THE IMPACT OF PUBLIC R&D EXPENDITURE ON BUSINESS R&D[Φ]

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Abstract:

This paper attempts to quantify the aggregate net effect of government funding on business R&D in 17 OECD Member countries over the past two decades. Grants, procurement, tax incentives and direct performance of research (in public laboratories or universities) are the major policy tools in the field. The major results of the study are the following: Direct government funding of R&D performed by firms has a positive effect on business financed R&D (except if the funding is targeted towards defence activities). Tax incentives have an immediate and positive effect on business-financed R&D; Direct funding as well as tax incentives are more effective when they are stable over time: firms do not invest in additional R&D if they are uncertain of the durability of the government support; Direct government funding and R&D tax incentives are substitutes: increased intensity of one reduces the effect of the other on business R&D; The stimulating effect of government funding varies with respect to its generosity: it increases up to a certain threshold (about 10% of business R&D) and then decreases beyond; Defence research performed in public laboratories and universities crowds out private R&D; Civilian public research is neutral for business R&D.

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1. Introduction

OECD governments spent around USD 150 billion in research and development (R&D) activities in 1998, almost one-third of total R&D expenditure in the concerned countries. Beside fulfilling public needs (such as defence), the economic rationale for government involvement in this area is the existence of market failures associated with R&D. These market failures are typically twofold. First, imperfect appropriability, or the diffusion of knowledge beyond control of the inventor, implies that the private rate of return to R&D is lower than its social return. In addition, high risk for research implies extremely high hurdles, discouraging firms from engaging in such activities. This is especially detrimental to small firms for which access to funding is more difficult. For both reasons, the amount invested by firms in research activities in a competitive framework is likely to be below the socially optimal level (Arrow, 1962).

The wedge between private and social returns is likely to be highest in basic research, requiring a stronger involvement of government in this area. But government may also want to stimulate R&D performed by business, either to reduce the private cost of R&D (*e.g.* grants) or to help firms in understanding the technological opportunities that are available, thus reducing both the cost and uncertainty of research. If these policies are effective, public and private funding may be complementary and increasing the former will enhances the latter. The effectiveness of policies aimed at stimulating private R&D outlays can be challenged on three main grounds, however.

First, government spending may crowd out private spending, by increasing the demand of R&D and hence its price. Goolsbee (1998) and David and Hall (2000) argue that the major effect of government funding is to raise the wage of researchers. When faced with higher research costs, firms will shift their funding to alternative investments. This implies that, even if the total amount of R&D is higher due to government funding, the real amount of R&D (adjusted for the higher cost of research) will be lower.

A second argument is that public money may directly displace private funding, as firms may simply substitute public support for their own, while undertaking the same amount of research as originally planned. In this case, the government supports R&D that would have been performed anyway, there is no “additionnality” coming from government funding. It is also possible that a firm starting a project thanks to government funding has the effect of deterring other firms to start a similar project although they were previously considering to do so. In such a case there is “aggregate level non additionality”, due to pre-emption of a research project thanks to government funds. It is a direct form of crowding out, or displacement, which does not work through the price mechanism.

Third, governments are less likely to allocate resources efficiently than market forces, which may generate distortions in the allocation of resources between fields of research. It may also distort competition between firms by supporting some at the expense of others.

The purpose of this paper is to assess the effect of government spending on R&D that is funded and performed by business. It addresses the following questions. Do public performed research, direct funding and fiscal incentives stimulate business-funded R&D? Does the stimulation effect dominate the crowding-out effect? How do the policy instruments interact with each other -are they complements or substitute? The analysis covers 17 OECD countries over the period 1981-1996. It is an integrated and cross-country approach at the macroeconomic level, covering three policy instruments, making it distinct from previous work. The next section identifies the various channels taken by money flows: where and how public money is spent. Section 3 presents the econometric model and the data. The empirical results are interpreted in section 4 and section 5 draws the conclusions and policy implications.

2. Public policies to support private R&D

The effect of public spending may differ according to the policy instrument. Three main policy instruments are typically used : public (government or university) performed research, government funding of business-performed R&D and fiscal incentives. Public research is carried out in public laboratories or universities, and is funded essentially by government. Examples are the national laboratories in the United States or the CNRS (Centre National de la Recherche Scientifique) in France. A key goal of these bodies is to satisfy public needs and to generate basic knowledge, some of which may eventually be used by firms in their own, applied, research. Government laboratories are primarily concerned with meeting public needs, while universities and similar institutions are more concerned with the generation of basic knowledge. Universities typically also have a more independent research agenda than government laboratories, making them less responsive to policy. However, the government controls much of the research budget of these institutions (through grants, contracts or fellowships), and university research is therefore a relevant instrument for policy makers. These two tools primarily provide indirect support to business R&D, however. It has been argued that the kind of science produced by public research facilities is irrelevant to the business sector (Kealey, 1996), with the idea that if it were useful, business would do it itself. However, weak appropriability of basic knowledge makes it difficult for firms to reap its rewards: as a contribution to this ongoing discussion, the effect of public spending in this area is tested in this document.

The second policy instrument is direct support of research performed by the business sector. According to the *Frascati Manual* (OECD, 1993), two categories of government funding can be identified. First, funding aimed at the procurement of R&D where the results of the R&D belong to a recipient that is not necessarily the performer. Second, funding for R&D performers in the form of grants or subsidies, where the results belong to the R&D performer. In both cases, subsidies are targeted to specific goals chosen by the funder. The government may fund technological projects that have a potentially high social return (*e.g.* “generic technologies” or “pre-competitive research”) or that are useful to the government’s own objectives (*e.g.* health, defence). Such government funding supports the recipient (the technology or the firm) even if the recipient may be initially inferior to competitors, which has led to the criticism that governments, rather than markets, are “picking winners”. Grants often include specific conditions, e.g. the firm may be required to establish research alliances with other firms, or to collaborate with universities.

Thirdly, government can help firms through tax breaks. Most OECD countries allow for a full write-off of current R&D expenditures, which implies that depreciation allowances are deducted from taxable income. Among the 17 countries included in the present study, about one-third also provided R&D tax credits in the mid-1990’s (see Annex Table A1). These are deducted directly from the corporate income tax and are based either on the level of R&D expenditures – flat rate – or on the increase in these expenditures with respect to a given base – incremental rate. In addition, some countries allow for an accelerated depreciation of investment in machinery, equipment and buildings devoted to R&D activities. Some countries also provide special R&D tax breaks for small firms. The drawbacks of tax credits are that they provide a windfall gain to firms, that they are unlikely to change a firm's R&D strategy, and that they primarily compensate for past effort.

Tax breaks do not discriminate much, implying that firms can use public money for any goal, whatever its social rate of return. Non-discrimination may be regarded as an advantage, since it does not distort the research agenda as shaped by market forces. However, tax incentives also have some discriminatory features, as they are not accessible to firms that are not taxable, *e.g.* new firms with investment higher than sales. Such companies may, however, be among the most innovative and may also be the most in need of liquidity. In some countries, special provisions in the tax law allow cash refunds for certain categories non-taxable firms.

Of the three policy instruments, only direct funding and tax breaks have thus far been the subject to quantitative analysis. This is unfortunate, since the three policy instruments have partly similar, partly complementary objectives. Potential interactions between these tools make it difficult to analyse the effectiveness of one instrument independent of the others. For instance, public research, whether performed in government labs or universities, provides basic knowledge that is especially helpful for firms in the most advanced technology areas (close to basic research). Grants help firms in the applied research stage and encourage co-operation, as another way to internalising externalities. R&D tax breaks, since they are not or weakly discriminatory, help all R&D performing firms, especially those that do not have access to grants (often small companies) or those that perform research that is not sufficiently "basic" to benefit from other policy instruments. There are also interactions between the instruments. Those affecting applied research, such as R&D tax credits, may enhance the efficiency of instruments oriented towards basic research, as they may strengthen the absorptive capacity of recipient firms. The different tools thus constitute a system, and their efficiency can be best captured by analysing the system as a whole.

3. The model and data

Previous studies attempting to evaluate the effectiveness of government support to business R&D have focused either on the relationship between R&D subsidies and business-funded R&D, or on the effect of fiscal incentives.[1] A comparison of these studies is difficult due to the heterogeneity of the empirical models used -*e.g.* regarding time periods, data sources, aggregation levels and econometric techniques. On average, however, most studies find a positive effect of government funding and tax incentives on privately financed R&D. This is even more clearly the case for studies at the aggregate, macroeconomic level; among seven such studies referenced by David *et al.* (1999), six find that public and private R&D expenditure are complementary, while the seventh finds no significant relationship. Nevertheless, the existing literature has disregarded two important dimensions. There has been no attempt thus far to test the effectiveness of all instruments simultaneously. And second, there are only few macroeconomic studies [of the 33 studies referenced by David *et al.* (2000), seven are macroeconomic], most empirical analyses being at the firm or industry level.

As compared to the firm level approach that is more common in the field, the macroeconomic approach allows indirect effects of policies– negative as well as positive spillovers- to be captured. These effects may be quite important. A firm benefiting from subsidies is likely to boost its own R&D activity, but the R&D activity of competing firms might decline, for instance because the financial advantage given to the recipient might reduce the rate of return of competing firms. Negative externalities can also occur between industries, as shown by Nadiri and Mamuneas (1996). Conversely, the recipient firm's research may generate knowledge spillovers that will also be beneficial to its competitors. The potential presence of these effects makes the case for empirical studies at an aggregate level, which implicitly take them into account (be they positive or negative).

1. David et al. (2000) and Capron and van Pottelsberghe (1997) survey studies on the impact of R&D subsidies; Mohnen (1997) and Hall and Van Reenen (2000) survey studies on the role of fiscal incentives. Guellec and van Pottelsberghe (1999) measure the simultaneous effect of direct government funding to business R&D and tax incentives on privately funded and performed R&D. This paper improves on these results by taking into account other types of public R&D and by performing new econometric specifications.

A second advantage of working at the macroeconomic level is that overall government funding of R&D can be considered as exogenous with respect to privately funded R&D. At the firm level, the relevance of the assumption of exogeneity is questionable because public authorities do not provide R&D subsidies to randomly selected companies. Or, in the words of Lichtenberg ; "*Federal contracts do not descend upon firms like manna from heaven*" (Lichtenberg, 1984, p. 74). Public authorities are more inclined to support firms that already perform R&D and that have good innovative records. This view is supported by recent empirical evidence (Czarnitzki and Fier (2001) and Wallsten (2000)) at the firm level. A positive and significant relationship between a firm's R&D and the government funds it received cannot be taken as an evidence of the efficiency of government support. This argument may also apply, though to a lesser degree, to cross-industry studies since R&D subsidies are mainly directed towards R&D intensive industries. At the macro level, the exogeneity assumption is more acceptable.

A problem at the macroeconomic level may be that both business and government expenditure could be influenced by common factors, which would bias the estimated relationship. Two factors are likely to be important. First, changes in the business cycle affect the financial constraints of government and business. To account for this problem, this study takes GDP growth as an explanatory variable for business funded R&D. Second, changes in the cost of R&D may affect both sectors. For instance, the price of specialised inputs or the wages of researchers may increase when government expands its spending, leading to a growth in business spending that is only nominal in character. This factor will be examined by accounting for the reaction of R&D prices to demand, as estimated by Goolsbee (1998).

The different policy instruments raise specific measurement issues. Public research is broken down into two components, government research and university research, for which standard data is available from OECD. Government funding of business R&D is composed of procurement and grants or subsidies. Altough the explicit goal of procurement is not to trigger a rise in business-funded R&D, such an effect is often called upon to justify government spending (the "leverage effect"). Due to data availability constraints, these two components of direct government funding are combined herein. Government funded

R&D performed by firms primarily consists of procurement and regular grants, although there are also other forms of support, such as loan guarantees, conditional loans, and convertible loans (Young 1998).

Fiscal incentives may take various forms, making international comparisons problematic. The so-called "B-index", designed by Warda (1996), gives a synthetic view of tax generosity (Annex 1 provides a complete description of the B-index). It is a composite index computed as the present value of before-tax income necessary to cover the initial cost of R&D investment and the corporate income tax, thus indicating the level at which it becomes profitable to perform research activities. It is a kind of average effective rate of taxation of R&D. The underlying methodology is highly flexible and enables various types of tax treatment to be modelled in a comparable manner.[2]

The empirical analysis relies on a simple R&D investment model that considers business-funded R&D as a function of output, the policy instruments (government funding of R&D performed by business, tax incentives, government intramural expenditure on R&D, research performed by universities), time dummies, and country-specific fixed effects.[3] Since research activities are subject to high adjustment costs, a dynamic specification that distinguishes short-run from long-run elasticities is required. The model allows for this dynamic mechanism by introducing the lagged dependent variable. This type of specification is not common in the existing literature on the effectiveness of government support to R&D.[4] On *a priori* grounds, however, lagged private R&D may be seen as an important determinant of present R&D investment. Mansfield (1964, p. 32) notices that "*First it takes time to hire people and build laboratories. Second, there are often substantial costs in expanding too rapidly because it is difficult to assimilate large percentage increases in R&D staff. (...) Third, the firm may be uncertain as to how long expenditures of*

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2. The B-index is similar to the marginal effective tax rate (METR) computed for eight OECD countries by Bloom *et al*. (2001). However, the latter is composed of a tax component and an "economic component" which is the sum of the firm's discount rate (actually, the interest rate) and R&D depreciation rate, less the rate of inflation. The empirical results of Bloom *et al*. show that the tax component significantly affects business-funded R&D expenditure, while the economic component has no significant impact.

3. These should take account of stable country characteristics that may influence the private decision to invest in R&D, especially in the long run, such as culture, tax policies, and institutional differences.

4. Only two of the 18 studies surveyed in Annex Table A2 adopt a partial adjustment mechanism for the R&D investment equation.

(desired) R&D levels can be maintained. It does not want to begin projects that will soon have to be interrupted." The behaviour of private investors can therefore be best described in terms of a dynamic mechanism that allows for a long-term adjustment path. The model is written as follows:

$$\Delta RP_{i,t}=\lambda\Delta RP_{i,t-1}+\beta_{VA}\Delta VA_{i,t}+\beta_{RG}\Delta RG_{i,t-1}+\beta_{B}\Delta B_{i,t-1}+\beta_{GOV}\Delta GOV_{i,t-1}+\beta_{HE}\Delta HE_{i,t-1}+\tau_{t}+e_{i,t} \quad (1)$$

This equation is a first-difference auto-regressive model. *RP*, *VA*, *RG*, *B*, *GOV*, and *HE* are respectively business-funded and -performed R&D, business sector value added, government funding of R&D implemented in business, the B-index (which reflects the fiscal generosity for R&D, see Annex 1), government intramural R&D expenditure (*i.e.* public labs), and higher education R&D outlays (*i.e.* university research). The 17 OECD countries are indexed by *i (=1, ..., 17)*, and the years 1983 to 1996 by *t (= 1, ..., 14)*. Δ is the first (logarithmic) difference operator and τ characterises time dummies.[5] In this model, the short- and long-term effects of the exogenous variables are [β] and [β/(1-λ)], respectively. The signs of the parameters associated with the four policy tools can be either positive or negative, depending on whether the stimulating and spillover effects outweigh the crowding-out, substitution and displacement effects.

The data on value added is taken from OECD (1999a). Privately funded R&D, direct R&D funding to business, and R&D outlays by public labs and universities are taken from OECD (1999b). All the variables except the B-index are expressed in constant USD PPP and deflated with the business sector's GDP price index (base year 1990). The B-index has been computed by the OECD from national sources (see Annex Table A1).

4. Results

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5. Country dummies, which would control for the fixed effects generated by "*level*" variables, are not included due to the first difference specification. In addition, in a dynamic context, adding country dummies would yield inconsistent estimates because the lagged endogenous variable is among the right-hand side variables. Indeed, Nickell (1981) and Keane and Runkle (1992) show that the within transformation introduces a correlation between the lagged endogenous variable and the error term. However, had they been introduced into the regression equation, unreported results have shown that they would have been similar. Time dummies are included to take into account technology

Before estimating the dynamic model (1) and its various extensions, it is helpful to investigate the influence of the policy instruments on business R&D in a simpler, non-dynamic framework, in order to show the basic relationships and their time pattern. Results reported in Table 1 show that the effect of value added on business R&D is essentially contemporaneous, with an elasticity of about 1.20. All policy instruments have a significant impact on business-funded R&D, although with different signs and time patterns. Government-funded R&D has a positive and significant effect, but only with a one and two-year lags. Fiscal incentives have both direct and lagged positive impacts (a lower B-index reflects higher tax breaks, leading to a negative sign).[6] The estimates also suggest that the effect of tax breaks is quicker than the effect of government funding, as business spending reacts immediately to a change in taxes. This finding also emerges from previous studies (Guellec and van Pottelsberghe, 1999; David *et al.*, 2000). It seems linked to the fact that tax concessions are not conditional on the type of R&D performed by the recipient. Instead of having to launch new projects conforming to government requirements, the firm will just spend more on on-going projects, hence accelerating their completion or improving the quality of the outcome. In contrast, Government subsidies and contracts apply to projects that are selected by the government or meet certain conditions imposed by the government. In many cases, the research is of a long-term, if not basic, nature, creating new opportunities that induce firms, at a later stage, to start further research projects with their own funds. This leverage effect of government funding will take some time before becoming visible in the data.

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

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shocks common to all countries that are not controlled for by the exogenous variables, such as the increasing use of information technology.

[6] These results are similar to the ones of Bloom *et al*. (2001), who estimate the impact of the user cost of R&D on total R&D investment as follows: ln (R&D) = •$_1$ * ln (user cost $_t$) + •$_2$ * ln (user cost $_{t-1}$). The authors estimate (see their Table II, column 2) an elasticity of total R&D with respect to the user cost lagged one year equal to -0.347 (non significant with the contemporaneous user cost). With our sample of 17 countries, for the same specification (including country and time dummies), we obtain a significant elasticity of –0.765. If we use the same sample than Bloom *et al*. (2001) (8 countries) the estimated parameter becomes –0.761. These higher estimates might be due to the fact that (i) Bloom *et al*. use total R&D investment as dependent variable, whereas we use business funded R&D; (ii) their sample ranges from 1979 to 1994 whereas our sample ranges from 1982 to 1996; (iii) the way we compute the user cost is different.

Government research has a negative and significant impact on business funded R&D. Moreover, this negative impact is spread over several years (although there is no contemporaneous impact). The crowding-out effect - which is due either to an induced increase in the cost of R&D or to direct displacement – appears to dominate the stimulating effect. Public laboratories are supposed to meet public goals, however, not those of business; spillovers may occur but they are not instantaneous and are not the primary goal. The zero impact of university research on business funded R&D may point to the difficulties in transferring basic knowledge to firms.[7]

Table 2 reports the panel data estimates of equation (1), correcting for the potential contemporaneous correlation of the error term across countries within a three-stage least squares (3SLS) method.[8] The Breush-Pagan test indicates that the error term of the OLS estimates is subject to significant contemporaneous correlation across countries.[9] The estimates presented in column 1 show that the short-term (long-term) private R&D elasticities are 1.38 (1.50) for value added, 0.07 (0.08) for government funding, -0.28 (-0.31) for tax incentives, -0.06 (-0.07) for government research and there is no impact of university research.[10] In order to detect potential outliers, and to test the robustness of our results with respect to the sample of countries, the model was estimated on 17 sub-samples of 16 countries. That is, all

7. It should be kept in mind, however, that a four-year lag might be too short to capture the longer-term effects of basic research. The effects of basic research can take several decades before reaching the application stage (Adams, 1990). Moreover, it is not clear whether positive externalities should translate into increased private R&D expenditures.

8. The first two stages, which are deemed to take into account the presence of the endogenous variable among the right-hand side variables, correspond to an instrumental variable procedure. The last stage is used to correct for the contemporaneous correlation of the residuals. Stage 1: fit ΔRPt with $\Delta RPt\text{-}2$ and all the other exogenous variables. Stage 2: regress equation (1) with the fit of $\Delta RPt\text{-}1$. Stage 3: correct for the contemporaneous correlation of the residuals.

9. This test has to be interpreted with caution. If it globally rejects the hypothesis of cross-sectional correlation for each pair of countries, there may still be a strong correlation between some pairs of countries. In this case, the correction for contemporaneous correlation has to be made, even if the null hypothesis is not rejected. With the present estimates, the test always rejects the hypothesis of no contemporaneous correlation of the error terms. The pairs of countries that are associated with the highest values of correlation between their error terms are often characterised by a cultural and geographical proximity, or size similarity.

10. These estimated long-term effects are similar to those obtained by summing up the significant parameters in the non-dynamic model that includes several lags (see Annex Table A1) : 1.57 for value added, 0.16 for government funding, –0.50 for fiscal incentives, -0.17 for government intramural expenditure, and 0 for university research.

countries were removed from the sample one at a time. This test of sensitivity further support the robustness of our results.

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

To examine how these estimated elasticities translate in dollar terms and analyse the impact of government policies on the amount of R&D spent by firms, it is helpful to translate the elasticities in marginal rates of return. These are reported in Table 3. The marginal rate of return is calculated as the product of the elasticity and the ratio of the impacted variable (business R&D) to the impacting one. If two policy instruments have the same elasticity, the one with the largest relative size will have the lowest rate of return. The results indicate that one dollar of direct government funding to business generates a 0.70 dollar marginal increase in business funded R&D, i.e. 1.70 dollar in total R&D. One dollar from government leads to a 0.44 dollar marginal reduction when spent on government research, and has no impact on business R&D when spent on university research. This reduction is less than the initial, one dollar, government expenditure implying that total R&D (public plus business) will rise after government has increased its spending. In other words, the crowding-out effect of the research performed in public laboratories is only partial. Finally, assuming that the average R&D intensity in the OECD is about 2%, a one dollar increase in value added induces an additional 0.03 dollar of private R&D.

Government spending may not only affect the amount spent on R&D by business, but also the price of R&D: increased demand for the scarce resources used for R&D, e.g. researchers, should increase its price up. Goolsbee (1998) estimates the long term elasticity of the R&D worker wage with respect to government spending to be 0.09. As wages account for nearly half of R&D expenditure, we divide this figure by two for having an estimate of the elasticity of the total cost of R&D. Subtracting this price effect from the coefficients estimated in Table 2 leads to an elasticity of 0.035 for direct funding in the long term (0.08 minus 0.045). This coefficient is lower than the one estimated above, but it still aknowledges a real impact of government funding. In addition, Goolsbee's estimate is based on data for the United States over the years 1968-94. The share of government R&D in the US was very high in the first part of this period (between 50 and 60% until 1980, compared with 33% in 1996). This is also substantially larger than the share of defence in R&D spending in other OECD countries included in this panel (the average share across OECD was 32% in 1996) and might therefore overestimate the situation in other countries. It remains true, however, that part of the effect identified above is due to an increase in price, not in the real amount of resources allocated to research.

Table 2 also reports a range of alternative specifications of equation 1, examining some of the features of the basic results in more detail. A first result is reported in column 2 of Table 2, where the private R&D elasticity of government R&D is allowed to vary across four groups of countries. The groups are based on the average subsidisation rate of each country over the whole period (see Table A1): countries with subsidisation rates over 19% (high), those with rates from 11-9% (medium-high), those from 4-11% (medium-low), and those below 4% (low). The largest elasticities are found for countries belonging to the two ‘medium’ groups, while countries with the highest and the lowest funding rates have non-significant elasticities. This suggests that the effectiveness of government funding increases up to a particular threshold and decreases after that. Unreported estimates with a more detailed country breakdown confirm these lower elasticities for countries with the highest and the lowest levels of funding. To test directly for this inverted U-curve that seems to characterise the relationship between government support and privately financed R&D, the estimated private R&D elasticity of government funding is combined with the rate of direct support, in a quadratic specification :

$$\beta_{RG\,i,t} = \alpha_1 x_{i,t} + \alpha_2 x_{i,t}^2 , \qquad (2)$$

where $x_{i,t} = \dfrac{RG_{i,t}}{RT_{i,t}}$.

The results of this specification, in which α_1 and α_2 are the parameters of interest, are reported in the third column of Table 2. They suggest that the elasticity of private R&D with respect to government support increases with the subsidisation rate up to a threshold (estimated to be around 10%), then decreases with the subsidisation rate, and becomes negative over a threshold of about 20%.

The variation across countries of the elasticity of private R&D with respect to government funding could simply reflect a constant marginal rate of return to R&D funding across countries. Indeed, a constant elasticity implies that an additional dollar of private R&D for each additional public dollar spent decreases with the rate of funding. An elasticity that varies across countries could thus translate into constant marginal effects.[11] As reported above, the product of the estimated elasticities (columns 1 and 2 in Table 2) and the ratio of private R&D to government funding shows that one dollar of government money induces an average increase of 70 cents in business-funded R&D. It varies across countries, from no significant marginal effects amongst the countries with high and low government funding rates, to about 50 cents and 1.01 dollar for countries with "medium-high" and "medium-low" rates, respectively.[12]

A second aspect that could affect the impact of different policy tools is their stability over time. This is investigated by combining the direct government funding and the B-index with indicators of their respective stability over time.[13] The two variables that reflect the stability of the schemes for each country are *GT-instability* and *B-instability*, which are respectively the standard deviation of the funding rate (*GT*) and of the B-index over the period 1983-96. For both policy tools, the estimates presented in column 4 of Table 2 show that the more volatile a policy, the less effective it is. R&D investment typically involves a long-term commitment and leads to considerable sunk costs. Such investment is therefore likely to be sensitive to uncertainty, including uncertainty that arises from fiscal or government funding. Unstable policies in the past are often taken by firms as a signal that future change is likely to take place. These results confirm a finding from Hall (1992), that the impact of R&D tax incentives on US firms increased

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11. With a constant elasticity, $\gamma = [(\partial RP/\partial RG) * (RG/RP)]$, the marginal effect $\rho = (\partial RP/\partial RG) = \gamma * (RP/RG)$ decreases as the rate of subsidisation increases.

12. Additional econometric results reported in Guellec and van Pottelsberghe (1999), were used to estimate directly marginal effects, by replacing the first (logarithmic) difference of government R&D by the ratio of the increment of government R&D to the level of private R&D. Results are similar to those reported here.

13. There is less of a case for the stability of government or university research affecting their impact on business-funded R&D as their effect is more spread over time.

over time, once it was clear that the scheme would be maintained in the future. Similar evidence concerning R&D subsidies is available at the industry level (Capron and van Pottelsberghe, 1997). They find for the G7 countries that R&D is more likely to be stimulated in industries where government funding is more stable.

The interaction between the various policy tools is also an important aspect, as their effects rely on different incentive mechanisms that may conflict with each other. Are the instruments complementary or substitutes in stimulating business-funded R&D, *i.e.* are they mutually reinforcing or do they partly cancel out? Estimates reported in column 5 of Table 2 show that government funding of business R&D is substitute to fiscal incentives. Increasing the direct funding (tax incentives) of business research reduces the stimulating effect of tax incentives (direct government funding). The strong interaction between the two 'direct' policy tools indicates that an integrated approach to R&D policy is needed; a loss of effectiveness is to be expected when the instruments are used separately.

A final alternative specification of equation 1 investigates the impact of defence-oriented R&D policy on business funded R&D. Defence technologies are less likely to be characterised by spillovers, as they are often specific, with little emphasis on cost but primarily on extreme performance in extreme conditions. Secrecy constraints may also imply that the results will only diffuse slowly to civilian applications.[14] Furthermore, because defence contracting is attractive- it generates high rewards at low risk - firms might allocate resources that would otherwise have been used for civilian research. Hence, even if defence R&D had a positive impact on business funded R&D, the effect would be expected to be lower than the effect of a same amount of funding that would flow into projects with a civilian purpose.

The share of defence in government R&D budgets in OECD countries is around 30% on average (OECD, 1999). There are huge differences across countries, however, with three countries having a high share (around 60% in the United States, and 30% in France and the United Kingdom) and the rest having

14. Defence-related funding of business R&D typically crystallize into procurements : the results do not necessarily belong to the R&D performer, or might be constrained towards government market. Lichtenberg (1987) shows that

shares below 10%. To estimate the impact of defence funding, the elasticities of private R&D (*RP*) with respect to direct government funding of business R&D (*RG*), to government intramural R&D (*GOV*), and to research performed in the higher education sector are allowed to have a fixed component and a component that varies with the share of defence in the total government R&D budget appropriation [as in equation (2)].[15] The results are reported in columns 6 to 8 of Table 2. They show that the three elasticities are inversely related to the share of defence-oriented public R&D; the higher the share of defence, the lower the effect of government funding on business R&D. It is worth noticing that the impact of higher education R&D, which was non significant in the previous estimates, becomes positive and significant when the defence component is taken into account. In a similar vein, the effect of government research, which was negative in the previous estimates, changes to zero when the defence component is netted out. This implies that non-defence government intramural research (public labs or academic), which is the bulk of government intramural R&D in most OECD countries, has no negative effect on business R&D.[16]

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the positive impact of public funding on business R&D disappears when the output is separated into sales to government and other sales.

15. In other words, we assume that β_{RG} , β_{HE} and β_{GOV} in equation (1) have the following form: $\beta = c + \gamma . DEFshare$, where c is the fixed component of the elasticity and γ reflects the impact on β of the share of defence-related R&D in total government budget appropriation on R&D.

16. Guellec and van Pottelsberghe (1999) relied on a different approach to obtain an insight into the effect of defence-related government support. Data on the share of government procurement for defence purposes were collected from five countries. It turned out that the defence component of direct government funding of business R&D has a negative and significant impact for the three countries with very high funding rates. In the present study, we use data available for 17 OECD countries, which is the share of defence in total government budget outlays on R&D (including procurement and intramural research).

5. Concluding remarks and implications for policy

Among the major instruments of government policy, both fiscal incentives and direct funding stimulate business-funded R&D, whereas research performed by government appears to have a crowding out effect and the research performed by the higher education sector has no impact. This implies that direct financial support is more effective than the indirect supply of knowledge as a policy instrument for enhancing business R&D outlays. Publicly produced knowledge may result in technology that is used by business, however, even though it may not affect research expenditure. Moreover, it is not the major purpose of government laboratories to produce knowledge for the business sector. A more detailed analysis shows that only the defence component of government research has a negative impact on business funded R&D, civilian R&D has no impact.

The effectiveness of these policies is affected by other factors. First, countries that provide a level of direct funding to business that is too low or too high stimulate private R&D less than countries with an intermediate level of public funding. The effectiveness of government funding of business R&D seems to have an inverted-U shape, increasing up to an average subsidisation rate of about 10%, and decreasing beyond. Over a level of 20%, additional public money appears to substitute for private funding. These figures are mainly illustrative, as the actual thresholds depend on the precise policies used and on economic conditions, which differ across countries and change over time. Second, stable policies are more effective than changing (volatile) policies. Third, the effectiveness of each of the various policy tools depends on the use of the others. In particular, government funding of business R&D and tax incentives are substitutes; greater use of one reduces the effectiveness of the other.

An analysis carried out at an international and aggregate level does not lead to specific conclusions with regards to policy design. However, broad policy recommendations can be drawn from these results. First, any type of government support to business R&D is more likely to be effective if it is integrated within a long-term framework, thus reducing to some extent the uncertainty that firms face. Second, the various policy instruments should be consistent, which implies co-ordination between the various administrative departments involved in their design and management. Third, if government whishes to stimulate business R&D, providing too low or too high a level of funding is not effective. Fourth, even if defence-related R&D funding is not aimed at stimulating private R&D expenditure, its crowding-out effect on civilian business R&D should be taken into account. Fifth, defence-related funding of business R&D, or defence-related research performed in public laboratories and the higher education sector tend to reduce business incentives to invest into research activities. This might be due to the fact that defence-related funding crystallizes essentially into procurements (as opposed to grants), under which any technological invention belongs to the government.

These results should be interpreted with caution. The precise design of policies varies substantially across countries and has evolved over time, in a way that cannot be fully reflected in the financial data that are used here. In addition, the estimates capture average relationships, that may hide differences in the effectiveness of public policies across countries and that may change over time. However, such an average relationship may be useful by itself, as it may provide a reference for individual countries to benchmark their policies. Finally, the comprehensive approach taken here allows an identification of the interactions between various policy tools.

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Annex 1 : The B-index

The B-index is a synthetic measure of fiscal generosity towards R&D. It has been elaborated by Warda (1996). Algebraically, the B-index is equal to the after-tax cost of a 1 dollar 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 into account all available tax incentives: B-index = $\frac{(1-A)}{(1-\tau)}$, where τ = statutory corporate income tax rate; A = the net present discounted value of depreciation allowances, tax credits, and special allowances on the R&D assets. In a country with full write-off and no other scheme, $A = \tau$, and consequently $B = 1$. The more favourable a country's tax treatment of R&D, the lower its B-index. The value for A may take three forms: *i)* the net present value (NPV) of depreciation allowances A_d,; *ii)* the NPV of special R&D allowances A_s; and *iii)* the NPV of R&D tax credits A_c. The proportions of the R&D costs that are entitled to standard depreciation allowances are, respectively, D_d, D_s, D_c. The net present value of all depreciation allowances and tax credit is:

$$A = D_d \, \tau A_d + D_c \, \tau^c + D_s A_s$$

If the depreciation allowance is granted at an exponential rate of d and with standard depreciation allowance: declining balance - DB: $A_d = \frac{\delta}{\delta + r}$, or with straight-line - SL: $A_d = \frac{(1-e^{-rL})}{r\,L}$

For a tax credit that applies on incremental expenditures, it depends on how the base is defined: *i)* last year's expenditures; *ii)* the previous largest expenditures, as in Japan; *iii)* a fixed year in the past; *iv)* an average of the past two years' expenditures, as in France and Spain; *v)* an average of the past three years' expenditures. Assumptions *i), ii)* and *iii)* are treated similarly, whereas for *iv)* and *v)*:

$$A_c = \tau^c \left[1 - \frac{1}{k} (\textstyle\sum_{k=1}^{K} (1+r)^{-k} \right]$$

If the credit is on real expenditures, then A_c is divided by $(1+\pi)$. In the three-year-average case *v)*, the term between brackets is equal to .171; in the two-year average case *iv)* it is .132; and in the one-year case it is .091. For example, the United States has an incremental tax credit of 20% of the amount by which R&D outlays of a fiscal year exceed a base amount. The base amount is the product of the "fixed-base percentage" and the average of the gross receipts for the four preceding years. The fixed-base percentage is the R&D intensity during the 1984-88 period (*i.e.* the share of R&D investments in gross receipts), which should not exceed 16%. The base amount therefore varies with the growth of output; the higher the output growth, the higher the base amount. The US treatment aims apparently at fostering the propensity to invest in R&D rather than the increase of R&D as such. The base amount cannot be less than 50% of the tax payer's current-year qualified research expenditures. Calculation of the B-index has been made under the assumption that the "representative firm" is taxable, so that it realises the full gain from the tax deduction. For incremental tax credits, calculation of the B-index implicitly assumes that R&D investment is fully eligible to the credit, and does not exceed the ceiling where there is one. Therefore, the flexibility of the policies according to refunding, carry-back and carry-forward of unused tax credit, and flow-through mechanisms are not taken into account by the B-index. In practical terms, the B-index of a country that applies both types of tax credits (level and incremental), depreciation allowances and taxable credits, is computed as follows:

$$B = \frac{1 - \tau \, A_d - D^{cL} \; \tau^{cL} \; (1-\tau) - D^{cI} \; \tau^{cI} \; (1-\tau)}{(1-\tau)}$$

Table A1. R&D tax treatment and subsidisation in OECD countries, 1996

	R&D depreciation rate (%)			Tax credit base		Flexibility		Corporate income tax	B-Index	Subsidisation rate
	Current exp.	Machin. & equip.	Buildings	Level	Increm.	Special Aalowances	Credit taxable	1981-96 (%)	1981-96	1981-96 (%)
Australia	150	3 ys, SL	40 ys, SL					46 - 36	1.01 - 0.76	8 - 3
Belgium	100	3 ys, SL	20 ys, SL			13.5% (M)		48 - 40	1.01 - 1.01	8 - 4
Canada	100	100	4, DB	20%			yes	42 - 32	0.84 - 0.83	11 - 10
Denmark	100	100	100			25% (C, M, B)		40 - 34	1.00 - 0.87	12 - 5
Finland	100	30, DB	20, DB					49 - 28	1.02 - 1.01	4 - 6
France	100	5 ys, SL or 40, DB	20 ys, SL		50%		no	50 - 33	1.02 - 0.92	25 - 13
Germany	100	30, DB	25 ys, SL					63 - 57	1.04 - 1.05	17 - 9
Ireland	100	100	100					10 - 10	1.00 - 1.00	14 - 5
Italy	100	10 ys, SL	33 ys, SL					36 - 53	1.03 - 1.05	9 - 12
Japan	100	18, DB	2, DB		20%	7% for high-tech (M)	no	55 - 51	1.02 - 1.02	2 - 2
Netherlands	100	5 ys, SL	25 YS, SL	12.5%		2% (M, B)	no	48 - 37	1.01 - 0.90	7 - 7
Norway	100	20, DB	5, DB					51 - 28	1.04 - 1.02	25 - 16
Spain	100	100	10 ys, SL	20%	40%		no	33 - 35	0.86 - 0.66	4 - 11
Sweden	100	30, DB	25 ys, SL					52 - 28	0.92 - 1.02	14 - 10
Switzerland	100	40, DB	8, DB					28 - 34	1.01 - 1.02	1 - 2
United Kingdom	100	100	100					52 - 33	1.00 - 1.00	30 - 12
United States	100	5 ys, DB	39 ys, SL		20%		yes	46 - 35	0.82 - 0.93	32 - 17

Note: These figures concern the tax treatment of large firms, which account for the bulk of total R&D investment in OECD countries. “ys” indicates the approximate number of years needed for a full depreciation of investment in machinery, equipment and buildings devoted to R&D activities. A level of 100 implies that the related expenditures can be fully depreciated during the year incurred. SL indicates a straight-line depreciation scheme, and DB a declining balance scheme. C, M, and B, are abbreviations for current expenditures, machinery, and buildings, respectively.
Source: OECD, *Technology, Productivity and Job Creation: Best Policy Practices*, 1998.

Table A2. Estimated marginal impact (or elasticity – ε) of publicly financed R&D on private R&D[1,2]

Author(s)	Comments on specification, RHS variables and results	β
Firm-level		
Rosenberg (1976) USA - 1963 - C.S. of 100 firms	Includes output growth, concentration and barrier to entry dummies, the market share, fraction of high-tech inputs, fraction of highly subsidised inputs, and employment; OLS.	2.35*
Shrieves (1978) ε USA - 1965 - C.S. of 411 firms	Includes output, technology profiles and product-market factors, and a concentration ratio; OLS. The estimated parameter is negative for different kinds of industries, except materials.	-.53*
Carmichael (1981) USA - 1977 - C.S. of 46 transport firms	Includes output. OLS. The estimated parameter is nil for large firms.	-.08*
Link (1982) USA - 1977 - C.S. of 275 firms	Includes firm's relative profits, product diversification, the ownership form, and a concentration ratio; OLS. The parameter is negative for basic research, nil for applied research, and positive for development.	.09*
Lichtenberg (1984) USA - 1977 - C.S. of 991 firms	No other variables, the estimated parameter stays negative in growth rates (1972-77); OLS.	-.22*
Scott (1984) ε USA - 1974 - C.S. of 3 387 lines of business	Includes output and firm dummy; OLS.	.08*
Switzer (1984) USA - 1977 - C.S. of 125 firms	***Dynamic*** specification, including change in output, capital investment, dividend payments, long-term debt, internal financing, a concentration ratio; 3SLS.	.08
Lichtenberg (1987) USA - 1979-84 - T.S.C.S. of 187 firms	Includes output and time dummies. When the output is separated into sales to government and other sales, the parameter becomes insignificant; OLS.	.13*
Holemans and Sleuwagen (1988) ε Belgium - 1980-84- T.S.C.S. of 59 firms	Includes dummies for output, employment, industry and foreign firms, a concentration ratio, a diversification index, and payment for royalties and fees; OLS.	.36*
Antonelli (1989) ε Italy - 1983 - C.S. of 86 firms	Includes output, a diversification dummy, the share of exports in total sales, US sectoral R&D intensity, price-cost margin, and profitability; OLS.	.37*
Leyden and Link (1992) USA - 1987 - C.S. of 137 laboratories	Includes shared efforts (*e.g.* in conferences), inter-laboratory agreements, and a two-digit R&D/Sales ratio; 3SLS.	1.99*
Industry-level		
Nadiri (1980) ε USA - 1969-75 - T.S.C.S. of 10 industries	***Dynamic*** specification, including value added, labour, fixed capital, utilisation rate, and the ratio of wage to user cost of capital; OLS. Negative impact for five durables industries.	.01*
Levin and Reiss (1984) [3] USA - 1967, 72, 77 - C.S. of 20 industries	Includes age of capital, a concentration ratio and sectoral dummies; Instrumental variables technique.	.12*
Lichtenberg (1984) USA - 1963-79 - T.S.C.S. of 12 industries	Includes time and industry dummies, variables in growth rates; OLS. When the time dummies are withdrawn from the model, the parameter becomes positive (.22*).	.01
Mamuneas and Nadiri (1996) USA - 1956-88 - T.S.C.S. of 15 industries	Translog cost function, including output, labour, physical capital, the relative price of materials, a time trend, and industry dummies; MML.	.54*

Table A2 (*cont'd*). Estimated marginal impact (or elasticity – ε) of publicly financed R&D on private R&D[1,2]

Author(s)	Comments on specification, RHS variables and results	β
Country-level		
Lichtenberg (1987) USA - 1956-83 - T.S.	Includes output and a time trend. Estimates adjusted for first-order serial correlation of residuals. When output is separated into sales to government and other sales, the parameter becomes insignificant.	.33*
Levy and Terleckyj (1983) USA - 1949-81 - T.S. (private business)	Includes output, corporate taxes, unemployment, and age of R&D stock. Generalised least squares.	.21*
Levy (1990) 9 countries -1963-84 -T.S.C.S.	Includes output and country dummies. Box-Cox procedure applied to the panel data. The estimates are positive for four countries (including the United States and Japan), insignificant for two, and negative for the United Kingdom and the Netherlands.	-.73* to .41*

1. The last column reports the average impact (or elasticity: ε) of government R&D on private R&D in the main existing empirical studies.
2. T.S. = time series; C.S. = cross section; T.S.C.S. = panel data; OLS = ordinary least squares; 3SLS = three-stage least squares, MML = maximum likelihood.
3. The estimates by Levin and Reiss have to be interpreted as a negative relationship between government and private R&D because the dependent variable is total R&D instead of privately financed R&D.
* Significantly different from zero at a 10% probability threshold.
Source: Adapted and extended from Capron and van Pottelsberghe (1997).

Table 1. The lag structure of the determinants of private R&D expenditures[1]

	Value added (ΔVA)	**Government funding (ΔRG)**	**Fiscal incentives (ΔB)**	**Government research (ΔGOV)**	**Higher education (ΔHE)**
Expected sign	(+)	(+)	(-)	(?)	(?)
Time lag					
T	1.200***	-0.007	-0.171***	0.011	-0.023
	(22.24)	*(-0.96)*	*(-3.01)*	*(0.56)*	*(-1.19)*
T-1	-0.011	0.082***	-0.330***	-0.056***	-0.021
	(-0.18)	*(10.69)*	*(-9.61)*	*(-2.84)*	*(-1.21)*
T-2	0.207***	0.084***	-0.017	0.011	0.002
	(3.19)	*(11.21)*	*(-0.49)*	*(0.53)*	*(0.09)*
T-3	-0.088	-0.020***	0.004	-0.072***	0.019
	(-1.29)	*(-2.66)*	*(0.13)*	*(-3.38)*	*(1.04)*
T-4	0.166***	0.015*	0.033	-0.042*	0.008
	(2.87)	*(1.77)*	*(0.92)*	*(-1.87)*	*(0.42)*
Sum	1.573	0.161	-0.501	-0.170	0.000

Note: The estimates cover 17 countries for the 1983-96 period (165 observations due to time lags). The variables are expressed in first differences of logarithms (growth rates). *RP*, the dependant variable denotes business-funded R&D investment, *VA* value added, *B* the B-index, *GOVRD* government intramural expenditure on R&D and *HERD* higher education expenditure on R&D. SURE estimates including one intercept. *** indicates the parameters that are significantly different from zero at a 1% probability threshold; ** at 5%; and * at 10%.

Table 2. The impact of policy instruments on business-funded R&D

	Dependent variable is ΔRP_t							
		Funding rate		*Instability*	*Interact.*	*Defence*		
Regression #	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
Fit (ΔRP_{t-1})	0.083*	0.096*	0.088*	0.081*	0.075*	0.088*	0.105**	0.098**
	(1.67)	*(1.85)*	*(1.75)*	*(1.69)*	*(1.75)*	*(1.82)*	*(2.03)*	*(2.05)*
ΔVA_t	1.377***	1.393***	1.412***	1.405***	1.362***	1.400***	1.332***	1.373***
	(19.58)	*(19.03)*	*(19.97)*	*(19.40)*	*(22.14)*	*(19.09)*	*(18.18)*	*(19.40)*
ΔRG_{t-1}	0.072***			0.105***	0.075***	0.082***	0.067***	0.069***
	(10.48)			*(9.83)*	*(11.11)*	*(9.79)*	*(8.20)*	*(9.39)*
ΔB_{t-1}	-0.281***	-0.278***	-0.264***	-0.866***	-0.198***	-0.279***	-0.264***	-0.286***
	(-7.34)	*(-7.49)*	*(-6.35)*	*(-4.09)*	*(-6.00)*	*(-7.18)*	*(-6.06)*	*(-7.56)*
$\Delta GOVRD_{t-1}$	-0.063***	-0.068***	-0.057***	-0.0691***	-0.072***	-0.060***	-0.074***	-0.014
	(-3.50)	*(-3.63)*	*(-3.18)*	*(-3.93)*	*(-4.02)*	*(-3.32)*	*(-3.74)*	*(-0.54)*
$\Delta HERD_{t-1}$	-0.012	-0.012	-0.015	-0.009	-0.014	-0.007	0.079***	-0.019
	(-0.70)	*(-0.67)*	*(-0.87)*	*(-0.54)*	*(-0.93)*	*(-0.40)*	*(-3.29)*	*(-1.11)*
ΔRG_{t-1}* *DGT-high*		-0.030						
		(-1.24)						
ΔRG_{t-1}* *DGT-medium high*		0.039*						
		(1.63)						
ΔRG_{t-1}* *DGT-medium low*		0.083***						
		(9.05)						
ΔRG_{t-1}* *DGT-low*		0.019						
		(0.64)						
ΔRG_{t-1}* (GT_{t-1})			1.906***					
			(9.92)					
ΔRG_{t-1}* $(GT_{t-1})^2$			-9.794***					
			(-8.54)					
ΔRG_{t-1}* *GT-instability*				-19.017***				
				(-4.67)				
ΔB_{t-1}* *B-instability*				3.630***				
				(2.92)				
ΔRG_{t-1}* ΔB_{t-1}					1.145***			
					(7.28)			
ΔRG_{t-1}* $DEFshare_{t-1}$						-0.002***		
						(-3.64)		
$\Delta HERD_{t-1}$* $DEFshare_{t-1}$							-0.007***	
							(-6.59)	
$\Delta GOVRD_{t-1}$* $DEFshare_{t-1}$								-0.004***
								(-2.75)
Adj-R2	0.370	0.366	0.366	0.371	0.381	0.363	0.368	0.361

Note: See Table 1. The estimates cover 17 countries for the 1984-96 period (199 observations). *DGT-high* = a dummy variable equal to one for the countries whose average subsidisation rate is over 19% and 0 otherwise, *DGT-medium high* [11% - 19%], *DGT-medium low* [4% - 11%], *DGT-low* [0% - 4%]. *GT* is the share of government funded R&D in total business-performed R&D, *GT-instability* and *B-instability* the standard deviation over the studied period of *GT* and *B*, respectively, and *DEFshare* the defence budget R&D as a percentage of total government budget appropriations or outlays for R&D. All regressions are estimated with the 3SLS method and include an intercept and time dummies. T-statistics are shown between parentheses; *** indicates the parameters that are significantly different from zero at a 1% probability threshold; ** at 5%; and * at 10%.

Table 3. Average marginal effect of a 1 dollar increase in public support to R&D[1]

	Business performed R&D	R&D performed by public institutions	
***X* =>**	**Government funded (*RG*)**	**Government intramural (*GOV*)**	**Higher education (*HE*)**
Long-term elasticities (β)	0.08	-0.07	0
(*RP/X*)	8.71	5.54	3.59
Marginal effect on *RP* (ρ)	0.70	-0.38	0
Marginal effect on total R&D	1.70	0.62	1

1. Since the elasticities β are equivalent to ($\partial RP/\partial X$) / (X/RP), X standing for *RG*, *GOV*, or *HE*; the marginal effects (ρ) of a 1 dollar increase in government support on private R&D investments are computed as follows : $\rho_X = \beta_X * RP/X$. The marginal effect on total R&D is equal to 1 + ρ_X. The elasticities come from Table 2, column 1, the ratio (RP/X) is for 1997, averaged over OECD countries.