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From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?

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JEL Classifications: O11, O40, O47, O50
Keywords: Science and technology policies, R&D, spillovers, growth.

CEB Working Paper N° 04/010
March 2004

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From R&D to Productivity Growth:

Do the Institutional Settings and the Source of Funds of R&D Matter?

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March 2004

Third revision, accepted for publication in the Oxford Bulletin of Economics and Statistics

Abstract

This paper presents estimates of the long-term impact of various sources of knowledge (R&D performed by the business sector, the public sector and foreign firms) on multifactor productivity growth of 16 countries from 1980 to 1998. The main results show that the three sources of knowledge are significant determinants of long term productivity growth. Further evidence suggests that several factors determine the extent to which each source of knowledge contributes to productivity growth. These factors are the absorptive capability, the origin of funding, the socio economic objectives of government support, and the type of public institutions that perform R&D.

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I. Introduction

Economic theory (Solow, 1957; Romer, 1990) points to technical change as the major source of productivity growth in the long run. New processes allow firms to increase output per worker or per unit of capital, and new products contribute to improving the well-being of consumers. While other factors, such as macroeconomic shocks, can affect productivity in the short to medium term, only the extension of technology can make economic growth sustainable, durable. Anecdotal evidence suggests that new technology, especially information technology over the nineties, has substantially contributed to recent improvement in the productivity of firms. The existing literature on more 'aggregated' economic analysis points to R&D as being the ultimate source of technological change. Most studies in this field of research have confirmed that domestic business R&D and foreign R&D are a major driver of economic growth. Fewer studies have also provided evidence about the economic effect of public research**.** In a recent paper (Guellec and van Pottelsberghe, 2002) we provided macroeconomic evidence of the simultaneous impact of business R&D, foreign R&D and public R&D on economic growth.

The main objective of the present paper is to contribute to this stream of empirical research by analysing the extent to which the components of the various sources of knowledge, their socio-economic objectives, and their interaction determine their effectiveness in contributing to economic growth. The estimates are based on a panel dataset composed of 16 major OECD countries over the period 1980-1998.

The paper is structured as follows. The next section defines the various sources of knowledge and new technologies and the way they have been taken into account in the literature. The empirical model and the data implementation are reported in the third section. Section 4 presents the econometric results and their interpretation. The final section concludes and draws some policy implications.

The main results show that the three sources of knowledge contribute significantly to output growth. The impact of business R&D has increased over the past 20 years, whereas the one of foreign R&D has been stable and the one of public R&D has decreased. We provide evidence that the origin of funding, the socio-economic objectives associated with these funding, and the institutional setting are important factors explaining cross-country differences in the effectiveness of the three sources of knowledge in contributing to multifactor productivity (*MFP*) growth. These results partly explain why the impact of business R&D (public R&D) has increased (decreased) over time.

II. Sources of knowledge and growth

Research and development is considered as a major source of technical change. As defined by the *Frascati Manual* (OECD, 1993, p. 29), R&D "comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications". R&D is not the only source of new technology: in modern, industrial economies, other activities, such as education and learning by doing are important sources of productivity growth. Education and learning by doing can improve economic performance through an improved ability to absorb new technologies coming out of domestic and foreign R&D (*e.g.* changes in the organisation of business due to the use of information and communication technology).

Although the relationship between R&D and innovation is complex and non-linear, it is clear that substantial advances in technology cannot occur without work undertaken on a systematic basis (even serendipity tends to develop in such a context), and R&D is a good indicator of this broader phenomenon. There are different types of R&D, however, and its effect on productivity may work through various channels. In order to capture the links between R&D and productivity it is necessary to take these aspects into account. R&D can be performed by the business sector and the public sector (public labs and higher education institutions). The R&D performed abroad can also be a significant source of domestic technical change. In what follows we briefly examine the potential impact of these various types of R&D. We start with business R&D, and its source of funding. We then look at the economic effects of public R&D and foreign R&D.

R&D performed by business results in new goods and services, in higher quality of output and in new production processes. These are sources of productivity growth at the firm level and at the macroeconomic level. The effect of business R&D on productivity has been investigated in numerous empirical studies, performed at all aggregation levels – business unit, firm, industry and country levels – and for many countries (especially the United States). All these studies reach the conclusion that R&D does matter, the estimated elasticity of output with respect to business R&D varying from 10% to 30% (see a survey of the literature by Nadiri, 1993). This large variation is mainly due to the fact that studies differ in terms of the econometric specification, data sources, number of economic units, measurement methods for R&D and economic performance, aggregation level, and periods of investigation. To the best of our knowledge the earliest panel data analysis has been performed by Soete and Patel (1985) for 5 countries. Lichtenberg (1993) probably pioneered the use of a very large number of countries for this kind of investigation. The author used a cross section of 53 countries to investigate the impact of R&D on labour productivity. Coe and Helpman (1995) and Park (1995) were the first to combine a large number of countries with long time series (22 industrialised countries from 1970 to 1990 for Coe and

Helpman and 10 OECD countries from 1970 to 1987 for Park). These panel data analyses all converge towards the conclusion that the “social” return to business R&D is substantial and significant.[1]

A more recent stream of empirical analysis underlines that business R&D can further enhance firms’ absorptive capability of outside knowledge. This argument is forcefully stated by Cohen and Levinthal (1989) and Geroski (1995) and has further empirical validation at the microeconomic level (e.g., Branstetter and Sakakibara, 1998). The survey results of Mansfield (1981) suggest that on average imitation costs are about 65 percent of the original innovation costs. Griffith *et al.* (2004) provide the theoretical foundations underlying the hypothesis of absorptive capability. In the next sections we intend to validate this hypothesis of absorptive capability, not only of business R&D but also of public and foreign R&D.

Business performed R&D may be funded by business itself or by the government: it might be that business R&D has a different effect on productivity, depending on its source of funds (which affects the research agenda and the incentive structure). Lichtenberg (1993) provides the only cross country attempt to test whether government funded R&D performed by firms had a different impact than business funded R&D. The author concludes that there is a negative impact of government support to business R&D. In the next sections we re-examine this relationship in the light of the socio-economic objectives associated with the government support to business R&D.

Government and university R&D have a direct effect on scientific, basic knowledge and on public missions. In many cases the effect of government research on productivity is not measured, either because it is indirect or because its results are not accounted in existing measures of GDP (health-

[1] The term ‘social’ is used because the analysis is performed at the aggregate level. It implicitly measures the direct impact of R&D (i.e. the internal rate of return at the firm level) and the externalities (i.e. the inter firm R&D

related research improves the length and quality of life, which are not taken into account in GDP measures).[2] Basic research performed mainly by universities enhances the stock of knowledge available for the society. New knowledge is not considered as an output in the current system of national accounts (contrary to new equipment and software for instance), and as such it is not included in GDP measures: hence the direct outcome of basic research is overlooked. However, basic research may open new opportunities to business research, which in turn might improve productivity.

It is therefore not surprising that there have been very few studies of the effects of public research on productivity. Only some components of public research have been used in empirical frameworks. For instance, Adams (1990) finds that fundamental stocks of knowledge, proxied by accumulated academic scientific papers, significantly contribute to productivity growth in US manufacturing industries. Another example is provided by Poole and Bernard (1992) for military innovations in Canada, who present evidence that a defence-related stock of innovation has a negative and significant effect on the multifactor productivity growth of four industries over the period 1961-85. Nadiri and Mamuneas (1994) formally include the stock of public R&D, along with the stock of public infrastructure, as a determinant of the cost structure of U.S. manufacturing activities. Their results suggest that public R&D capital has significant productive effects and is associated with a substantial "social" rate of return. However, in its panel data analysis of 10 OECD countries, Park (1995) finds that public R&D loses its significant impact on productivity growth when business R&D is included among the explanatory variables.

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spillovers) generated by innovative activities.

2. The most direct and visible effect of research in defence is to capture resources that could be devoted to more economically productive use (see Guellec and van Pottelsberghe, 2003), although defence may contribute to support the institutional framework that is conducive to technical change, something which escapes from direct measurement.

The knowledge generated in other countries is a third source of new technology for any national economy. There are many ways for technology to cross borders, as knowledge coming out of a given country's research is used by another country's enterprises or benefits directly another country's customers. Companies can buy patents, licences or know-how from foreign firms, they can observe competition (*e.g.* reverse engineering), they can hire foreign scientists and engineers, they can interact with foreign competitors who invested in their country (foreign direct investment), read the scientific and technological literature, or have direct contacts with foreign engineers in conferences or fairs. The impact of foreign-produced knowledge on a country's productivity may depend on the capacity of the recipient country to digest such knowledge, to make efficient use of it, which requires a sufficient technological activity of its own. This is traditionally labelled as "absorptive capacity".

Mohnen (2001) provides an in depth survey of the existing evaluations of international R&D spillovers. The macroeconomic studies performed by Park (1995), Coe and Helpman (1995) and Lichtenberg and van Pottelsberghe (1998, 2001), have estimated the effect of foreign R&D on productivity. This is done by regressing multifactor productivity on a stock of domestic R&D and a stock of foreign R&D. Coe and Helpman find that domestic R&D contributes significantly to productivity growth and that this impact is substantially higher for the G7 than for other developed countries. In addition, foreign R&D incorporated into trade flows has a significant impact on *MFP* growth. van Pottelsberghe and Lichtenberg (2001) show that foreign R&D can affect domestic performance through both imports and outward foreign direct investment (technology sourcing and learning practices).

Although not taken into account in the present empirical analysis, education, or human capital, can be an important determinant of productivity growth, especially in less developed countries.

Few studies have actually attempted to measure the economic impact of human capital. Engelbrecht (1997) and Frantzen (2000) show within a traditional productivity model that human capital contributes substantially to productivity growth.

III. The model and data

Based on the above framework, we estimate the contribution of technical change to productivity growth. The following system of equation is generally referred to in order to evaluate the contribution of research to output growth:

$$Y = TFP\ F(L, K)$$

$$TFP = G(R, O)$$

$$R_t = \sum w_h\ I^R_{t-h}$$

Where Y is output, L and K are measures of labor and capital inputs, respectively. TFP is the current state of technology (total factor productivity). R is the measure of accumulated research capital (as a proxy for the knowledge stocks generated by domestic firms, public research institutions and foreign institutions). O stands for the other forces affecting productivity (among which disembodied technical change), I^R measures the gross R&D expenditures in period t, and w_h connects the level of past research to the current state of knowledge. For estimation purposes, the explicit structure of a country i's production function is generally of the Cobb-Douglas type, which has a useful log additive form, and O is approximated by an exponential trend (t).

$$Y_i = \exp[\phi_i t + u_i] L_i^{\alpha_1} K_i^{\alpha_2} R_i^{\beta} \qquad i = 1, ..., \text{n} \qquad (1)$$

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

$$LY_i = \phi_i t + \alpha_1 LL_i + \alpha_2 LK_i + \beta LR_i + u_i \quad , \tag{2}$$

It is common to derive an index of total (or multi) factor productivity (*LMFP*) from equation (2):

$$LMFP_i \equiv LY_i - \hat{\alpha}_1 LL_i - (1-\hat{\alpha}_1) LK_i = \phi_i t + \beta LR_i + u_i \tag{3}$$

It requires the assumption of constant returns to scale with respect to labor and capital and payment of these traditional inputs (i.e., a perfect competition environment). In other words, the output elasticities with respect to labor (capital) are assumed to be equal to the labor (capital) costs share in total output and α_2 is equal to *(1-α_1)*.

For our empirical purpose, we distinguish the various sources of technical change: domestic, foreign, and public R&D.[3] We also include time dummies and two control variables: the business-cycle effects (*U*) which can strongly influence productivity in the short run, and a dummy variable for the German reunification (G). Taking into account the time dimension, the long-term (stationary) form of the model is as follows:

$$LMFP_{it} = \beta_1 LBRD_{it-1} + \beta_2 LFRD_{it-1} + \beta_3 LPRD_{it-2} + \sigma_U LU_{it} + \sigma_G G + \phi_i t + \varphi_t + \mu_{it} \tag{4}$$

The variables (for country *i* and time *t*) are defined as follows:

MFP is an index of multi factor productivity of industry. *MFP* is computed as the ratio of the domestic product of industry to the weighted sum of the quantity of labour and fixed capital stock, the weights being the annual labour cost share and the capital cost share, respectively (cf. equation 3). Although these assumptions of perfect competition and constant returns to scale might be

3. The present empirical model focuses essentially on R&D variables. It could be improved by taking into account public infrastructure (see Mamuneas and Nadiri, 1994 and 1996), several other channels of international R&D spillovers (see van Pottelsberghe and Lichtenberg, 2001), and human capital (see Engelbrecht, 1997, and Frantzen, 2000).

considered as being too restrictive, we rely on this standard and convenient approach because it is extensively used by most macroeconomic and microeconomic empirical investigation of the link between R&D and economic growth. In addition, it is difficult to disentangle empirically the impact of returns to scale from the one of technological change, since they both lead to more output with the same level of input. The series used to compute the *MFP* come from the OECD National Accounts data base (OECD, 2001).

BRD is the domestic business R&D capital stock. It has been computed using the perpetual inventory method from total intramural business R&D expenditures, in constant 1990 GDP prices and US PPPs. The depreciation rate is 15% (sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate). The stock of business R&D is lagged one year, as in Coe and Helpman (1995), in order to have an approximation of the stock of knowledge at the beginning of the year. It does not preclude the existence of longer lags since stock relies on past business R&D expenditures. The series come from the OECD Main Science and Technology Indicators (MSTI).

FRD is the foreign R&D capital stock, which is the weighted sum of the domestic business R&D capital stocks of the 15 other countries of the panel. The weights correspond to the bilateral technological proximity between countries (see Appendix A, this measure is similar to the one used by Jaffe (1988) and Park (1995)). The underlying assumptions are two-fold: first, technology circulates directly, with no explicit need for exchange of goods as a vector (although this may help). This assumption differs from that of Coe and Helpman (1995), who measure foreign capital stock for any country as the sum of other countries' R&D capital stock weighted by the foreign trade structure of the country. However, our assumption is consistent with available evidence on the circulation of knowledge across borders (see the discussion by Pierre Mohnen, 2001, pp. 54-

55).[4] The second assumption is that a country will benefit more from foreign knowledge relating to the same technology fields it works on than from knowledge in other fields. Since we rely on an indicator of technological proximity, the stock of foreign R&D might be considered as a proxy to measure knowledge spillovers instead of rent spillovers (see Griliches, 1992). However, it is very difficult to disentangle empirically rent spillovers from knowledge spillovers. Indeed, any measure of rent spillovers always incorporates to some extent knowledge spillovers, and vice versa.

PRD is total public R&D capital stock, which comprises R&D performed in the higher education sector and in the government sector (public laboratories). It has been computed using the perpetual inventory method from total intramural public R&D expenditures, in constant 1990 GDP prices and US PPP's. The depreciation rate is 15% (again, sensitivity analysis shows that the results of the regressions do not change significantly with the chosen depreciation rate). Since these R&D activities are not performed by the business sectors, we expect a longer delay before they affect business productivity and therefore include them in the model with a two year lag. The basic series come from the OECD Main Science and Technology Indicators.

U is a control variable that intends to capture the business cycle effect: it is equal to 1 minus the unemployment rate. This should be a better proxy than the usually applied rate of utilisation of capital, which applies to manufacturing industries only (which account for about 20% of GDP in OECD countries). In the context of this study, it is also better than the output gap, as the calculation of the output gap relies on certain assumptions on *MFP* growth: by using it, we would be faced with simultaneity problems (if *MFP* is the same on both sides of the equation) or

4. Eaton and Kortum (1999) show that, except for small countries very near the source of information, trade is not the major conduit for the spread of new technology. Their results suggest that benefits from innovation spread primarily through the transmission of ideas themselves, rather than through the export of goods embodying them.

inconsistency (if two different *MFP*s are used on the two sides of the equation). G is a dummy equal to 1 for Germany in 1991, and 0 otherwise; it is a control variable that takes into account the exogenous shock of the German unification. ϕ_i are country dummies. They take into account the country-specific exogenous technical change and the framework conditions that might affect long-term growth. φ_t are time dummies which take into account potential exogenous shocks that would be common to several countries.

The basic equation we estimate is adapted from equation (4) in an error correction model (ECM) that allows the distinction of short-term from long-term effects and induce better cointegration tests of the error term than equation (4).

$$\begin{aligned}\Delta LMFP_{it} = {} & \tau\,\Delta LMFP_{it-1} + \alpha_{brd}\,\Delta LBRD_{it-1} + \alpha_{frd}\,\Delta LFRD_{it-1} + \alpha_{prd}\,\Delta LPRD_{it-2} + \theta\,LMFP_{it-2} \\ & + \beta_{brd}\,LBRD_{it-2} + \beta_{frd}\,LFRD_{it-2} + \beta_{prd}\,LPRD_{it-3} + \sigma_U\,\Delta LU_{it} + \sigma_G \cdot G + \phi_i + \varphi_t + \mu_{it}\end{aligned} \tag{5}$$

Where Δ is the first difference operator. In this equation, the long-term elasticity of *MFP* with respect to, say business R&D (*BRD*), is $[-\beta_{brd}/\theta]$. It should be similar to β_1 in equation (4).[5] The parameters that are to be estimated are assumed to be constant across countries and over time; they are defined as follows:

β_{brd} The elasticity of *MFP* with respect to domestic business R&D.

β_{frd} The elasticity of *MFP* with respect to foreign business R&D.

β_{prd} The elasticity of *MFP* with respect to public R&D.

σ_U The elasticity of *MFP* with respect to the capacity utilisation rate.

5. Estimates of equation (4) are presented in Table B1 of appendix B. The error term in the ECM presented in equation (5) turns out to be more stationary than the error term of the traditional 'within' estimates presented in equation (4).

σ_G The impact of the German unification on *MFP* in Germany.

Interpretation of these elasticities should take into account the fact that the explained variable is not output (or gross domestic product of industry) but *MFP*. That means that we capture the social excess return to R&D, not the total effect on output growth (which includes also the direct effect, or private return). The 'excess' return concerns especially business R&D: part of the private resources devoted to R&D (labour and capital) are already included in the production factors used to compute *MFP*, as they are included in the economy's stock of capital and pool of labour.[6] Therefore, the estimated impact is similar to a premium associated with the labour and capital used for research activities. In other words the excess rate of return to R&D reflect the extent to which R&D inputs are characterized by an *'above and beyond normal remuneration'* (cf. Griliches, 1979) to traditional inputs. In addition, the estimated impacts of business and public R&D reflect the 'social' return to R&D because they most probably capture substantial inter-firm and inter-industry externalities (rent and knowledge spillovers), or domestic spillovers. A positive and significant elasticity would therefore witness the existence of a premium associated with business R&D activities and the presence of positive externalities, or spillovers.

Foreign business R&D is partly paid for by domestic business users, in the form of international payments for technology transfers (patents, licences and know-how contracts). However, such payments are relatively small in most countries (less than 0.4 % of GDP on average in the OECD area, including payments for software which are not taken into account directly in this analysis) and probably cover only a small fraction of all the benefits that accrue to users: the international

6. The potential impact of this 'double counting' procedure (the labour and capital used for research activities are in both the left-hand side and the right-hand side variables) has been measured by Schankerman (1981). The author finds that in a 'level' specification (as opposed to growth rate of *MFP*) this double counting might bias the estimated impact of business R&D. However, Cunéo and Mairesse (1984) argue that the double counting bias is more likely to

market for technology is still very incomplete. Being treated by national accounts as intermediate consumption, payments for technology, be it to domestic or to foreign suppliers, are not accounted for as such in GDP, hence in *MFP*. For instance, increased payments for foreign technology will not impact *directly* on the level of GDP, as it is not considered as value added. The effects we will therefore capture are 'only' spillovers, the portion of the benefits for which users do not pay. In general, business users do not fully compensate government for the benefits from public R&D. Hence, most of its effect on business activity is spillovers.

As a consequence, this model captures most of the effect of public and foreign R&D but only the social excess return to business R&D. A further caveat is that the assumptions used for calculating *MFP* may not hold totally: increasing returns to scale and imperfect competition are often associated with R&D (*e.g.* Romer, 1990). If that is the case, the *MFP* index that we explain is subject to measurement errors which might be correlated with the right-hand-side variables. In order to mitigate this problem, we conducted estimates with instrumental variables.

Table 1 reports average annual growth rates of the main variables for all countries, over the period going from 1980 to1998. *MFP* growth ranges from 0.3% a year in Germany to 3.4% in Ireland. Most countries, however, are very close to 1% a year (ten countries are between 0.9% and 1.4%). *MFP* growth, as well as R&D growth, is high for Ireland as this country has been catching up over this period. Business R&D (capital stock) growth ranges from 1.9% (United Kingdom) to 8.9% (Finland) and even 10.8% for Ireland, with most countries around 4% to 7%. In most countries the growth of business R&D has been higher in the 1980s than in the 1990s. Foreign R&D growth rates fluctuate around 4% for all countries except Ireland where it was about 7% a year, on

be present in the cross-sectional dimension and much less if the time dimension is taken into account. The authors show that in a growth rate specification (similar to our specification), the bias disappears.

average. In most countries, the growth of public performed R&D was much lower than that of business R&D over this period. It ranges from 1.9% (United Kingdom) to 6.6% (Finland). The major reasons for this lower growth of public R&D spending are the end of the cold war (reduced defence spending) and strained budgetary conditions in many countries.

***** Insert Table 1 around here *****

The correlations between the average growth rates (1980-98) of these variables are reported in Table 2. *MFP* is quite highly correlated with business R&D and with foreign R&D, which are the two variables expected to have the more direct relationships. It is also positively correlated with public R&D, although the relationship is weaker. Business R&D is significantly correlated with the other two R&D variables. Foreign R&D is not correlated with public R&D and there is no reason to expect such a relationship. The positive correlation between foreign and business R&D can be explained as follows: foreign R&D is a weighted average of other countries' R&D, with the weights reflecting technological proximity. As a country expands its R&D expenditures, it is likely to broaden the range of technologies it covers, thus increasing its correlation with other countries' specialisation. Such a mechanism applies especially to countries starting from a relatively low technological level, where the range of technologies covered is quite limited (Ireland is a case in point).

***** Insert Table 2 around here *****

IV. Estimation results

The econometric estimates are performed in two stages. We first examine the robustness of the basic model. We then test whether the elasticities of *MFP* with respect to the three types of R&D capital stocks have been stable over time and investigate what are the factors that might improve our understanding of the contribution of the three sources of knowledge to output growth. These factors are related to the absorptive capability of a country, its size, the origin of funding, the socio economic objectives of government support, and the type of public institutions that perform R&D.

The basic model is estimated with various econometric techniques in Appendix B. We performed static regressions, in log-level (or 'within' estimates, as in equation (4)) and in growth rate (see Table B1), in order to compare them with the ECM. The results reported in appendix Table B1 confirm the estimates of the error correction model (Table B3). Panel cointegration tests have also been performed and are reported in appendix Table B2. They suggest that the combination of the time series seem to satisfy the required statistical properties needed for meaningful estimations. The preferred econometric method is presented in column 1 of Table B3, it is the three stage least square method that combines the SURE method and instrumental variables (see Appendix B). This method has been used for all the variants of the basic model that are presented in Table 3.

The two control variables (for the business cycle and for German unification) are of the expected sign and are significant (see Table B3). The employment rate has a large and positive impact on productivity growth, which confirms previous findings that productivity is essentially pro-cyclical. The German unification dummy takes account of the sharp drop in average productivity in Germany following the 1990 events.

The long-term elasticity of *MFP* with respect to business R&D is 0.13 (Table 3, column 1).[7] This value is in line with estimates reported in the literature (Nadiri, 1993), although in the low range,

7. The long-term coefficients are obtained as follows (in accordance with the error correction model presented in equation (5)): For a variable *X* (*X* = *BRD*, *FRD* or *PRD*), divide the estimated coefficient for *LX* by the minus of the estimated parameter associated with *LMFP* in the same regression. For instance, the long-term coefficient for business R&D is: 0.027/(-(-0.205))=0.132 (see the results of column 1 in Table 3 or column 1 in Table B3). This long term elasticity is very close to the estimates performed with the traditional 'within' model presented in Table B1 in appendix B.

which might be due to the fact that public and foreign R&D capital stocks are among the explanatory variables and capture some of the effects attributed to business R&D in other studies which do not include them. As the direct impact of business R&D on output is at least partly accounted for in *MFP* (see foot note 6), this parameter mainly captures spillovers (domestic inter-firm and inter-industry spillovers) and the premium (coming in addition to normal remuneration of capital and labour) arising from R&D activities. It can be compared with the ratio of business R&D to business GDP (around 2% in the OECD over the 1980s and 1990s).[8] The social return on business R&D is therefore much higher than the "normal private return".

The long-term elasticity of *MFP* with respect to foreign R&D is about 0.45. This figure may seem surprisingly high, as this is essentially low cost technology for the economy (the direct cost of absorbing new technology *when the domestic conditions are right* must be substantially lower than the cost of inventing it, which is the *raison d'être* for technology transfers). Estimates by Coe and Helpman (1995), although lower, are in the same order of magnitude: 0.29. This is high also as compared with the elasticity of business R&D reported above, leading to the conclusion that for any country, other countries' R&D matters more than domestic R&D for the purpose of productivity growth, provided that the country has the capacity to absorb technology from abroad. This result is consistent with the fact that the domestic social return on R&D is higher than the private return: if technology spillovers occur within countries, there is no reason for it to stop at the border, and international spillovers should occur. As any country is small as compared with the whole OECD (the share of any country in new knowledge generated by the 16 countries is small), the benefits from other countries may dwarf those arising from domestic technology.

8. The cost share of R&D in GDP (the labour and capital devoted to research activities) is part of the cost share of total labour (L) and total capital (K) already accounted for in the calculation of *MFP* (see equation (3)), and is approximately 2 percent.

The long-term elasticity of *MFP* with respect to public research (performed in government laboratories and universities) is around 0.17.[9] The long term impact of R&D seems to be higher when it is performed by the public sector than when it is performed by the business sector, probably because the former concentrates more on basic research, which is known to generate more externalities. Since more uncertainty is associated with basic research, it is logically associated with a higher social return.

***** Insert Table 3 around here *****

For each stock of R&D we then investigate whether its impact has changed over time. Interacting the elasticity of the three stocks of R&D with a time trend (Table 3, column 2) shows whether the role of each source of knowledge as a determinant of productivity growth has been stable over time. The impact of business R&D on *MFP* has been growing over time (an increase of about 0.005 a year). This finding confirms the impression given by business reporting that R&D is an increasingly important activity for firms in the knowledge-based economy: firms in most OECD countries are close to the technological frontier (after several decades of catching up). Keeping pace with competition implies not only to build physical capacities, but increasingly to innovate. This increasing elasticity of *MFP* with respect to business R&D is consistent with the widely-discussed idea that "intangible" capital is now of great importance to companies. For instance, information technology is an important part of the 'intangible' capital, and has been an important factor of productivity growth in the nineties, as it has been diffused and used as a knowledge diffusion medium (see the assessment by Temple (2002) for an in-depth analysis of the *New Economy*).

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9. The impact of public R&D reflect mainly a 'social' return as it is not accounted for in the *MFP* (based on the domestic product of industry), whereas the impact of business R&D reflect both a social return and the premium associated with private R&D.

The interaction of the two other sources of knowledge with a time trend shows that there is no significant increase over time in the elasticity of *MFP* with respect to foreign R&D, but that the trend of the elasticity of *MFP* with respect to public research over time is negative. This is at odds with the trends in business research. One explanation may be that in many countries the public research sector has been slow to engage in new technology areas, especially ICT, which have spurred *MFP* growth in recent years. This lack of flexibility could have contributed to the decreasing impact of public research on productivity.

The next estimates aim at identifying the conditions that enhance or reduce the estimated elasticities across countries (Table 3, column 3 to 7). We first investigate whether the origin of funding and the absorptive capability do affect a country's elasticity of *MFP* with respect to business R&D. The estimates presented in column 3 show that a country's business R&D intensity (the ratio of business R&D expenses to business GDP) has a positive effect on the elasticity of *MFP* with respect to the business R&D capital stock: a further percentage point in a country's R&D intensity increases the elasticity by about 0.004. This finding points to some kind of increasing returns from investment in research. A speculative interpretation would be that by spending more on R&D, firms might be able to reap internal economies of scale, to set up networks and to benefit from each other's discoveries. It might also witness an improved ability to absorb the knowledge generated by other firms and/or industries. This result confirms those of Griffith *et al.* (2000) who test the absorptive capability hypothesis on a panel dataset composed of 15 industries in 12 OECD countries.

The share of government funding has a negative effect on the elasticity of MFP with respect to business R&D. In this respect we confirm the results of Lichtenberg (1993). Nevertheless, we disaggregated the share of government funding according to its socio economic objectives (civilian purposes or defence-related objectives). Column 4 of Table 4 shows that only the defence-related part of public funding has a significant negative effect on *MFP*. A potential explanation for this negative impact of defence-related public funding of business R&D is that it often takes the form of procurement (see Lichtenberg, 1984): the performer of the research project is not the owner of the technological output. In other words, the firms receiving procurements are not allowed to exploit freely their new technological competencies on the market. There are four or five OECD countries that have a substantial defence R&D budget and might be concerned by this issue. Actually, public funding with a civilian objective has a (weak) positive effect on the elasticity of business R&D. As this elasticity mainly captures spillovers, this might indicate that government funding is fairly successful in enhancing business R&D with higher social return.

We now turn to the impact of foreign R&D on productivity growth. Since the countries that compose the panel vary greatly in term of size (e.g., the US and Belgium), we might wonder whether the elasticity of *MFP* with respect to foreign R&D is larger for small countries than for large ones (the world abroad is even more important for smaller countries). The number of researchers is lower the smaller a country is. Hence the probability that the colleagues with whom you interact are located abroad is higher when you are in a small country. This is confirmed in Guellec and van Pottelsberghe (2001), who use patent data to show that smaller countries have a higher share of their inventions that involve co-operation with other countries (as opposed to inventions made by domestic inventors only). This size effect might be compensated by a specialisation effect, as researchers interact mainly with colleagues *working in a similar scientific field*: a small but highly specialised country may be as intensive as larger ones in the fields it covers, but the number of fields it covers may be lower. We test the "size effect" hypothesis by interacting foreign R&D with an indicator of size for each country: the average over the 1980-

1998 period of (log) GDP (see Table 3, column 5). The negative and significant parameter confirms that smaller countries do benefit more from foreign R&D than larger ones. In addition to previous findings that R&D is more internationalised in smaller countries, these results confirm that smaller countries also benefit more, in terms of productivity, from such internationalisation.

Size is not the only factor of differentiation of the role of foreign R&D across countries. A high absorptive capability would probably improve the role of foreign knowledge for any economy. We tested this hypothesis by interacting the foreign R&D capital stock with business R&D intensity.[10] The results presented in column 6 show that the impact of domestic R&D intensity on the elasticity of *MFP* with respect to foreign R&D is positive and significant: a 0.1% difference in R&D intensity between two countries generates a spread of about 0.004 between their elasticities. It seems therefore that any firm intending to adopt or improve the knowledge generated by other firms or public institutions (be they domestic or foreign) would have to invest in 'imitative' or 'adaptive' research activities.

Public R&D might also have differentiated impacts across countries. We investigate whether absorptive capability, the socio-economic objectives of public research, the type of institution that perform the research, and the source of funding are factors that might explain cross-country differences in the elasticity of *MFP* with respect to public R&D. The results are presented in column 7 of Table 3. The elasticity of *MFP* with respect to public research is higher when the business R&D intensity of the economy is higher: this shows the importance of the business

10. When we introduce simultaneously the average size and R&D intensity (both interacting with foreign R&D), the size parameter is not significant any more. We decided to introduce them separately into the model because it seems that there is a negative correlation between size and R&D intensity among the countries included in the present analysis. This does not mean that small countries are in general more R&D intensive than large ones (a systematic negative relationship between size and R&D intensity). This is the case with our sample of countries because the small countries for which all the data were available are generally intensive in R&D (*e.g.* Sweden, Finland, the Netherlands). To state it another way, there is a tendency for small countries with low R&D intensity not to have as much data available as large countries with low R&D intensity.

sector being able to seize opportunities raised by public research. Part of the effect of public research on productivity seems therefore to be indirect, flowing through the use of its discoveries by the business sector. Stronger links between public and private research, which governments in most OECD countries are trying to build, should enhance this effect.

The impact of public R&D is also positively affected by the share of universities (as opposed to government laboratories) in public research. This may point to the fact that much government performed R&D is aimed at public missions that don't impact directly on productivity (health, environment, defence), whereas universities are providing the basic knowledge that might eventually be used in later stages by industry to perform technological innovation. This is confirmed by the negative effect of the share of defence in public R&D budgets, as it is not the main purpose of defence R&D to increase productivity. Another possible explanation for the higher impact of university research has to do with the way funds are allocated: in most OECD countries, an important share of funding for university research is allocated on project-based evaluations, whereas government laboratories have an institutional funding. The former might induce a faster adaptation to changing technological priorities than the latter (dropping technological lines which turn out to offer little opportunities, switching to promising areas), and may have a bigger impact on productivity. More in-depth case studies would be necessary to validate this interpretation.

A further result is that the impact of public research decreases with the share of industry funding of the higher education sector: The more university research is financed by the business sector, the lower is its impact on growth. Partnership between firms and universities probably involves more applied R&D than usual university research, and applied R&D has a lower potential long term effect on growth than basic research. The two previous results could be interpreted as follows.

The preferable situation for funding of public research would be more competitive (as opposed to institutional) and would come from the government (as opposed to enterprises).

V. Concluding remarks and policy implications

One must be careful when drawing policy conclusions on the basis of an empirical analysis undertaken at an aggregated level and using OECD-wide averages over almost two decades. Any policy lesson should be confirmed by more detailed, country level investigations and case studies. However, overall, the study confirms the importance of technology, be it developed by business, the public sector or foreign countries, as a significant determinant of economic growth. It also shows the strong interactions between the various channels and sources of technology, which underline the necessity for government to have a broad and coherent policy approach.

The fact that the social return on business R&D is much higher than its private return justifies some sort of government support to firms performing R&D. Our estimates not only confirm that business R&D has strong spillover effects, but also that it enhances the ability of performing firms to absorb ‘outside’ technology. The existing literature has shown that absorptive capability of domestic R&D is an important factor determining economic performance. Our findings provide further evidence on the importance of being able to absorb the knowledge generated by public institutions and foreign firms. The impact of new knowledge on productivity depends also on its diffusion, which is determined by the own effort of firms on R&D. It can be viewed as a perpetual “active learning” process. This underlines the importance for government to keep in mind the diffusion side, in addition to the production side, when elaborating technology policy. It also underlines the need to ensure the openness of a country to foreign technology, through the flows of goods, of people and ideas.

The main contribution of the present paper to the existing literature relates to more specific policy issues. Indeed, for the two main sources of domestic knowledge (i.e., business and public R&D), we have investigated whether the origin of funding, the underlying socio-economic objectives, and the type of performing institutions determine the effectiveness of research.

Business R&D has two major sources of funding: the private sector and the government sector (subsidies, loans, procurements…). The estimates show that higher shares of government funding are associated with lower elasticity of *MFP* with respect to business R&D. This finding corroborates the few existing findings (e.g., Lichtenberg, 1993). However, when the share of government funding is disaggregated according to its socio economic objectives, a different picture emerges. It is only the defence-related part of public funding that seems to have a significant negative impact on the effectiveness of business R&D, probably because such type of funding takes the form of procurement: the performer of the research project is not the owner of the technological output. Public funding with a civilian objective actually has a positive effect on the elasticity of business R&D, showing that government funding is fairly successful in enhancing business R&D with higher social return.

R&D performed in public institutions has a large effect on productivity growth. However, this impact can vary greatly across countries, according to three factors. First, the research performed in the higher education sector seems to have a greater impact on growth than the research performed in public laboratories. This result points to the potential need of reviewing the way in which research is funded in the government sector (i.e., the way the research agenda is set and performance is monitored). This also points to the necessity for government to encourage co-operation between public laboratories and the private sector, for a better diffusion of the knowledge generated through public research. Second, the type of socio-economic objective also seems to determine the effectiveness of public research. The long term impact on growth of public research decreases when the objective becomes more defence-related. Third, the higher the share of business in the funding sources of university research, the lower is its impact on productivity. This last result underlines the necessity of university research to keep control of its research agenda: it might be that it is by doing what it is good at (basic research) that university can have a more socially useful role, not by doing applied research (in place of firms). On the other hand, the increasing share of private funding of universities might partly explain the increase in the elasticity of *MFP* with respect to business R&D.

Appendix A: Calculation of the Technological Variables

1) R&D capital stocks

R&D capital stocks are calculated following the perpetual inventory method. The stock at time *t* is equal to the new investment at time *t* plus the stock at time *t-1* minus depreciation:

$$R_t = r_t + (1-\delta)R_{t-1} \tag{A1.1}$$

$$R_t = r_t + (1-\delta)r_{t-1} + (1-\delta)^2 r_{t-2} + (1-\delta)^3 r_{t-3} + ... \tag{A1.2}$$

To construct the initial stock we assume a constant annual rate of growth of the past investments,

$$R_t = r_t + (1-\delta)\lambda r_t + (1-\delta)^2 \lambda^2 r_t + (1-\delta)^3 \lambda^3 r_t + ... \tag{A1.3}$$

$$R_t = \frac{r_t}{1-\lambda(1-\delta)} \tag{A1.4}$$

where R_t is the R&D capital stock at time *t*; r_t is R&D expenditures at time *t*; and δ is the depreciation rate (constant over time).

$$\lambda = \frac{1}{1+\eta} \quad \text{and} \quad \eta \text{ is the mean annual rate of growth of } r_t \text{ .}$$

The same formula has been used to calculate the business R&D capital stock (*BRD*) and the public R&D capital stock (*PRD*).

2) Foreign R&D capital stock

FRD is the foreign R&D capital stock calculated as the weighted sum of the domestic R&D capital stocks of 15 industrialised countries, the weights being the technological proximity between pairs of countries. The technological proximity is computed as in Jaffe (1986, 1988) using patents granted by the USPTO:

$$FRD_i = \sum_{j \neq i} \omega_{ij}^{M3} \cdot BRD_j \qquad i,j = 1, \ldots, 16 \text{ industrialised countries.} \tag{A1.5}$$

$$\omega_{ij} = \frac{F_i \, F_j'}{F_{ij} \, F_{ji}} \qquad F_i = \left| \frac{P_i^{TC1}}{\sum_{z=1}^{50} P_i^{PCz}} \quad \frac{P_i^{TC2}}{\sum_{z=1}^{50} P_i^{PCz}} \quad \cdots \quad \frac{P_i^{TC50}}{\sum_{z=1}^{50} P_i^{PCz}} \right|$$

F_i is the frequency distribution across 50 technological classes of patent granted by the USPTO to country *i*. The weights that are used (ω^{M3}) to compute the foreign R&D capital stock are a three-year moving average of ω. P^{TC} is the number of patents invented in a country and belong to one of the fifty technological classes (TC_Z; Z = 1,…, 50).

Appendix B: Estimates of the Basic Model

The robustness of regressions of the ECM can be assessed by first estimating regressions in log-levels – according to equation (1'). As such a model misses the dynamics of the linkages between the variables, the purpose is primarily to look for simple, long term static relationships. Results are reported in Table B1. In columns 1 to 4 we progressively extend the range of variables (R&D capital stocks) in the regression. The estimated coefficients for all variables of interest are of the expected sign and are significant. The coefficient for business R&D is reduced as new variables are introduced into the regression. It drops from 0.2 to 0.1 when all variables are there. The coefficient for foreign R&D is 0.4, which may look high; explanations for that are reported in the main text. Column 5 reports regression results in growth rate (or first logarithmic difference). The coefficient associated with business R&D is not substantially different from the estimation in log-levels. The coefficient for foreign R&D is still significant, but much lower than in the level regression: this may reflect a dynamic adjustment that is different for this variable. The impact of public R&D is no longer significant. Estimates in growth rate 'only' capture short-term variation from a long-term equilibrium relationship. This non-significant parameter may therefore reflect the fact that public research has essentially a long-term impact on *MFP* growth.

TABLE B1

Multifactor productivity estimation results, in log-levels

Dependent variable		*LMFP*	*LMFP*	*LMFP*	*LMFP*	*ΔLMFP*
Regressions		*1*	*2*	*3*	*4*	*5*
Business R&D (t-1)	*LBRD*	0.208*	0.168*	0.127*	0.104*	0.087*
		(150.8)	*(72.2)*	*(74.27)*	*(48.11)*	*(7.11)*
Foreign R&D (t-1)	*LFRD*			0.385*	0.410*	0.049*
				(42.39)	*(35.64)*	*(3.01)*
Public R&D (t-2)	*LPRD*				0.083*	0.015
					(11.76)	*(0.77)*
Control variables						
Employment rate growth (t)	*ΔU*	1.382*	1.448*	1.156*	1.295*	0.143*
		(53.21)	*(39.03)*	*(36.96)*	*(38.98)*	*(3.76)*
German reunification	*G*	-0.076*	-0.078*	-0.074*	-0.075*	-0.099*
		(-20.40)	*(-*	*(-27.29)*	*(-26.74)*	*(-26.58)*
Country dummies		yes	yes	yes	yes	no
Time dummies		no	yes	yes	yes	yes
Adjusted R-squared		0.839	0.835	0.892	0.896	0.274

Note: Panel data, 16 countries, 1980-98, 302 observations. T-stat are between parentheses. The estimation method is SURE (seemingly unrelated regression equations) that corrects for the contemporaneous correlation of the error terms across countries. * indicates the parameters that are significant at a 5% probability threshold.

We then perform several panel cointegration tests on various specifications and econometric models. The models were the standard within estimates of the basic model, the growth rate estimates (or the so-called first difference estimates), and the error correction model (ECM). Due to our limited degrees of freedom (about 19 years for each country) we could not test the complete ECM model. We therefore implemented the cointegration tests on more simple models (i.e. with less explanatory variables) : one with business R&D as the only regressor (X); one with business R&D, foreign R&D and public R&D as regressors (Y); and one with business R&D and the two control variables as right-hand side variables. Since the econometric theory of panel data cointegration tests is not yet fully worked out we performed seven different cointegration tests that are available in the literature. The results reported in Table B2 show that, with the specification that only include business R&D as explanatory variable, only one out of the seven tests confirms that the error term of the 'within' estimates is stationary. Once the other sources of knowledge are injected in the model, or the two control variables, the cointegration tests of the within estimates become more convincing, with four tests out of seven that confirm the cointegration hypothesis. The tests in first difference also support the hypothesis of cointegration. The error correction model seems to be cointegrated as suggested by six out of the seven tests performed on the model that includes the control variables.

TABLE B2

Panel cointegration tests for various specifications

Econometric model [1]	*Within*			*First Difference*			*ECM*	
Specifications [2]	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Z*
Panel v-statistic [3]	2.18*	2.30*	-0.65	5.91*	2.36*	1.63*	3.73*	0.68
Panel ρ-statistic	-0.24	0.53	2.17*	-4.19*	-1.12	0.29	-0.78	1.88*
Panel t-statistic A	-0.77	-1.38	1.11	-5.91*	-5.86*	-2.77*	-6.88*	-5.80*
Panel t-statistic B	-0.62	-3.33*	1.13	-5.82*	-7.48*	-2.70*	-6.89*	-8.20*
Group ρ-statistic	1.07	2.10*	3.64*	-3.32*	0.08	1.38	0.55	3.23*
Group t-statistic A	-0.13	-1.09	2.09*	-7.42*	-6.95*	-3.71*	-8.32*	-7.14*
Group t-statistic B	-0.30	-8.04*	2.03*	-7.47*	-10.5*	-3.57*	-9.16*	-16.28*

Notes: **1.** The econometric models are 'within' (all variables are in logarithm, with country dummies); 'first difference' (all variables in first logarithmic difference); or 'ECM' as defined in equation (2) in the main text.
2. The specifications are : X (the business R&D capital stock is the only right-hand side variable); Y (the three R&D variables are included simultaneously – business, foreign and public R&D capital stocks); Z (the right-hand side variables are the business R&D capital stock and the two control variables – employment rate and the German reunification).
3. The cointegration tests reject the null hypothesis of no cointegration above the absolute value of 1.64 (10% probability threshold); 1.96 (5%) or 2.57 (1%). The panel t-statistic A is nonparametric, whereas the B, which corresponds to Levin and Lin (1993) is parametric. All the panel cointegration statistics are reported in Pedroni (1999), Table 1. * indicates the parameters that are significant at a 10% probability threshold.

Different ranges of estimates of the error correction model were conducted in order to test the stability of the estimated parameters corresponding to the ECM: one allowing short-term parameters to vary across countries (Table B3, column 4); simple OLS (Table B3, column 3), SURE (Table B3, column 2) and 3SLS (Table B3, column 1) procedures have been used; and the model has been estimated over different sub-periods (columns 5 and 6). The seeming unrelated regression method (SURE) is used to correct for potential correlations between the error terms associated with the 16 countries. Despite the use of time dummies to control for contemporaneous shocks, we still observed significant correlations of the error terms between several pairs of countries. In addition, the Lagrange multiplier test of Breusch and Pagan confirms that the error terms are correlated across countries, hence the need for the SURE method. 3SLS (three-stages least squares) controls for both contemporaneous shocks and the presence of the lagged dependent variable among the right-hand-side variables. It controls for potential simultaneity biases, due to the possible influence of the dependent variable on certain of the right-hand side variables. Instruments for the 3SLS regressions are all the right-hand-side variables (including dummies) and the left-hand-side variable lagged two years (adding more instruments did not change the results). There are no significant differences between the parameters estimated with these various techniques, denoting the robustness of the estimates.

For detecting possible outliers, and the robustness of the results with respect to the sample of countries, the basic model was estimated on 16 sub-samples of 15 countries, which means that each country was dropped consecutively. These unreported results further supported the robustness of our estimates. In all cases the coefficients remained stable, positive and significantly different from zero.

Lags for the long-term relationships have been set at 2 years for business and foreign R&D, and 3 years for public R&D. The longer lag for public R&D is consistent with the view that it is more basic than applied research or development, and takes more time to affect productivity. In any case, the long term coefficients of an ECM reflect relationships *in levels,* and therefore the choice of lags is not as important as in other types of model.

TABLE B3

Multifactor productivity estimation results, error correction model

Dependent variable ΔLMFP		*80-98*	*80-98*	*80-98*	*80-98*	*80-96*	*84-98*
		3SLS	*SURE*	*OLS*	*SURE*	*3SLS*	*3SLS*
Regressions		*1*	*2*	*3*	*4*	*5*	*6*
Multifactor productivity growth (t-1)	*ΔLMFP*	-0.396*	-0.088*	-0.043		-0.419*	-0.370*
		(-7.81)	*(-3.41)*	*(-0.74)*		*(-13.17)*	*(-30.20)*
Business R&D growth (t-1)	*ΔBRD*	-0.024	-0.019	-0.028	-0.010	-0.046*	0.024*
		(-1.12)	*(-1.13)*	*(-0.70)*	*(-0.72)*	*(-2.43)*	*(2.78)*
Foreign R&D growth (t-1)	*ΔFRD*	0.055*	0.069*	0.040	0.042*	0.044*	0.125*
		(2.93)	*(4.14)*	*(1.34)*	*(2.40)*	*(2.94)*	*(20.34)*
Public R&D growth (t-2)	*ΔPRD*	0.091	0.067*	0.061	0.041	0.073*	0.125*
		(2.66)	*(2.32)*	*(0.97)*	*(1.54)*	*(2.23)*	*(8.96)*
MFP level (t-2)	*LMFP*	-0.205*	-0.181*	-0.170*	-0.162*	-0.211*	-0.192*
		(-11.20)	*(-13.04)*	*(-6.33)*	*(-10.88)*	*(-13.19)*	*(-29.47)*
Business R&D (t-2)	*LBRD*	0.027*	0.024*	0.022*	0.024*	0.029*	0.022*
		(5.28)	*(5.17)*	*(2.90)*	*(5.52)*	*(5.82)*	*(6.11)*
Foreign R&D (t-2)	*LFRD*	0.094*	0.079*	0.091*	0.067*	0.090*	0.127*
		(7.74)	*(7.83)*	*(4.64)*	*(6.67)*	*(8.32)*	*(26.85)*
Public R&D (t-3)	*LPRD*	0.035*	0.028*	0.033*	0.029*	0.025*	0.035*
		(5.12)	*(4.20)*	*(2.72)*	*(4.70)*	*(4.34)*	*(16.28)*
Control variables							
Employment rate growth (t)	*ΔU*	0.380*	0.372*	0.379*	0.338*	0.376*	0.378*
		(8.95)	*(11.05)*	*(4.22)*	*(9.44)*	*(10.17)*	*(39.41)*
German reunification dummy (t)	*G*	-0.100*	-0.096*	-0.092*	-0.097*	-0.099*	-0.094*
		(-20.78)	*(-28.63)*	*(-6.59)*	*(-26.94)*	*(-23.30)*	*(-52.81)*
Country-specific short-term effects		no	no	no	yes	no	no
Number of countries		16	16	16	16	16	16
Adjusted R-squared		0.501	0.477	0.485	0.477	0.525	0.505
Breush and Pagan stat.				137.3			
nobs		302	302	302	302	272	238

1. Panel data, 16 countries, 1980-98. All regressions include country-specific intercepts (within estimates) and time dummies. The SURE estimation method (seemingly unrelated regression equations) corrects for the contemporaneous correlation of the error term across countries and the 3SLS method (three-stages least squares) corrects for the presence of the lagged endogenous variable among the right-hand side variables. * indicates the parameters that are significant at a 5% probability threshold.
2. The instrumental variables for the 3SLS (three-stages least squares) estimates are all the exogenous variables (including dummies) and the endogenous variables (lagged two years).
3. The long-term coefficients as mentioned in the main text are obtained as follows (in accordance with the error correction model as developed in Section 3): For variable X (X = BRD, FRD or PRD), divide the estimated

coefficient for LX by the opposite of estimated coefficient for LMFP in the same regression. For instance, in the first regression (column 1), the long-term coefficient for business R&D is: 0.024/0.180=0.13.

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TABLE 1

Descriptive statistics: average annual growth rates, 1980-98 (%)

Country	*Business R&D*	*Foreign R&D*	*Public R&D*	*MFP growth*
AU	7.50	3.80	3.69	0.84
BE	4.07	4.19	2.11	1.34
CA	6.71	3.84	2.46	0.69
DK	7.08	3.41	4.23	1.02
FI	8.86	5.11	5.86	2.60
FR	3.80	4.10	3.45	1.05
GE	3.62	3.71	2.41	0.30
IR	10.76	7.15	3.35	3.39
IT	4.83	3.92	4.18	1.08
JP	6.31	3.56	3.71	0.94
NL	2.66	4.27	2.68	1.05
NO	5.41	4.34	3.32	1.08
SP	4.40	4.41	1.95	1.38
SW	5.79	4.27	4.25	1.20
UK	1.90	4.21	1.83	1.03
US	3.66	4.47	2.04	0.94

Sources : OECD, MSTI and own calculations

TABLE 2

Correlation matrix between average annual growth rates for 16 countries, 1980-98

	Business R&D	*Foreign*	*Public*
MFP	0.675	0.909	0.383
Public R&D	0.622	0.094	
Foreign R&D	0.528		

Sources : OECD, MSTI and own calculations

TABLE 3

MFP estimation results: error correction model and interactions

Dependent variable is ΔLMFP	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Multifactor productivity level *LMFP* (t-2)	-0.205*	-0.214*	-0.193*	-0.208*	-0.206*	-0.210*	-0.248*
	(-11.20)	*(-10.60)*	*(-9.74)*	*(-9.45)*	*(-11.68)*	*(-11.66)*	*(-14.16)*
Business R&D *LBRD* (t-2)	0.027*	0.016*	0.020*	0.017*	0.026*	0.019*	0.014*
	(5.28)	*(2.91)*	*(3.65)*	*(2.94)*	*(5.25)*	*(3.78)*	*(2.60)*
Trend * *LBRD* (t-2)		0.001*					
		(2.79)					
R&D intensity (*IRD*) * *LBRD* (t-2)			0.044*	0.067*			
			(2.96)	*(4.49)*			
Share of public funding * *LBRD* (t-2)			-0.002*				
			(-2.17)				
Defence share of public funding * *LBRD* (t-2)				-0.011*			
				(-4.83)			
Civilian share of public funding * *LBRD* (t-2)				0.003*			
				(2.17)			
Foreign R&D *LFRD* (t-2)	0.094*	0.080*	0.088*	0.096*	0.159*	0.092*	0.105*
	(7.74)	*(5.71)*	*(7.42)*	*(7.56)*	*(4.63)*	*(7.51)*	*(8.25)*
Trend * *LFRD* (t-2)		0.001					
		(0.93)					
Log (average *DPI*) * *LFRD* (t-2)					-0.003*		
					(-2.09)		
IRD * *LFRD* (t-2)						0.395*	
						(4.34)	
Public R&D *LPRD* (t-3)	0.035*	0.041*	0.033*	0.032*	0.026*	0.024*	0.034*
	(5.12)	*(5.80)*	*(4.83)*	*(4.45)*	*(3.71)*	*(3.92)*	*(3.68)*
Trend * *LPRD* (t-3)		-0.001*					
		(-3.80)					
Business R&D intensity * *LPRD* (t-3)							0.053*
							(4.37)
Higher education as % of public * *LPRD* (t-3)							0.004*
							(4.19)
Defence as % GBOARD * *LPRD* (t-3)							-0.003*
							(-3.67)
Industry funding share of HE * *LPRD* (t-3)							-0.007*
							(-5.57)
Adjusted R-squared	0.501	0.502	0.519	0.532	0.508	0.513	0.544
nobs	302	302	302	297	302	302	298

Note: Panel data, 16 countries, 1980-98. All regressions include country-specific intercepts (within estimates) and time dummies, the short-term parameters and control variables are not reported for the sake of space (see Table B3). 3SLS method. The results presented in Column 1 correspond to those presented in Column 1 of Table B3. * indicates the parameters that are significant at a 5% probability threshold.