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THE IMPACT OF PUBLIC R&D EXPENDITURE ON BUSINESS R&D

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This document is a study carried out by the Economic Analysis and Statistics division. It presents for the first time quantitative estimates of the effect of various types of government R&D policies and university research on business R&D spending and analyses their interaction.

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EXECUTIVE SUMMARY

1. The share of government in the funding of R&D in 1998 was 30% in the OECD, 31% in the U.S., 36% in Europe and 19% in Japan. Such an effort may have various effects on the dynamics of technology, including contributing to basic knowledge, to the government's own missions, and to economic growth. One channel often assumed for the latter effect is a leverage effect by government funding on business funding: thanks to government support, or to the basic knowledge produced on government funds, the private return on investment in R&D is improved, triggering higher expenditure on R&D by companies. However, it is also possible that government funding crowds out business, either directly (government pre–empts a technological field) or gives money to firms for projects that they would have carried out anyway, or indirectly (by increasing demand, hence the market price of resources needed for research). It is uncertain whether, economy-wide, the leverage effect dominates the crowding out effect or not. This document attempts to quantify the aggregate net effect of government funding on business R&D in 17 OECD Member countries over the past two decades.

2. Government funding of R&D is extremely variegated, across countries and within countries. Government can directly fund business for doing research, either under procurement programs (the result is government property) or as a grant (the result belongs to the recipient). The bulk of the former is made of defence contracts.

3. A second way for government to support R&D is through tax incentives, notably R&D tax credit (now in 10 OECD countries).

4. A third way for government is to perform R&D itself, in public laboratories. Such research generally serves the government's own needs, in the defence, energy or public health areas for instance. Finally, the government funds university research, with the objective in general to generate basic knowledge. The direct purpose of these last two instruments is not to contribute to industrial technology, but they may have such an impact through "technology spillovers".

5. The major results of the study are the following:

- Government funding of R&D performed by firms and tax relieves have a positive effect on business financed R&D. One dollar given to firms results in 1.87 dollars of research.

- These two policy instruments 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 of them reduces the effect of the other on business R&D.

- The impact of direct government funding on business R&D is more long-lived than that of tax relieves, reflecting the fact that government programs target research projects with a longer time horizon than those on the agenda of business.

- The stimulating effect of government funding varies with respect to its generosity: it increases up to a threshold of about 14 per cent of business R&D and decreases beyond. Funding too much or too little is less effective that being somewhere in the middle.

- Defence research performed in public labs and universities crowd out private R&D. This is due partly to the increase in cost of research generated by government outlays (which boosts the demand for researchers and other resources, hence their market price). Civilian public research is neutral for business R&D. The impact of knowledge spillovers coming out of university (mainly basic) research takes too long a lag to be seen in the data.

- The negative effect of university research is mitigated when government funding of business R&D increases. Targeted government programs probably help firms to digest the knowledge generated by universities.

6. These results are averages over many countries. As the design of policies differs widely across countries, such conclusions may apply to a various extent to each individual country. However, they point to lessons that may be useful to policy makers. One lesson is that well designed government programs have a leverage effect on business R&D -this is not wasted money. Second, frequently redesigning a policy instrument -e.g. the rules and generosity of R&D tax credit or government programs- reduces its effectiveness. Third, a piecemeal approach to technology policy is detrimental to its effectiveness: tax breaks and direct funding of business are substitutes, whereas direct funding and university research are complements. Hence, the various policy instruments should be consistent with each other, which implies that the various administrative departments involved in their design and management need to be co–ordinated. Fourth, if government is willing to stimulate business R&D, providing too low or too high a level of funding is not effective. Fifth, although defence-related R&D funding does not aim at stimulating private R&D expenditure, its crowding-out effect on business, civilian R&D, has to be taken into account. Sixth, the research performed in universities presents a potential usefulness for business that can be improved through targeted government funding enhancing the transfer of technology.

1. INTRODUCTION

7. OECD governments spent around US$ 150 billion in research and development (R&D) activities in 1998, which is 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. Imperfect appropriability, or the diffusion of knowledge uncontrolled by the inventor, implies that the private rate of return to R&D is lower than its social return. Therefore, the amount invested by firms in research activities is likely to be below the socially optimal level (Arrow, 1962). In this line of argument, the wedge between private and social return is likely to be higher in basic research, requiring a stronger involvement of government in this area. The effectiveness of the policies aiming at stimulating private R&D outlays has been challenged on three main grounds.

8. First, government spending may crowd out private money, by increasing the demand, hence the cost, of R&D. Goolsbee (1998) and David and Hall (1999) argue that the major effect of government funding is to raise the wage of researchers. Faced with higher research costs, firms will allocate money to other activities so that, even if the total amount of R&D is higher due to government funding, its “real amount” (measured, e.g., by the number of researchers) will be lower and of lesser economic efficiency.

9. A second argument is that public money directly displaces private funding, as firms just substitute public money for their own, while keeping the same amount of research as planned. Therefore, the government supports projects that would have been implemented anyway.

10. Third, government funding, being allocated to projects in a less efficient way than market forces would do, generates distortions in the allocation of funding between the various fields of research. It may also distort competition between firms, by helping some of them at the expense of others. The purpose of this document is to assess the first line of argument: What is the effect of government spending on R&D funded and performed by business firms? Does the externality effect dominate the crowding out effect?

11. In order to assess the effect of government spending, it is necessary to identify the various channels money flows take: where and how the money is spent. The effect of public spending may differ depending on the policy instrument used. There are three main policy instruments used by government: public research, government funding of business performed R&D, and fiscal incentives. Public research, carried out in public laboratories or universities, and funded by government, is exemplified by National laboratories in the United States or the CNRS (Centre National de la Recherche Scientifique) in France. The goal of these bodies is to satisfy public needs and to provide the basic knowledge that is used downstream by firms in their own, applied, research. Government laboratories are more concerned with the former, universities and similar institutions are more concerned with the latter. Universities are usually endowed with much more independence with regards to their research agenda than government laboratories, making them a less responsive instrument for policy. However, as the government controls much of the research budget of these institutions (through grants contracts or fellowships) it is relevant to include them in the list of policy instruments. Some argue 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.

12. A second policy instrument is public funding of research performed by the business sector. According to the Frascati Manual (OECD, 1993) used by statisticians of R&D, two categories of government funds to business firms can be identified: *(i)* those which are specifically for the procurement of R&D (the results of the R&D belong to a recipient which is not necessarily the performer) and *(ii)* those which are provided to the performers of R&D in the form of grants or subsidies (the results belong to the R&D performer). In all cases subsidies are targeted to specific goals chosen by the funder: Government gives money to firms for particular technological projects that are seen as having a high social return (e.g. “generic technologies” or “pre-competitive research”) or that are useful for the government own objectives (health, defence). Hence the criticism of government “picking the winners” in the place of the market. Moreover grants are often conditional on some aspect of the firm strategy: they may require for instance that the recipients set up research alliances with other firms (co-operation), or that they collaborate with universities. Finally, government can help firms indirectly, through tax breaks. Most OECD countries allow for a full write-off of current R&D expenditures (depreciation allowances are deducted from taxable income). Amongst the 17 countries included in the present study, about one third also provide R&D tax credits (see Table A1). These are deducted 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. In some countries there are special tax breaksrelated to R&D for small firms. The main criticism to this instrument is that it is windfall money for firms: they do not change their R&D strategy (what the government is expecting), but are refunded for it. In a way, this argument is contrary to the one opposed to targeted funding: tax breaksare not discriminatory enough, so that firms may use public money for any goal that suits their own strategy, whatever the social return.

13. Among these three policy instruments, only the last two ones have been subject to distinct quantitative evaluation. This is unfortunate, since the three policy tools have partly similar, partly complementary objectives that make it difficult to analyse the effectiveness of one of them separately from the others. Government research provides basic knowledge. Grants help firms in the applied research stage and encourage co-operation (another way of internalising externalities). R&D tax credit, as not discriminatory, helps all R&D performing firms, especially those that do not have not access to grants for whatever reason. Public R&D, whether performed in public labs or universities, generates knowledge that can be used by business firms. These tools and their interactions constitute a system, whose efficiency can be best captured as a whole. It is the purpose of this study to do so.

14. This document investigates whether public performed research, direct funding and fiscal incentives stimulated business-funded R&D in 17 OECD countries over the period 1981-1996. This is an integrated (three policy instruments), macroeconomic, and international approach that makes this study distinct from previous work in this field. The main results are that:

- Direct government funding of business R&D and tax relieves have a positive impact on business spending in R&D.
- The effect of public funding, is more long-lived than that of tax relieves.
- The impact of R&D subsidies varies with respect to the funding rate: it increases up to a threshold of about 14 per cent and decreases beyond.
- The two policy tools are more effective when stable over time and they are substitutes (increasing the use of one of them reduces the impact of the other - this finding contradicts the “complementarity thesis” mentioned above, while supporting the integrated approach taken in this study).

- Public research and university intramural research exert a negative impact on business funded R&D: the crowding out effect seems to dominate the spillover effect (alternatively, it can be argued that the latter takes indirect channels or a too long lag for being captured by econometric techniques).

- However, the negative effect of university research is mitigated when government funding is increased: the knowledge generated by academic research is better transferred to firms when targeted funding is implemented.

- Finally, defence-oriented public funding seems to be the main factor underlying the crowding-out effect of government intramural R&D outlays.

15. Of course these results should be taken with some caution. The precise design of policies varies substantially across countries, in a way that is not totally captured by the financial flows used here. The estimates herein capture an average, that may hide differences in the effectiveness of public policies across countries. However, such an average is useful by itself, as a reference for individual countries.

2. THE MODEL AND DATA

16. 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 (see the survey by Capron and van Pottelsberghe, 1997), or the effect of fiscal incentives (see the survey by Mohnen, 1997). [1] A comparison exercise of these studies is rather hazardous, due to the heterogeneity of the empirical models used - e.g. different time periods, data sources, aggregation levels and regression characteristics. On average, however, the balance tilts towards the recognition of a positive effect of government-funding and tax incentives on privately-financed R&D. Nevertheless, it can be seen in Table A2 that the existing literature has disregarded two important dimensions. The first one is that there has been no attempt so far to test simultaneously for the effectiveness of all instruments. The second one is that there is a lack of macroeconomic investigation, most empirical analyses having been implemented at the firm or industry level.

17. As compared to the firm level approach that is more common in the field, the macroeconomic approach allows to capture indirect effects of policies - negative as well as positive spillovers. 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 they see their chances of having a competitive edge as waning due to the financial advantage given to the recipient. Negative externalities can also take place between industries, as shown by Nadiri and Mamuneas (1996) with US manufacturing industries. At the opposite, it can be argued that the recipient firm's research will generate knowledge spillovers that will flow to its competitors as well. The potential presence of these effects makes the case for empirical studies at an aggregate level, which implicitly take them (be they positive or negative) into account. A second advantage of working at the macroeconomic level is that government funding of R&D can be considered as exogenous with respect to privately-funded R&D. Indeed, at the firm level the relevance of the assumption of exogeneity is rather questionable because public authorities do not provide R&D subsidies to randomly chosen companies; « *Federal contracts do not descend upon firms like manna from heaven* » [Lichtenberg, 1984, p. 74]. Public authorities may be more inclined to support firms which do R&D and which already have good innovative ideas. In other words, a positive and significant relationship between private R&D and government-funded R&D, cannot be taken as a piece of evidence of the efficiency of government support. The same argument holds, although to a lesser extent, for cross-industry studies since R&D subsidies are directed mainly towards R&D intensive industries. At the macro level, the exogeneity assumption is much more acceptable.

18. For each of the policy tools there are specific measurement issues. Public research is broken down into two major components, namely government research and university research. For government funding of business R&D, it is composed of procurement and grants or subsidies, the latter being of special interest here. However, even if the explicit goal of procurement is not to trigger a rise in business funded R&D, such an effect is often called upon for justifying government spending ("leverage effect"). Due to data availability constraints, these two components of direct government funding of business R&D are

[1] An attempt to measure the simultaneous effect of direct government funding to business R&D and tax relieves on privately-funded and performed R&D is presented in Guellec and van Pottelsberghe (1999). The present document improves on these results by taking into account the other types of public R&D and by performing new specifications.

mixed in one aggregated variable. If government-funded R&D performed by business firms primarily consists of procurement and regular grants, it should be noticed that there are other forms of support, such as loan guarantees, conditional loans, and convertible loans. However, as shown by Young (1998), government procurements and grants, and fiscal incentives, account for the bulk of government support to business R&D.

19. Fiscal incentives may take various forms, which make international comparisons problematic. The so-called 'B-index', as defined 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 to pay the corporate income tax, so that 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]

20. We rely on a simple R&D investment model that considers business-funded R&D as a function of output, four 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 might be required. The model allows for a dynamic mechanism by introducing the lagged dependent variable. It is worth noticing that a dynamic specification for an R&D investment equation is not a common procedure in the existing literature on the stimulating effect of R&D subsidies.[4] On *a priori* grounds, however, the inclusion of 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 (desired) R&D levels can be maintained. It does not want to begin projects that will soon have to be interrupted. »*. Therefore the behaviour of private investors can be best described in terms of a dynamic mechanism that allows for a long term adjustment path. The model is written as follows:

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

21. This equation is a first-difference autoregressive 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 appendix 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*

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[2] The B-index is similar to the marginal effective tax rate (METR) computed for 8 OECD countries by Bloom *et al*. (1997). 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, whereas 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 out of the eighteen studies surveyed in Table A2 adopt a partial adjustment mechanism for the R&D investment equation.

(= 1, ..., 14). Δ is the first (logarithmic) difference operator. τ characterises time dummies.[5] In this model, the short and long-term effects of the exogenous variables are [β] and [$\beta/(1-\lambda)$], respectively.

22. The data on value added is derived from OECD (1999a). Privately-funded R&D, direct R&D subsidies to business firms, and R&D outlays by public labs and universities are taken from OECD (1999b). All the variables but the B-index are expressed in constant US PPP$ and deflated with the business sector's GDP price index (base year 1990). The B-index has been computed by the OECD secretariat from national sources (see table A1 in the appendix).

23. OECD countries performed about 500 billion US PPP dollars of R&D outlays in 1998. The lion' share of these activities (70%) was performed by business firms, followed by higher education institutions (i.e. universities : 17%) and government intramural research (or public labs : 11%). Government is by far the major source of funding for the two latter types of institutions; whereas only 10 per cent of the R&D performed by private firms was financed by government. Over the past 20 years this distribution of R&D outlays by sources of fund and institutions of performance has substantially changed, witnessing a gradual reduction of the government share, both in financing and performance. In the early 1980s as compared with the late 1990s, the share of government in the funding of business R&D expenditure (23%) was more than twice as large, and research performed in public labs accounted for 17 per cent of total R&D activities.

24. Beside these OECD-wide average, important differences occur between countries. Public labs in the US and Japan account for about 8 per cent of domestic research activities, against 15 per cent in the European Union. [6] A similar difference appears across the Triad with respect to the share of research performed by universities: it is 21 per cent in the European Union, against 14% in the United States and Japan. Smaller countries seem to rely much more on that type of research than larger ones (more than 25% in Australia, Norway, Spain, Belgium, and the Netherlands). Given that the business in Japan and the United States performs more than 73% of total research activities (about 63% in the European Union), it is clear that the funding structure differs significantly. In the United States and the European Union the share of business performed R&D that is financed by government is 15 and 10 per cent respectively. In Japan it is about 1 per cent.

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[5] Country dummies, which would control for the fixed effects included in the '*level*' variables, are not included due to the first difference calculation. 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 shocks common to all countries, that are not controlled for by the exogenous variables, such as the increasing use of information technology.

[6] Smaller countries in the European Union, like Belgium and Sweden (4%) tend to have a lower share of public research than larger ones, especially France and Italy (more than 20%).

3. RESULTS

25. Before estimating the dynamic model (1) and its various extensions, we investigate with a simpler, non dynamic, framework the influence of the policy instruments on business R&D, with the purpose to capture basic relationships and their time pattern. Results reported in table 1, show that the main effect of value added on private R&D investment is 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.

26. Government-funded R&D has a positive and significant effect only with one and two-years lags. Fiscal incentives have a (small) contemporaneous and a (larger) one year lagged positive impact (remember that a lower B-index reflects higher tax breaks). Why these different time patterns? Tax concessions may induce firms to enhance or to accelerate their current projects, while direct subsidies are generally focused on projects selected by government. Such new projects may create new opportunities that induce firms, later, to start further research projects with their own money. This result is in line with Mansfield and Switzer (1984), who notice that performing companies have learned to form realistic expectations about future government support. As a result, they develop R&D proposals for the government in a way that takes account of their own R&D planning.

27. Government and university research both have a negative impact on business funded R&D. Moreover, this negative impact is spread over several years (although there is no contemporaneous impact), especially for government research. The crowding out effect (due either to an induced increase in the cost of R&D or to direct displacement) dominates the stimulating effect. As a matter of fact, public labs are supposed to work mainly for the government, not for business, and spillovers may occur but are not the primary goal. The negative impact of university research shows the difficulty of transferring basic knowledge to firms.[7]

[7] It should be kept in mind however that a four year lag might be too short to capture the longer term effect of basic research. The effect of basic research can take several decades before reaching the application stage (Adams 1990).

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	1.201*** *(23.32)*	-0.009 *(-1.25)*	-0.163*** *(-3.01)*	0.014 *(0.80)*	-0.002 *(-0.15)*
T-1	-0.032 *(-0.52)*	0.085*** *(11.66)*	-0.343*** *(-10.92)*	-0.072*** *(-3.99)*	-0.070*** *(-5.14)*
T-2	0.210*** *(3.36)*	0.090*** *(13.02)*	-0.007 *(-0.21)*	-0.002 *(-0.09)*	-0.031** *(-2.30)*
T-3	-0.057 *(-0.88)*	-0.018** *(-2.33)*	0.007 *(0.23)*	-0.084*** *(-4.44)*	0.033* *(1.89)*
T-4	0.170*** *(3.14)*	0.013 *(1.59)*	0.039 *(1.19)*	-0.043** *(-2.03)*	0.013 *(0.71)*
Sum	1.581	0.157	-0.506	-0.199	-0.134

Note: The estimates cover 17 countries for the 1983-1996 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 per cent probability threshold; ** at 5 per cent; and * at 10 per cent.

28. Table 2 presents the panel data estimates of equation (1), correcting for the potential contemporaneous correlation of the error term across countries with the SURE method. The Breush-Pagan test indicates that the error term of the OLS estimates is subject to significant contemporaneous correlation between countries.[8] The estimates presented in column 1 show that the short-term (long-term) private R&D elasticities are 1.01 (1.51) for value added, 0.07 (0.10) for government R&D, -0.24 (-0.36) for tax incentives, -0.09 (-0.14) for government research and -0.05 (-0.07) for university research.[9]

[8] This test has to be interpreted cautiously. 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 characterized by a cultural and geographical proximity, or size similarity.

[9] 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 table A1) : 1.58 for value added, 0.16 for government R&D, –0.51 for fiscal incentives, -0.20 for government intramural expenditure, and 0.13 for university research.

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***
ΔRP_{t-1}	0.335***	0.338***	0.323***	0.322***	0.333***	0.346***
	(9.78)	*(9.62)*	*(9.79)*	*(9.44)*	*(9.87)*	*(9.71)*
ΔVA_t	1.007***	1.037***	0.980***	1.036***	0.983***	1.035***
	(16.70)	*(16.56)*	*(17.59)*	*(16.58)*	*(16.88)*	*(15.22)*
ΔRG_{t-1}	0.066***			0.087***	0.046***	0.074***
	(10.21)			*(9.37)*	*(5.81)*	*(8.84)*
ΔB_{t-1}	-0.241***	-0.241***	-0.242***	-0.736***	-0.158***	-0.250***
	(-5.42)	*(-5.75)*	*(-5.12)*	*(-3.76)*	*(-4.26)*	*(-5.94)*
$\Delta GOVRD_{t-1}$	-0.095***	-0.097***	-0.099***	-0.100***	-0.119***	-0.043
	(-5.75)	*(-5.94)*	*(-6.08)*	*(-6.35)*	*(-7.11)*	*(-1.46)*
$\Delta HERD_{t-1}$	-0.047***	-0.049***	-0.058***	-0.045***	-0.073***	-0.048***
	(-3.63)	*(-3.64)*	*(-4.43)*	*(-3.47)*	*(-5.74)*	*(-3.24)*
ΔRG_{t-1} * *DGT-high*		-0.036*				
		(-1.75)				
ΔRG_{t-1} * *DGT-medium high*		0.055***				
		(2.61)				
ΔRG_{t-1} * *DGT-medium low*		0.076***				
		(9.66)				
ΔRG_{t-1} * *DGT-low*		-0.006				
		(-0.22)				
$\Delta RG_{t-1} * (GT_{t-1})$			1.343***			
			(8.32)			
$\Delta RG_{t-1} * (GT_{t-1})^2$			-4.738***			
			(-5.08)			
ΔRG_{t-1} * *GT-instability*				-11.441***		
				(-3.22)		
ΔB_{t-1} * *B-instability*				3.005***		
				(2.80)		
$\Delta RG_{t-1} * \Delta B_{t-1}$					1.115***	
					(6.26)	
$\Delta RG_{t-1} * \Delta GOVRD_{t-1}$					-0.189**	
					(2.35)	
$\Delta RG_{t-1} * \Delta HERD_{t-1}$					0.419***	
					(4.90)	
$\Delta RG_{t-1} * DEFshare_{t-1}$						-.002***
						(-3.77)
$\Delta GOVRD_{t-1} * DEFshare_{t-1}$						-0.003**
						(-2.46)
Adj-R2	0.424	0.420	0.423	0.421	0.434	0.416
Durbin-Watson	2.07	2.09	2.08	2.04	1.95	2.09

Note: See table 1. The estimates cover 17 countries for the 1981-1996 period (216 observations). *DGT-high* = a dummy variable equal to one for the countries whose average subsidisation rate is over 19 per cent and 0 otherwise, *DGT-medium high* [11 per cent - 19 per cent[, *DGT-medium low* [4 per cent - 11 per cent[, *DGT-low* [0 per cent - 4 per cent[. *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 SURE 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 per cent probability threshold; ** at 5 per cent; and * at 10 per cent.

29. How do these elasticities translate in dollar terms? What is the impact of one dollar spent in any of these policies on the amount of R&D spent by firms? Estimates of the marginal effect of these policies, consistent with the estimated elasticities, are reported in table 3. The marginal effect is calculated as the product of the elasticity and the ratio of the impacted variable (business R&D) on the impacting one. If two policy instruments have the same elasticity, the one which represents the biggest amount will have the lowest effect. It turns out that one dollar of government spending generates at the margin a 0.87 dollar increase in business R&D when it is direct funding, a 0.78 dollar reduction when it is spent in government research, a 0.25 dollar reduction when it is spent in university research. As these reductions are less than the initial, one dollar, government expenditure. In other words, total R&D (public + business) will raise after government has increased its spending: the crowding out effect of these last two instruments is only partial.

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

	Business performed R&D	R&D performed by public institutions	
	Government funded	**Government intramural**	**Higher education**
***X* =>**	**(*RG*)**	**(*GOV*)**	**(*HE*)**
Long term elasticities (β)	0.10	-0.14	-0.07
(*RP/X*)	8.71	5.54	3.59
Marginal effect on *RP* (ρ)	0.87	-0.78	-0.25
Marginal effect on total R&D	1.87	0.22	0.75

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 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.

30. In column 2 of table 2, the private R&D elasticity of government R&D is allowed to vary across four groups of countries. The countries are grouped according to their average subsidisation rates: over 19 per cent for the highly funded, from 11 to 19 per cent for the medium-high funded, 4 to 11 per cent for the medium-low funded, and under 4 per cent for the low funded. The largest elasticities, are obtained for the countries belonging to the two 'medium' groups. The countries with the highest funding rates are characterised by a negative private R&D elasticity of government funded R&D. The countries that provide the lowest level of funding exhibit a non-significant elasticity. These figures suggest that the effectiveness of government funding increases up to a particular threshold and then decreases. Other estimates, with a finer breakdown of countries, also emphasised much weaker elasticities for the countries with the highest or the lowest levels of funding.

31. In order to test directly for this inverted U-curve that seems to characterise the relationship between government and privately financed R&D, the estimated private R&D elasticity of government funding is combined with the subsidisation rate within a quadratic specification :

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

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

32. 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 private R&D elasticity with respect to government support increases with the subsidisation rate up to a threshold of 14 per cent, then decreases with the subsidisation rate, and becomes negative after a threshold of 28 per cent.

33. It could be argued that the variation across countries of the private R&D elasticity with respect to government R&D simply reflects a constant marginal effect of (or rate of return to) R&D funding across countries. Indeed, a constant elasticity implies that the additional dollar stimulus to private R&D for each additional dollar spent - i.e. the marginal effect of R&D funding - decreases with the rate of subsidisation. Hence, an elasticity varying across countries could translate into constant marginal effects. [10] The product of the estimated elasticities (columns 1 and 2 in Table 2) and the ratio of private R&D to government R&D shows that one dollar of R&D subsidies induces an average increase of 45 cents in business funded R&D investment. It varies across countries from a negative marginal effect of 16 cents amongst the highly

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

subsidised countries, to a positive 39 cents and 58 cents for 'medium-high' and 'medium-low' subsidised countries, respectively, to no significant effect for the lowly subsidised countries.[11]

34. The effect of the time stability of the policy tools on their effectiveness is investigated by combining the direct subsidies and the B-index with proxies for their respective stability.[12] 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 1983-1996. For both policy tools, the estimates presented in column 4 of Table 2 show that the more volatile a policy is, the less effective. R&D investment involves a long-term commitment and translates into sunk costs. Such investment is therefore likely to be sensitive to uncertainty, including uncertainty arising from fiscal or government funding. Past instability is taken by firms as a signal of likely future change. These results confirm Hall's (1992) result that the impact of R&D tax incentives on US firms grew over time, after it appeared that the scheme was to be maintained in the future. Similar evidence concerning R&D subsidies is reported in Capron and van Pottelsberghe's (1997) at the industry level. They find for the G7 countries that those industries that benefit from stable subsidisation rates are most likely to be stimulated by government-funded R&D.

35. The interaction between the various policy tools is also important. The question is whether they are complementary, or substitutes in stimulating business-funded R&D - i.e. are they mutually reinforcing or do they partly cancel out each other ? The results (reported in column 5 table 2) shows that government funding of business R&D is substitute to fiscal incentives and to government research, but that it is complementary to university research. In other words, increasing the direct funding (tax relieves) of business research, reduces the stimulating effect of tax relieves (direct government funding). When government funding of business research is high, the negative effect of government intramural research on private R&D is magnified, but the negative effect of university research is reduced. It is as if government funding were helping firms to digest knowledge (otherwise poorly used) coming from university. In a way, this results shows the potential usefulness of university research to the economy, as soon as complementary instruments are used to help its transfer to firms. The strong interaction between the various policy tools underlines the necessity of an integrated approach to R&D policy: a loss of effectiveness is to be expected when the instruments are used separately.

36. We now investigate whether defence-oriented R&D funding has a special effect on business-funded R&D. The usual argument of technology spillovers does not fit very well to defence R&D. Military technology is quite specific, with less emphasis on cost constraint but requirement of robustness in the extreme conditions of a battle field. There are also severe secrecy constraints attached to defence R&D that make its outcome difficult to apply to largely diffused civilian products. In addition, the results of R&D procurement may not necessarily be used by the R&D performer, which implies that firms do not provide their own financial contributions to such R&D, leading to no leveraging effect. But, because defence contracting is attractive (high reward, low risk) firms might allocate there their own resources (researchers, equipment), that otherwise would have been used to civilian purposes. Hence, even if defence R&D had a positive impact on business funded R&D, the effect may be expected to be lower than the effect of a same amount of funding that would flow into projects with a civilian purpose.

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

[11] The econometric results, unreported here, are available on request. The marginal effects were estimated 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.

[12] There is less case for an effect of the stability of government or university research affecting their impact on business funded R&D.

10%. In order to estimate the specific impact of defence funding, we allow the elasticities of private R&D (*RP*) with respect to both direct government funding of business R&D (*RG*) and government intramural R&D (*GOV*) to have a fixed component and a component that varies with the share of defence in total government R&D budget appropriation (as in equation (2)).[13] Column 6 in table 2 shows that the two 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. The effect of government research, which was negative in the estimates above, jumps to zero when it is cleaned of its 'defence' component. In other words, it seems that non-defence government intramural research, which is overwhelming in most OECD countries, has no negative effect on business R&D.[14]

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[13] In other words, we assume that β_{RG} 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 reflect the component that varies with respect to the share of defence-related R&D in total government budget appropriation on R&D.

[14] Guellec and van Pottelsberghe (1999) relied on a different approach to get 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 the 17 OECD countries, which is the share of defence in total government budget outlays on R&D (including procurement and intramural research).

4. POLICY IMPLICATIONS

38. Among the major instruments of government policy, both fiscal incentives and direct funding stimulate business funded R&D, whereas government and university performed research seem to have a crowding out effect. In short, apparently when the purpose is to increase business funded R&D, it is better to give money than knowledge to busines However, it must be reminded that publicly produced knowledge may result in technology that is used by business while not inducing it to increase its research expenditure. Moreover, it is not the major purpose of government laboratories to produce knowledge for the business sector. When the defence component is isolated from the civilian one, only the former has a negative impact on business, the latter being neutral. For university research, barriers to the transfer of knowledge to business can be mitigated by government (targeted) funding of business R&D. And, whereas the crowding out effect is immediate (contemporaneous with the research spending), spillovers may take time before reaching the industry, beyond the horizon of our estimates. Various features affect the effectiveness of these policies. First, countries that provide a level of direct funding to business firms 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 a subsidisation rate of about 14 per cent, and decreasing beyond. Over a level of 28 per cent, additional public money is likely to be substituted for private R&D. Second, stable policies are more effective than 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 relieves are substitutes, the increased use of one of them reduces the effectiveness of the other.

39. An analysis carried out at an 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 facing firms. Second, the various policy instruments should be consistent with each other, which implies that the various administrative departments involved in their design and management be co-ordinated. Third, if government is willing to stimulate business R&D, providing too low or too high a level of funding is not effective. Fourth, although defence-related R&D funding does not aim at stimulating private R&D expenditure, its crowding-out effect on business, civilian R&D has to be taken into account. Fifth, the research performed in universities presents a potential usefulness for business that can be improved through targeted government funding enhancing the transfer of technology.

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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 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 - DB - Declining balance: $A_d = \frac{\delta}{\delta + r}$, 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 years 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. The assumptions (i) and (ii) 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 years case (iv), the term between brackets is equal to .171; in the two-years case it is .132; and in the 1 year case it is .091. For example, the United States has an incremental tax credit of 20 per cent 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 4 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 per cent. The base amount is therefore varying 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 per cent 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 when there is one. Therefore, the flexibility of the policies according to refunding, carryback and carryforward of unused tax credit, and flowthrough mechanisms are not taken into account by the B-index. Practically, the B-index of a country that would apply 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 Allowances	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].

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 subsidized 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 kind of industries, except materials.	-.53*
Carmichael (1981) USA - 1977 - C.S. of 46 transport firms	Includes output. OLS. The estimated parameter is nil for the big 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 (1972-1977); OLS.	-.22*
Scott (1984) ε USA - 1974 - C.S. of 3387 lines of business	Includes output and firm dummie; 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 output, employment, industry and foreign firms dummies, 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 the shared efforts (e.g. in conferences), inter-laboratory agreements, and a 2-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, Labor, fixed capital, utilization rate, and the ratio of wage to user cost of capital; OLS. Negative impact for 5 Durables industries.	.01*
Levin and Reiss (1984) [4] 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, labor, physical capital, the relative price of materials, a time trend, and industry dummies; MML.	.54*
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. Generalized least squares.	.21*
Levy (1990) [3] 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 4 countries (including the United States and Japan), insignificant for 2, and negative for the UK and the Netherlands.	-.73* to .41*

Source: Adapted and extended from Capron and van Pottelsberghe (1997).

Note: **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 de dependent variable is total R&D instead of privately-financed R&D.

* Significantly different from zero at a 10% probability threshold.