to be successful in the innovation process.

(iv) **Industry structure:** For obvious reasons BERD is expected to be higher the greater the inherent R&D intensity of the industry structure is. If a country is specialised in industries typically characterised by a high degree of R&D intensity, then aggregate business R&D intensity will generally be high. The point is not so much to verify a positive coefficient on the latter, but to control for the effects of a given R&D intensity when evaluating the impact of various public intervention measures. Specifically, the main research question is to asses the effectiveness of special fund initiatives given some industry structure that is fixed in the short run. The inherent R&D intensity of the industry structure is modelled by a country's share of high-tech manufacturing exports in total manufacturing exports. The former 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]

Table 1 summarises potential determinants of R&D intensity and lists their expected signs according to the economic theory. In order to provide an overview on the empirical evidence related to each of the R&D determinants, the last column of Table 1 lists the qualitative results of six recent studies using cross-country data. They comprise studies for 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 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.

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[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 1 Overview of previous empirical studies

Variable category	Specific variable	Expected sign	Empirical findings
Lagged R&D intensity	log of R&D intensity	+	+ and high degree of persistence Lederman/Maloney (2003)
	log of business-sector R&D intensity	+	+ high degree of persistence Reinthaler/Wolff (2004)
	log of business-funded and performed R&D	+	0 or low degree of persistence: Guellec/Pottelsberghe (2003)
Direct R&D subsidies	Government funded BERD, % GDP	Ambiguous	
	Government funded BERD, % total BERD	Ambiguous	+ (long-run elasticity = 1.36) Reinthaler/Wolff (2004) + (long term elasticity = 0.08 and marginal effect= 0.70) Guellec/Pottelsberghe (2003) 0 Bassanini/Ernst (2001)
R&D tax incentives	R&D user costs of capital	-	- Bloom et al. 2002.
	B-index	-	- Guellec/Pottelsberghe (2003),
Public sector R&D	HERD, % GDP	Ambiguous	- Reinthaler/Wolff (2004); 0 Guellec/Pottelsberghe (2003),
	GOVERD, % GDP	Ambiguous	0 Reinthaler/Wolff (2004) - Guellec/Pottelsberghe (2003),
Specialisation in high tech industries	High-tech export share	+	
GDP	Real GDP in constant ppp	+	+ Reinthaler/Wolff (2004), - + Guellec/Pottelsberghe (2003)
	Real GDP growth rate		0 Bebczuk (2002) 0 Lederman/Maloney (2003) 0 Kanwar/Evanson 2003
	GDP per capita in constant ppp	+	+ Lederman/Maloney (2003)
Protection of property rights	Ginarte-Park index of patent rights	Ambiguous	+ Varsakelis (2001) + Lederman/Maloney (2003) + Kanwar/Evanson 2003
	Kaufmann et al. Rule of Law Index	Ambiguous	+ Bebczuk (2002)
Human capital	Average years of schooling in population over 15 years	+	0 Kanwar/Evanson 2003
	Total literacy rate in population over 15	+	+ Kanwar/Evanson 2003
	Tertiary school enrolment	+	0 Bebczuk (2002)
	Share of university graduates	+	
Openness	exports and imports as percentage of GDP	+/ 0	+ Reinthaler/Wolff (2004) - Bebczuk (2002)
price-cost markup	price-cost markup ratio	Ambiguous, non-linear	+ and inverted u-shaped curve, becomes negative at high levels, Griffith and Harisson (2004)
Investment	Investment ratio	+	- Bebcuk (2002)
Firm size	Employment share of large firms	+	+ Bassanini/Ernst (2001)
collaboration	Index of collaboration between enterprises and universities		+ Lederman/Maloney (2003)
quality of research institutions	Index of quality of academic research institutions		+ Lederman/Maloney (2003)
barriers to starting new business	Fraser institute index of the ease of starting a new business		- Griffith and Harrison (2004)
tariff rate	Fraser institute index of average tariff rate		- Griffith and Harrison (2004)
	OECD Indicator	-	+ Bassanini/Ernst (2001)
tariff and non tariff barriers	OECD indicator	-	- Griffith and Harrison (2004)
Employment protection	OECD indicator	-	- Griffith and Harrison (2004)

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.

3. Empirical model and hypotheses

The factor demand for business sector R&D intensity may be specified by the following regression equation:

$$\ln\left(\frac{BERD_{it}}{GDP_{it}}\right)^{*} = \beta_0 + \alpha_1 \ln\left(\frac{SUB_{it}}{GDP_{it}}\right) + \alpha_2 \ln(BINDEX_{it}) + \beta \ln X_{it} + \lambda_t + \mu_i + \varepsilon_{it}.$$

The index t denotes five-year averages. An asterisk denotes the desired demand for R&D. The left-hand side variable is given by $BERD_{it} / GDP_{it}$, i.e. total expenditures on R&D in the business sector (BERD) as a percentage of GDP. SUB_{it} / GDP_{it} denotes government-financed R&D expenditures (i.e. direct support in the form of grants, loans etc) in the business sector as a percentage of GDP. To capture fiscal incentives, the B-index is employed, measuring the generosity of the tax system.[3] 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 should be significantly negative. X_{it} denotes observable characteristics. μ_i is a country effect and may be correlated with X_{it} and ε_{it} is assumed to be white noise.

We then assume a simple partial adjustment mechanism,

$$\ln\left(\frac{BERD_{it}}{GDP_{it}}\right) - \ln\left(\frac{BERD_{i,t-1}}{GDP_{i,t-1}}\right) = \theta\left(\ln\left(\frac{BERD_{it}}{GDP_{it}}\right)^{*} - \ln\left(\frac{BERD_{i,t-1}}{GDP_{i,t-1}}\right)\right), \quad 0 < \theta \leq 1,$$

Assuming a simple partial adjustment of short-run R&D intensity towards its long-run equilibrium, the lagged R&D intensity is included in the model. Combing both equations gives the regression equation:

$$\ln\left(\frac{BERD_{it}}{GDP_{it}}\right) = \tilde{\beta}_0 + \gamma \ln\left(\frac{BERD_{i,t-1}}{GDP_{i,t-1}}\right) + \tilde{\alpha}_1 \ln\left(\frac{SUB_{it}}{GDP_{it}}\right) + \tilde{\alpha}_2 \ln(BINDEX_{it}) + \tilde{\beta} \ln X_{it} + v_t + \omega_i + e_{it}.$$

with $\tilde{\beta}_0 = \theta\beta_0$, $\lambda = 1-\theta$, $\tilde{\alpha}_1 = \theta\alpha_1$, $\tilde{\alpha}_2 = \theta\alpha_2$, $\tilde{\beta} = \theta\beta$, $v_i = \theta\mu_i$, $\omega_t = \theta\lambda_t$ and $e_{it} = \theta\varepsilon_{it}$. The long-run effects can be easily recovered by dividing $\tilde{\beta}_0$, $\tilde{\alpha}_1$ and $\tilde{\alpha}_2$ by 1-λ.

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[3] For more details refer to Warda (1996).

Observable characteristics include the ratio of R&D expenditures within the higher education sector to GDP (i.e. HERD, % GDP) and the ratio of intramural government sector R&D expenditures to GDP (GOVERD, % GDP). We also include total public sector R&D that is the sum of both GOVERD, % GDP and HERD, % GDP. Note that public sector R&D is specified as the total amount of R&D performed in the public sector, irrespective of its funding. Since any given input factor demand depends on output, GDP per capita in constant PPP-$ is included into the model. In addition, the share of high-technology exports in total manufacturing exports enters the equation. High-technology exports are characterised by a high intensity of research and development and measures the technology-intensity of a country's exports. It could be argued that the share of high-technology exports is a measure of innovation output rather than a factor explaining innovation input. However, the share of high-technology exports also reflects the degree of specialisation in high-tech activities. They include high-technology products such as aerospace, computers, pharmaceuticals, scientific instruments and electrical machinery (see OECD STI Scoreboard 2003). Finally, we include the price-cost markup ratio, two indicators for human capital, indicator measuring patent protection and the investment rate into the regression.

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 the 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 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).[4] 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 get some insight into the triggering role of tax credits on R&D.

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[4] 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.

The dynamic panel data model is estimated using the first-differenced GMM and system GMM estimator. 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 panel 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, variables are instrumented using their own lags. We use levels of the relevant variables lagged at least twice and first differences of the same variable lagged at least once as instruments in the first-differenced and level equations, respectively. We also report results for the static fixed effects model.

4. 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 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. The price-cost margin (PCM) is taken from the article by Salgado (2002) and is measured at the beginning of each five-year period. Ginarte-Park index of patent rights is provided by W. Park and is available quinquennially (i.e. 1970, 1965, 1970, 1976, 1980, 1985, 1990 and 1995). This protection index uses a 0-5 scale, and is based on several features, extent of coverage, membership in international agreements, loss of protection, enforcement and duration of protection (see Ginarte and Park, 1997). Average number of schooling years is taken form de la Fuente and Domench (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 the education at a glance database. 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. average years of schooling and patent protection index) average we do not have averages but the data refers to 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 average 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 price-cost margin for the entire business enterprise sector averages 0.16 with considerable variation within countries. The highest levels can be observed in Italy, France, Spain and Greece that have a mean of over 0.2. The lowest mean mark-ups are in Denmark and Finland. The share of university graduates in 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%. Table 2 also shows the between and within standard deviation. In most of the cases, the variation in the cross-sectional dimension is larger than the time dimension. Given the properties of our sample, one should also use the information in the cross-sectional dimension.

Table 2: Summary statistic (pooled)

Variable	obs	Mean	Std. Dev.	Std. Dev., between	Std. Dev, within	Min	Max
BERD, % GDP	132	0.010	0.006	0.006	0.003	0.0004	0.033
Government funded BERD, % GDP	100	0.001	0.0011	0.0010	0.001	0.000003	0.006
B-index	102	0.96	0.10	0.09	0.05	0.60	1.13
HERD, % GDP	101	0.004	0.0016	0.0015	0.001	0.0004	0.008
GOVERD, % GDP	101	0.003	0.0012	0.0012	0.000	0.0003	0.006
HERD + GOVERD, % GDP	101	0.006	0.0019	0.0018	0.001	0.0014	0.010
High-tech export share, %	105	0.13	0.09	0.08	0.04	0.01	0.48
High-tech export share (wide def.)	105	0.16	0.11	0.10	0.05	0.01	0.52
GDP per capita in const. ppp (in 1000s)	147	27.4	6.8	4.6	5.1	12.2	42.7
Ginarte-Park index of patent rights (0-5 scale)	126	3.4	0.6	0.5	0.4	2.0	4.9
Average years of schooling, (years)	147	10.2	2.0	1.9	0.8	4.9	13.4
Share of university graduates, %	121	0.157	0.095	0.085	0.045	0.019	0.480
Price-cost markup, %	115	0.161	0.098	0.083	0.060	0.001	0.464
Openness, %	147	0.618	0.301	0.286	0.110	0.126	1.779
Investment ratio, %	147	0.228	0.036	0.026	0.026	0.163	0.356
Private investment ratio, %	140	0.198	0.038	0.022	0.031	0.131	0.300

Source: see Table 8 in appendix. Negative values of the markup ratio are replaced by 0.001.

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 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 the 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 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 2000s.

The Ginarte-Park index of patent rights protection increased steadily over the sample period indicating an increase in patent protection. The mark-up ratio for the entire business enterprise sector averages 0.19 and decreases over the period 1980 to 2000. Norway, Switzerland, Japan and Finland experienced a rapid decline in the mark-up over the 1980s and 1990s, while Ireland, New Zealand, United Kingdom experienced increasing mark-ups for the sample period.

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	
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	
Price-cost markup	0.198	0.173	0.186	0.171	0.123	0.120	
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 8 in appendix.

5. Estimation results

Results of the bivariate analysis

Table 4 provides an initial look at the determinants of business enterprise R&D intensity. 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 static panel data model is estimated using a fixed-effects estimator for an unbalanced panel of N = 21 OECD countries with T ranging between four and 7 time intervals, resulting in 99 to 132 observations.

Table 4: Determinants of Business R&D intensity: Fixed effects estimates (examined separately)

	coeff	t-value	time effects (p-value)	R2 within	# of obs	# of countries
Government funded BERD, % GDP	0.27**	5.62	0.00	0.64	100	21
B-index	-1.01**	-2.79	0.00	0.55	99	21
HERD, % GDP	0.54**	5.78	0.00	0.65	101	21
GOVERD, % GDP	0.32**	2.86	0.00	0.55	100	21
HERD + GOVERD, % GDP	0.81**	5.60	0.00	0.65	100	21
High-tech export share	0.45**	5.11	0.09	0.63	102	21
High-tech export share (wide def.)	0.51**	5.20	0.09	0.64	102	21
GDP per capita in constant ppp	0.02	0.07	0.00	0.53	132	21
Ginarte-Park index of patent rights	1.24**	3.80	0.00	0.60	114	21
Average years of schooling	0.98	1.52	0.03	0.54	132	21
Share of university graduates	-0.25	-0.88	0.00	0.54	109	21
Openness	0.16	0.73	0.00	0.53	132	21
Price-cost markup	-0.11**	-4.18	0.00	0.59	106	20
Investment ratio	-0.39	-1.41	0.00	0.54	132	21
Private investment ratio	-0.67**	-3.29	0.00	0.58	127	20

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

The results based on the static fixed effects model show that government funded R&D in the business sector and the B-index all have a strong and significant positive impact on R&D intensity. The findings of positive effects of direct and indirect government intervention support earlier finding in the literature (e.g. Guellec and van Pottelsberghe, 2003). Furthermore, we find that public sector R&D significantly positively influences business enterprise R&D expenditures. Specifically, both government and university R&D are significantly positively related to the business-sector R&D intensity entered into the regression equation separately. As expected, we find that HERD as a percentage of GDP has a larger impact than government R&D as a percentage of GDP. Furthermore, the share of high-technology exports in total manufacturing is significantly positive. This indicates that countries with a large share of technology driven industries also have a high business R&D intensity. Furthermore, the strength of intellectual property rights protection is positively and significantly associated with R&D. Thus, countries that provided stronger patent protection tends to have higher R&D intensity. Countries with a educated working age population seems to invest more in research in development but the coefficient is not significantly different from zero at the 10% level. However, for shorter time periods (e.g. the period 1980-2002) we obtain a statistically significant coefficient on average years of schooling. This is consistent with Kanwar and Evenson (2003) who use data over the period 1981-1990. Openness is not statistically significant even though the sign is consistent with a priori expectations. Furthermore, we obtain negative and significant effects of business-sector investment as a share of GDP indicating that private investment and R&D investment are substitutes. We also find that the markup ratio is significantly negatively related to the business-sector R&D intensity. This suggests that countries with the highest markup ratio have lower R&D intensity. One interpretation of this finding is that high markup ratios are associated with lower competition and less incentives to conduct R&D. Aghion et al. (2002) and Griffith and Harrison (2004) pointed to the possibility of a nonlinear relationship between R&D intensity and markup ratio. They suggest that observations with low and high markup ratio have lower R&D intensity. We test for such nonlinearities by introducing quadratic terms into the model. Unreported results show that markup and markup ratio are jointly significant with a p-value of 0.00. Figure 1 shows the resulting relationship between business-sector R&D intensity and that log business-sector R&D intensity. R&D intensity is increasing with decreasing logarithm of the mark up ratio starting from a threshold of -2.3 (equal to a markup ratio of 10%). For markup ratios ranging between -2.3 and -0.76 (equal to markup-ratios between 10%and 46%) R&D intensity is decreasing with the decreasing of the markup ratio. Thus, a threshold effect is not supported because there is a positive relationship at low levels of the price-cost markup ratio. This finding is not consistent with the hypothesis of an inverted u-shaped curve between the level of competition and R&D intensity. Somewhat surprisingly, we do not find any statistically significant effect of GDP per capita measured in constant USD ppp.

Table 5 shows the results of each explanatory variable using first-differenced and system GMM estimators. Again, a complete set of period dummies is included in all specifications to control for effects that are common across time. In order to investigate whether our model is correctly specified we use the Sargan/Hansen test, difference Sargan test and tests for second order correlation of the residuals in the differenced equation. The results for the dynamic panel data model estimated by the system GMM show that the coefficient on lagged R&D intensity is positive and significant in all specifications. We interpret this as a rejection of a static model in favour of a dynamic model. The coefficients of lagged business-sector R&D estimated using system GMM range between 0.82 and 0.90 suggesting a high degree of persistence. This gives a rate of convergence in business-sector R&D intensity in the range between 1.9% and 3.4% per year and between 10% and 18% within a five-year period. The low rate of convergence 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. As expected, the coefficient on lagged R&D intensity using first-difference GMM is considerably lower suggesting a much higher speed of adjustment. However, as emphasised by Bond et al. (2001), the first-differenced GMM estimator is likely to be biased when the time series are persistent and short as it is also the case for business-sector R&D intensity.

In general, the comparison between the static and dynamic panel data estimators shows that some potential determinants of R&D intensity become insignificant or much less significant when lagged R&D intensity is included in the regression. This implies that controlling for lagged R&D intensity eliminates most of the variation across countries. The results using system GMM indicate that only 4 out of 14 potential determinants are significantly different at the 10% significance level when entering the regression equation separately. In particular, higher education expenditures on R&D (HERD) as a percentage of GDP and GDP per capita are positive and significant at the 5% level, while B-index and private investment ratio are significant at the 10% 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 5.2% (equalling 0.052 percentage points given the sample mean of 0.01%). To capture a possible nonlinear relationship between business-sector R&D intensity and GDP per capita, we regress R&D intensity on GDP per capita and GDP per capita squared. The results indicate that R&D intensity increases with GDP per capita, but at a decreasing rate (see Figure 2). 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 be explained at least in part by the use of a different sample: OECD countries vs. industrialised and developing countries. Furthermore, government funded R&D as a percentage of GDP, specialisation in high-tech industries, markup-ratio and patent protection no longer have significant effects using the system GMM estimator compared to the static fixed effects model. Unreported results show that log quadratic functional form for markup ratio is also rejected. Both markup ratio and its squared value are jointly not significant from zero (with a p-value of 0.93 as indicated by the F-Test for joint significance).

The results using the first-differenced GMM estimator suggest that higher education expenditures as a percentage of GDP, B-index, high-tech export share and continues to be statistically significant at the 5% level, even after controlling for lagged R&D intensity and endogeneity. In two cases the statistical significance declines considerably. The Ginarte-Park index for patent protection and the share of government funded R&D are only significant at the 10% level. Furthermore, the mark-up ratio and investment ratio in the business sector are no longer significant at conventional significance levels. Average years of schooling, the share of university graduates and openness are not significant for both GMM estimators.

Table 5: Determinants of Business R&D intensity: Dynamic panel data results (examined separately)

	exog. var.		business R&D intensity		time effects	Sargan	AR(1)	AR(2)	obs	countries
	coeff.	t-value	coeff.	t-value	p-value	p-value	p-value	p-value	# of	# of
				System GMM						
Government funded BERD, % GDP	0.04	0.73	0.83**	12.4	0.00	0.01	0.66	0.59	94	21
B-index	-0.38*	-1.83	0.90**	34.1	0.00	0.07	0.62	0.48	93	21
HERD, % GDP	0.27**	2.48	0.82**	17.9	0.00	0.03	0.53	0.25	95	21
GOVERD, % GDP	0.03	0.59	0.89**	29.2	0.00	0.00	0.67	0.59	93	21
HERD + GOVERD, % GDP	0.15	1.10	0.86**	15.5	0.00	0.00	0.75	0.49	93	21
High-tech export share	0.03	1.16	0.89**	30.5	0.00	0.02	0.67	0.53	95	21
High-tech export share (wide def.)	0.01	0.35	0.90**	30.2	0.00	0.02	0.60	0.54	95	21
GDP per capita in constant ppp	0.52**	2.17	0.82**	17.8	0.00	0.14	0.26	0.37	110	21
Ginarte-Park index of patent rights	0.13	0.59	0.88**	19.5	0.00	0.22	0.48	0.48	92	21
Average years of schooling	0.19	1.20	0.88**	20.6	0.00	0.05	0.32	0.50	110	21
Share of university graduates	0.09	1.34	0.89**	27.5	0.00	0.04	0.67	0.47	87	21
Openness	0.00	0.08	0.90**	37.5	0.00	0.05	0.09	0.55	110	21
Price-cost markup	0.03	0.61	0.89**	25.6	0.00	0.13	0.23	0.26	86	20
Investment ratio	-0.43	-1.64	0.90**	33.6	0.00	0.35	0.10	0.63	110	21
Private investment ratio	-0.30*	-1.73	0.89**	35.0	0.00	0.13	0.18	0.27	106	20
				GMM First differences						
Government funded BERD, % GDP	0.15*	1.93	0.38**	2.26	0.00	0.00	0.59	0.51	73	21
B-index	-1.52**	-4.11	0.42**	2.21	0.04	0.00	0.96	0.48	72	20
HERD, % GDP	0.61**	3.07	0.18*	1.90	0.00	0.00	0.55	0.66	74	21
GOVERD, % GDP	-0.17	-0.73	0.59**	4.82	0.00	0.00	0.75	0.61	72	21
HERD + GOVERD, % GDP	0.43	1.24	0.26**	2.74	0.00	0.00	0.51	0.72	72	21
High-tech export share	0.33**	2.11	0.27	1.64	0.03	0.00	0.52	0.29	74	21
High-tech export share (wide def.)	0.36*	1.96	0.24	1.48	0.03	0.00	0.47	0.26	74	21
GDP per capita in constant ppp	0.22	0.80	0.58**	4.00	0.00	0.00	0.16	0.62	89	21
Ginarte-Park index of patent rights	0.47*	1.66	0.43**	2.83	0.00	0.00	0.56	0.37	71	21
Average years of schooling	0.57	0.64	0.57**	3.36	0.01	0.00	0.23	0.65	89	21
Share of university graduates	0.03	0.04	0.51**	5.74	0.00	0.00	0.37	0.32	66	21
Openness	0.53	1.05	0.48**	2.87	0.00	0.00	0.39	0.72	89	21
Price-cost markup	0.05	0.88	0.65**	6.44	0.00	0.00	0.46	0.39	66	20
Investment ratio	-0.11	-0.30	0.61**	3.40	0.00	0.00	0.24	0.75	89	21
Private investment ratio	-0.27	-1.16	0.53**	4.14	0.00	0.00	0.34	0.40	86	20

Notes: ** and * denote significant at 5% and 10% level. All variables are expressed in their logarithms. Estimation period varies between 1970-2002 and 1980-2002 with data derived from five-year averages and one three-year average. The dynamic panel data model is estimated using one-step GMM and system GMM estimators. t-values are based on robust standard errors. Dependent variable is log BERD % GDP (in first differences or levels and first differences combined). We use levels of the explanatory variables lagged at least twice and first differences of the same variable lagged at least once as instruments in the first-differenced and level equations, respectively.

Results of the multivariate analysis

Table 6 presents the main results of the R&D equation. The middle panel presents system GMM results, while the lower panel presents the results using the first-differenced GMM estimator. In order to compare the results with previous studies using a static model the fixed effects estimates are presented as well. Diagnostic tests are presented for the first and second order correlation. We use lagged instruments in the level equations once. The Sargan test of overidentifying restrictions is not significant at the 5% level in all cases. The first specifications of each panel provide estimates of the impact of HERD and B-index. In specification (2) and (3) the high-tech export share and GDP per capita are included as a control variable in the regression. In (4) we add publicly financed business R&D as a share of GDP. In (5) we add GDP per capita.

The coefficient of the lagged dependent variable is significant at the 5% level in all specifications using the system GMM estimator. This indicates that there is catch-up and convergence observable in the level of business-sector R&D intensity across OECD/EU countries. Countries with a low initial level of business-sector R&D intensity (e.g. Portugal, Greece, Spain and Ireland) experienced a higher growth. The coefficients on lagged business enterprise R&D intensity range between 0.77 and 0.82 implying business-sector R&D intensity is slow to adjust to its desired level. Overall between 18%and 23% of the desired adjustment takes place within the five-year period. The resulting rate of convergence ranges between 3.4% and 4.2 % per year. The high persistence of business-sector R&D intensity also implies that the long run effects of policy and non-policy factors are between four and five times as large as their respective short-run effects. Using the first-differenced GMM, we find that the coefficient on lagged of BERD as a percentage of GDP is of magnitude 0.41 or less and is not significant at the 10% level in some cases. Again, it is well known that the coefficient of BERD is significantly underestimated using the first difference GMM method when there is high persistence as it is the case for business-sector R&D intensity.

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 specifications. The results are also robust with respect to the estimation technique. The short run elasticity of about -0.21 indicates that a 1% reduction in the B-index (increase in generosity of tax incentives for R&D) leads to a 0.21% increase in the business-sector R&D intensity. The long-run elasticity equals -0.91.[5] This finding is consistent with former evidence on 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 about -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 elasticity of -0.81. Guellec, 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.

HERD, representing higher education expenditures on R&D as a share of GDP achieves statistical significance at the 5% level with a positive sign in most of the cases. 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 high-tech export share and HERD as a percentage of GDP. An F-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 1.04, respectively. This means that a 1% increase in the ratio of HERD to GDP in the long-run is associated with a 1.04% increase in business-sector R&D intensity. It may be useful to know how the elasticity estimates translates 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.[6]

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 earlier literature. The long-run elasticity estimates range between 0.27 using the fixed effects model and 0.11 (calculated as 0.08/(1-0.27)) using the first-differenced GMM estimator. In order to test whether government-funded R&D in the business sector is a complement or a substitute to private R&D in the business sector, the estimated coefficients are transformed into marginal effects. Note that the dependent variable is total R&D expenditures in the business sector, i.e. government-financed BERD is included. This means that the estimated coefficients associated with government R&D have to be interpreted differently. The results suggest that an increase of one

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[5] 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).

[6] 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.

dollar of government funded R&D expenditures will generate an increase of total business sector R&D expenditures between 1.06 and 1.65 dollar (the share of government funded R&D to total BERD is 0.10 in the sample). Since the coefficient is higher than 1.0, one can conclude that government-funded R&D is a complement for private R&D.

Furthermore, estimates using system GMM show that the GDP per capita in constant USD ppp is positive but significant at the 10 level. The share of high-technology exports in total manufacturing is significantly positive only in the first-difference GMM specification. Patent protection has a positive sign but fails to achieve statistical significance and is therefore not included in the regression. Openness turns to have a positive influence but the coefficient is only significant at the 10% level in the first-difference specification.

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 each significant at the five percent level. The effects model explains around 83% of the within variation in R&D intensity. For reference the set of industry and country dummies alone explain 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.

Finally, we also report the results for first-differenced GMM estimator not controlling for endogeneity. Estimates not controlling for endogeneity reveal only minor differences in results (see Table 7 in appendix).

Table 6: Determinants of Business R&D intensity

		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.	openness	Sargan /Hansen test	AR(1)	AR(2)	# of obs	# of countries	R2 within
							Fixed Effects model								
(1)	c.			-0.62*	0.52**								99	21	.68
	t			-1.98	5.49										
(2)	c.			-0.58*	0.52**		0.43						99	21	.69
	t			-1.86	5.49		1.37								
(3)	c.			-0.48*	0.47**	0.48**							99	21	.79
	t			-1.87	5.98	5.94									
(4)	c.		0.13**	-0.46*	0.32**	0.45**							99	21	.80
	t		2.69	-1.86	3.41	5.79									
(5)	c.		0.14**	-0.41*	0.31**	0.45**	0.57**						99	21	.82
	t		2.98	-1.68	3.34	6.05	2.36								
(6)	c.		0.15**	-0.43*	0.27**	0.45**	0.50**		0.32*				99	21	.83
	t		3.26	-1.79	3.01	6.05	2.07		1.88						
(7)	c.		0.17**	-0.63**	0.35**	0.40**	-3.96	0.68	0.32**				99	21	.84
	t		3.65	-2.37	3.45	5.12	-1.43	1.62	1.91						
							System GMM estimator[a]								
(1)	c.	0.82**		-0.27*	0.26**					0.09	0.61	0.33	93	21	
	t	17.8		-1.89	2.54										
(2)	c.	0.83**		-0.24*	0.21**		0.12			0.37	0.62	0.26	93	21	
	t	15.3		-1.67	2.73		0.61								
(3)	c.	0.78**		-0.20	0.27**	0.06				0.14	0.63	0.42	93	21	
	t	11.7		-1.58	2.45	1.11									
(4)	c.	0.79**	0.01	-0.22*	0.25**	0.05				0.24	0.73	0.44	92	21	
	t	10.0	0.46	-1.76	2.38	1.00									
(5)	c.	0.77**	0.01	-0.21*	0.24**	0.05	0.17			0.28	0.72	0.37	92	21	
	t	8.6	0.44	-1.80	2.50	1.22	1.12								
							First-differenced GMM estimator[a]								
(1)	c.	0.39**		-0.93**	0.40**					0.99	0.97	0.61	73	21	
	t	4.33		-2.97	3.11										
(2)	c.	0.41**		-0.91**	0.42*		0.42**			0.98	0.90	0.28	73	21	
	t	2.18		-4.16	1.91		2.25								
(3)	c.	0.25		-0.95**	0.29	0.40**				0.95	0.80	0.88	73	21	
	t	1.49		-2.81	1.06	3.21									
(4)	c.	0.28*	-0.01	-0.90**	0.32	0.38**				0.97	0.70	0.90	73	21	
	t	1.74	-0.25	-2.84	1.07	2.90									
(5)	c.	0.27	0.08**	-0.75**	0.21	0.29**	0.55**			0.99	0.69	0.36	73	21	
	t	1.43	2.56	-3.10	1.06	2.73	2.30								

Notes: ** and * denote significant at 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.

Conclusions

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

The main results of the empirical analysis can be summarised as follows. Estimates using a 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 about -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. Countries characterised by a low level mark-up ratio appear to have higher R&D intensities but this effect disappears after controlling for lagged R&D intensity. Direct R&D subsidies and the specialisation in high-tech industries also contributes 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. Estimates of the rate of convergence in R&D intensity range between 2% and 4% per year.

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Appendix

Table 7: 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” include 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, A. and R. Doménech (2001) and OECD Education at a glance
Share of university graduates	log of working population with a degree in non-university tertiary + short and long term university courses	De la Fuente, A. and R. 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.
Price-cost markup	log of price average cost markup is calculated as the ratio of GDP at market prices less net direct taxes to the sum of labour and capital income where the latter is the product of the real product, capital price deflator and the real rental rate of capital	Salgado (2002)
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.

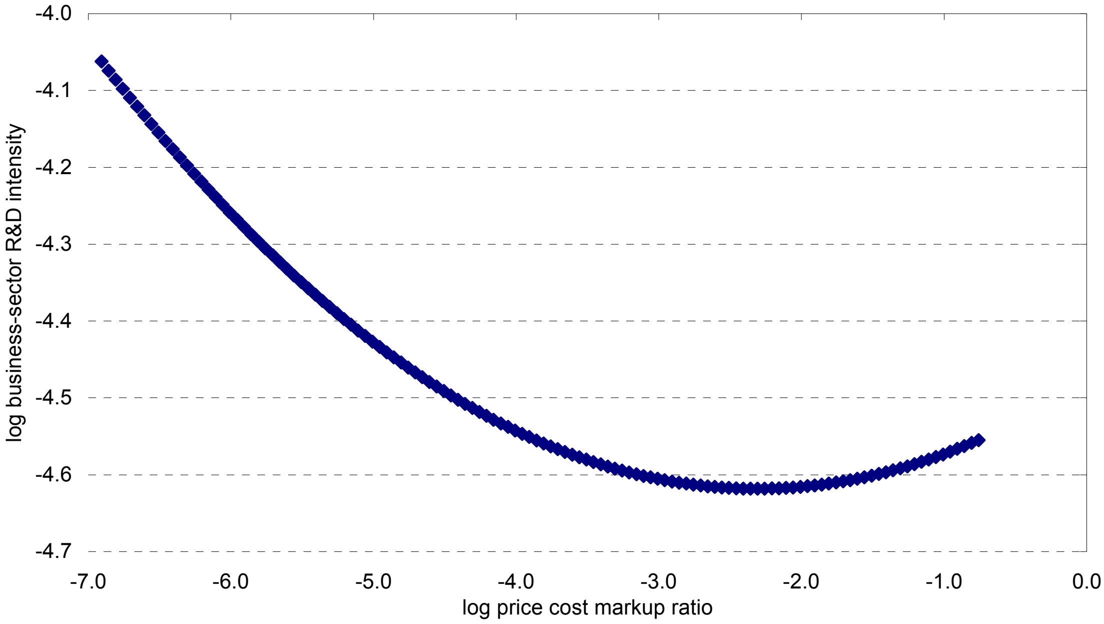
Table 8: Determinants of Business R&D intensity (first-differenced GMM not controlling for endogeneity)

		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.	openness	Sargan/Hansen test	AR(1)	AR(2)	# of obs	# of countries	R2 within
(1)	coeff	0.42*		-1.06**	0.24					0.94	0.99	0.75	72	21	
	t-val.	1.96		-3.49	1.03										
(2)	coeff	0.42**		-0.65**	0.39*		0.26			0.94	0.90	0.80	72	21	
	t-val.	2.29		-2.42	1.81		1.22								
(3)	coeff	0.26		-0.88**	0.25	0.32**				0.99	0.87	0.90	72	21	
	t-val.	1.58		-2.78	1.16	3.50									
(4)	coeff	0.29*	0.08	-0.80**	0.20	0.31**				0.99	0.80	0.92	72	21	
	t-val.	1.84	1.64	-2.89	0.88	3.40									
(5)	coeff	0.31	0.10**	-0.61**	0.18	0.28**	0.51**			0.98	0.80	0.83	72	21	
	t-val.	1.60	2.77	-2.23	0.89	2.56	2.05								

Notes: ** and * denote significant at 5% and 10% level. Dependent variable is log BERD % GDP. All variables are expressed in their logarithms. The dynamic panel data models are estimated using the one-step GMM estimator in first differences. In all equations estimated using GMM 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.

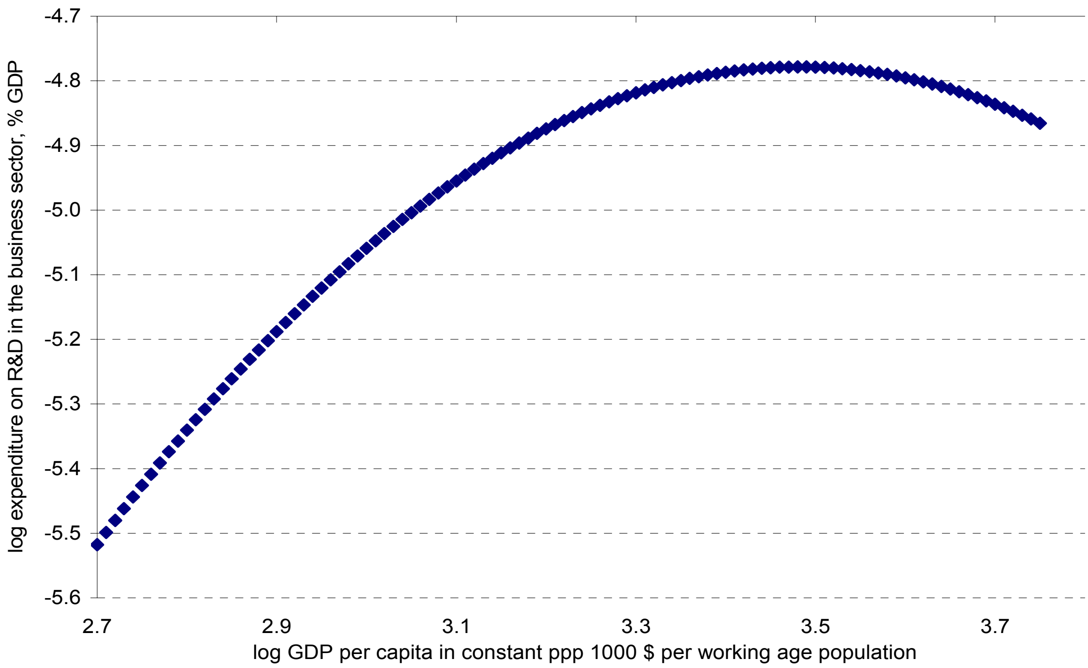
Appendix

Figure 1: Relationship between R&D intensity and markup ratio in the business sector



Notes: Both figures are the results of a fixed regression analysis where log businesses R&D intensity is the dependent variable and markup, markup squared and period dummy variables are independent variables. Negative values for the markup ratio are replaced by the lowest positive markup ratio in the sample that is 0.001.

Figure 2: Relationship between R&D intensity and log GDP per capita



Notes: The figure shows the results of a system GMM regression analysis where log businesses R&D intensity is the dependent variable and GDP per capita, GDP capita squared and period dummy variables are independent variables. The coefficients of GDP per capita and GDP per capita squared are 8.42 and -1.21, respectively with t-values of 2.52 and -2.42.

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