Chapter 10

PUBLIC SUPPORT TO BUSINESS R&D: A SURVEY AND SOME NEW QUANTITATIVE EVIDENCE

by

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Introduction

The objective of this paper is to provide, with reference to the integrated assessment scheme suggested by Capron and van Pottelsberghe (1997*a*), some policy implications that might arise from a quantitative evaluation of the effectiveness of R&D subsidies in seven major industrialised countries. Ultimately, we would like to see whether econometric estimates would allow innovation policies to become, tomorrow, "a little bit less a matter of faith and a little bit more a matter of understanding", thus challenging the famous statement of Rothwell and Zegveld (1988).

Our empirical framework covers two categories of studies. First, we test whether R&D subsidies have a direct impact on productivity growth. Second, we evaluate the stimulation effect of these subsidies on private R&D investment. The evaluation procedure is implemented both at the aggregate manufacturing level and for 22 disaggregated manufacturing industries.

The paper is structured as follows. The existing quantitative literature on the effectiveness of R&D subsidies is surveyed in the next section. The third section concentrates on the evaluation of the impact of R&D subsidies on productivity and on the private decision to invest in R&D. The conclusions and some suggestions related to the design of public investment policies are presented in the final section.

Impact assessment of R&D subsidies: A review of the literature

Empirical studies on the effects of R&D subsidies fall into two main categories. The first estimates the direct impact of R&D subsidies on output growth. The ubiquitous and fairly pessimistic finding which emerges from the literature is that privately funded R&D contributes significantly to output growth, whereas publicly financed R&D has little or no direct effect. The second category of studies argues that the role of R&D subsidies in the production process is indirect, via the stimulation of private R&D investment. However, the empirical evidence from this second category of studies is far from unambiguous, depending on the countries and/or the manufacturing industries analysed.

This stresses the need for further empirical tests and analyses concerning the interrelationship between R&D subsidies, the private decision to invest in R&D, and productivity growth; especially in countries other than the United States, which has so far been the centre of interest.

Consider the following production function and disaggregate the total R&D (*RT*) input into its two main components (or sources of funds), private R&D (*RP*) and government R&D (*RG*):

$$Q = A \exp(\lambda t)\, SRP^{\alpha_1}\; SRG^{\alpha_2} \prod_k X_k^{\beta_k} \tag{1}$$

Q denotes real output; *SRP* and *SRG* represent the stock of private R&D, and the stock of government R&D, respectively. *X* characterises the *k* traditional inputs: labour, fixed capital stock, intermediate inputs and energy. Should we expect to find a difference between the direct effects of publicly- and privately financed R&D? *A priori*, and within a firm, the answer is negative because "a dollar is a dollar, irrespective of source" (Griliches, 1979, p. 110). However, at the aggregate level, one may expect some differences in the estimated rates of return to private and government R&D because strong government support to R&D in a given industry may favour externalities and limit appropriability opportunities for the companies in that industry. This may explain why most studies which attempt to estimate a direct effect of R&D subsidies have been carried out at the aggregate industry level.

Van Pottelsberghe (1997) surveys the empirical literature which differentiates the impact of private R&D from the impact of R&D subsidies on output growth. While there is a *lack* of empirical evidence for many countries, the conclusions drawn from the few US applications remain fairly pessimistic. The three main findings that emerge from the literature overview are that: *i)* private R&D has a substantial and significant direct effect on productivity growth which is greater than the impact of total R&D; *ii)* public R&D appears to have a much weaker, if not insignificant, direct effect; and *iii)* the rate of return to total R&D or to private R&D is lower in those industries which are relatively highly subsidised.

One hypothesis which could account for the apparent poor direct performance of R&D subsidies is that their impact on productivity growth tends to be indirect, via the stimulation of the private decision to invest in R&D. According to Levy (1990), a firm could consider government R&D as a public good which can be employed at no private cost. Levy argues that if government R&D can be employed by the private sector at zero cost, then, in equilibrium, its marginal product must be equal to zero. Therefore the non-significant impact of *RG* on output growth cannot be taken as a validation for the (in)efficiency of R&D subsidies. Using the production function approach, it would not be possible to compare levels of production with and without publicly financed R&D.

Consequently, the question that arises is to understand the influence of R&D subsidies on the marginal physical product of private R&D. It can be assumed that the amount of private R&D investment is an upward sloping function of its own marginal physical product. Hence, since the marginal physical product of private R&D is likely to increase with R&D subsidies, an increase in the latter should foster private R&D expenditures. Suppose that a firm's private R&D investments respond to the level of R&D subsidies according to the following formula:

$$RP = \gamma_1 + \gamma_2\; RG\ , \tag{2}$$

and, for simplicity, the form of the total factor productivity growth equation is:

$$\dot{TFP} = \alpha_0 + \alpha_1 \frac{RP}{Q} + \alpha_2 \frac{RG}{Q} \quad . \tag{3}$$

Then, the total derivative of $\dot{TFP}$ with respect to *(RG/Q)* is:

$$\frac{\partial \dot{TFP}}{\partial (RG/Q)} = \alpha_2 + \alpha_1 \gamma_2 \tag{4}$$

which is a function of the return to R&D subsidies (α_2) and of the product of the return to private R&D (α_1) by the reaction of private R&D to government support (γ_2). Therefore, the impact of publicly funded R&D on productivity growth will be positive if $\gamma_2 > -\alpha_2 / \alpha_1$. The empirical evidence described above shows that α_2 / α_1 is very small and most probably insignificantly different from zero. Despite their negligible rate of return, R&D subsidies may contribute to foster productivity growth if, and only if, they stimulate private investment in research activities. On the other hand, if R&D subsidies have a relatively weak direct impact on output and if they deter – or are a substitute for – private R&D expenditures, then a rise in government support will slow down productivity growth.

Are publicly funded R&D and privately funded R&D *substitutes* or *complements*? In the case of complementarity, one would assume an indirect path of stimulus to productivity of R&D subsidies, via an inducement to perform private R&D. Most of the studies which implicitly test the complementarity assumption between the two main sources of funds for research activities are presented in Table 1. Only a small fraction is this analysis based on manufacturing sector or macroeconomic data. Of the 13 studies at the micro level, eight support the complementarity assumption, four reject it,[1] and one is inconclusive.

Concerning the three US meso-economic studies, the results are also mitigated. Nadiri (1980) and Levin and Reiss (1984) estimate that private R&D and government support are complementary. Lichtenberg (1984) fails to obtain any significant relationship. The three macroeconomic estimates support the stimulation hypothesis for the United States. However, Levy (1990)'s contribution shows that in Japan, Germany, Sweden and France there is complementarity between government R&D and private R&D, while a substitution relationship appears for the United Kingdom and the Netherlands, and the results are inconclusive for Italy and Switzerland.

These studies are mostly related to the US economy and the divergences between them are to a large extent due to different time periods, data sources or regression characteristics. Most of the samples used in the micro-level regression studies are highly non-random, inducing the potential presence of a sample selection bias. Further, the fourth to seventh columns of Table 1 clearly indicate that the empirical models differ markedly across studies. In addition, there are divergences among studies with respect to their way of controlling for firm and/or industry fixed effects. Therefore, one could ask whether or not this divergence among the econometric results is a consequence of the diversity of empirical models.[2] In this respect, five issues deserve to be discussed.

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

Author(s)	Country – years – structure[1]	Sample	RP_{t-1}	Q_t	*C4*	*other*	β
Firm level							
Rosenberg (1976)	US – 1963 – C.S.	100 firms		+	+	+	2.35*
Shrieves (1978) ε	US – 1965 – C.S.	411 firms		+	+	+	
		manufacturing					-.53*
		non-spec. durables					-.89*
		materials					1.26*
		spec. durab. equip.					-1.02*
		consumer goods					-.78
Carmichael (1981)	US – 1976-77 – C.S.	46 transport firms		+			-.08*
		big firms					-.07
		small firms					-.06*
Link (1982)	US – 1977 – C.S.	275 firms		+	+	+	.09*
Lichtenberg (1984)	US – 1972 – C.S.	991 firms – level					.10*
	US – 1977 – C.S.	level					-.22*
	US – 1972-77 – C.S.	growth rates					-.17*
	US – 1967-77 – C.S.	growth rates					-.26*
Scott (1984) ε	US – 1974 – C.S.	3387 lines of business		+		+	.08*
Switzer (1984)	US – 1977 – C.S.	125 firms	+	+	+	+	.08
Lichtenberg (1987)	US – 1979-84 – TSCS	187 firms		+			.13*
						Q_g	-.00
Holemans and Sleuwagen (1988) ε	Belgium – 1980-84 – TSCS	59 firms		+	+	+	.30*
Antonelli (1989) ε	Italy – 1983 – C.S.	86 firms		+		+	.37*
Leyden and Link (1992)	US – 1987 – C.S.	137 laboratories				+	1.99*
Crott (1995) ε	Belgium – 1984-87 – TSCS	30 firms		+		+	.50*
Fölster and Trofimov (1996)[3]	Sweden – 1982-90 – TSCS	249 groups	+	+		+	.20*
Industry level							
Nadiri (1980) ε	US – 1969-75 – TSCS	10 industries	+	+		+	.01*
		5 durables					-.04*
		5 non durables					.02*
Levin and Reiss (1984)[4]	US – 1967, 72, 77 – C.S.	20 industries			+	+	.12*
Lichtenberg (1984)	US – 1963-79 – TSCS	12 ind. (growth rate)					.01
Mamuneas and Nadiri (1996)	US – 1956-88 – TSCS	15 industries		+		+	.54*
Country level							
Lichtenberg (1987)	US – 1956-83 – T.S.	Macro		+			.33*
						Q_g	.11
Levy and Terleckyj (1983)	US – 1949-81 – T.S.	Private business		+		+	.21*
Levy (1990)[2]	9 countries– 1963-84 – TSCS	US		+			.30*
		UK					-.73*
		Italy					.05
		Japan					.16*
		Germany					.23*
		Sweden					.41*
		Netherlands					-.13*
		France					.33*
		Switzerland					.02

1. T.S. = time series; C.S. = cross section; TSCS = panel data. *RP* = private R&D expenditures; *Q* = total sales; *C4* = industry concentration ratio, *Qg* = sales to government; *Other* = time dummies or industry dummies, proxy of company diversification, technological opportunity dummies, and appropriability conditions. 2. The estimates reported for Levy (1990) are taken from Capron (1992*a*). 3. The estimates by Fölster and Trofimov (1996) have to be interpreted as a negative relationship between government and private R&D (*cf.* endnote 1). * Significantly different from zero at a 10% probability threshold.
Source: Van Pottelsberghe (1997).

First, a large number of studies estimate an average effect of government R&D (*RG*) on private R&D (*RP*), restricting the parameter to be invariant across manufacturing industries or firms. There is, however, little evidence to show that the relationship between government and private R&D may be different from one industry to another, regardless of the characteristics of empirical models. Nadiri (1980a) and Shrieves (1978) provide evidence that the estimated private R&D elasticity of government R&D is positive for the non-durables industries and materials industries, while it is negative and significant for durables industries.

The second issue is related to the dynamic perspective of the models to be estimated. Only three of the 19 studies presented in Table 1 adopt a partial adjustment mechanism for R&D investment. On *a priori* grounds, the inclusion of lagged R&D may be seen as an important determinant of current R&D investment. Mansfield (1964, p. 32) notes 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." We therefore strongly believe that the behaviour of private investors can be best described in terms of a dynamic mechanism. It is worth noting that Fölster and Trofimov (1996) at the micro level, and Nadiri (1980) for durable industries, who rely on a dynamic empirical specification, are among the few studies which estimate a negative effect of government R&D on private R&D investment. It would therefore seem essential to test whether an adjustment process is at work and whether it affects the amplitude and/or the sign of the estimated impact of R&D subsidies on private R&D.

The third issue concerns the influence of technological competition on the behaviour of R&D investors. Fölster and Trofimov (1996) is the only study which attempts to comprehend the role of R&D rivalry. Their main finding is that the total R&D efforts of several competing firms in Sweden tend to decline when they receive subsidies. If only one firm benefits from subsidies, its own R&D activities increase but total R&D by all competing firms is likely to decline. Thus, it is not surprising to find a crowding-out effect at the sectoral level, even if the firms which benefit from subsidies increase their private R&D investment. The potential presence of such a negative impact of government R&D on private R&D at the aggregate (sectoral) level emphasizes the need for empirical studies at the industry level.

The fourth issue is related to the implicit assumption that the level of government support is viewed as an exogenous determinant in the company R&D expenditures models. The relevance of this assumption is rather questionable because public authorities do certainly not give R&D subsidies to randomly chosen companies. Quoting Lichtenberg (1984), "Federal contracts do not descend upon firms like manna from heaven" (p. 74). Public authorities may be more inclined to support firms which carry out R&D and which already have good innovative ideas. The fact that private R&D intentions are perhaps among the main determinants of R&D subsidies may explain the presence of a statistical interrelationship between private R&D and R&D subsidies irrespective of the effectiveness of subsidies. This is why Kauko (1996) argues that, at the firm level, the assumption of exogeneity of R&D subsidies is almost certainly unacceptable. Therefore, econometric estimates of the impact of publicly financed R&D on companies' private R&D investments are likely to be subject to substantial simultaneity bias. The same argument could hold, but to a much lesser extent, for cross-industry studies if R&D subsidies were directed mainly towards R&D-intensive industries. At the macro level, the exogeneity assumption is much more acceptable.

The final issue is that introduced by Lichtenberg (1987), who provides empirical evidence, using both macro and micro US data, that most of the models which estimate regressions of private R&D expenditures on federal R&D funding and other variables overstate the federal R&D coefficient. This mis-specification could be a direct result of the failure to distinguish government sales from other sales. The econometric analysis supports the view that "a large part of what had been interpreted as the effect of federal R&D funding on privately funded R&D expenditure is in fact attributable to variation in the government's share of output" (p. 103). However, these results should be treated with caution since they mean that government purchases and government R&D are correlated. Hence, both variables could reflect the degree of government interventionism, again raising the question of whether or not such interventionism has a stimulating impact on private R&D.

Despite the heterogeneity of the empirical models referred to in the literature, which makes any comparison exercise hazardous, the balance seems to tilt towards the recognition of a complementary effect between the two sources of funds. However, there are some indications that in some industries, or in some countries, government R&D is a substitute for private R&D. Furthermore, it would seem that the empirical specification may also influence the sign of the parameter of interest. A satisfactory answer to this debate is crucial for R&D policy design. In what follows we attempt to better understand the interrelations between government R&D, private R&D and productivity growth. The empirical analyses will concentrate on all the manufacturing industries of seven industrialised countries. Homogenous estimates across these countries will facilitate cross-country comparisons and should therefore provide some clues to whether R&D subsidies contribute directly to output growth and/or stimulate private R&D investment.

We first try to estimate the direct impact of R&D subsidies on productivity growth. If Levy (1990)'s argument that "we cannot answer the question of what would be produced without R&D subsidies with this estimation strategy" (p. 169) were right, we could have skipped this step. However, we have some reservations about the idea that government support can be employed at zero cost. In order to benefit from R&D subsidies, firms have to lobby, to prepare R&D projects, and to compete with other firms. All these activities aimed at attracting government support are associated with substantial costs. These costs are undoubtedly lower than the full private costs for the supported project and may partly explain why some studies estimate positive direct impacts of government R&D on output growth which are much weaker than the impact of privately funded R&D. We will then go on to tackle the question of the potential *indirect* effectiveness of R&D subsidies, via the stimulation of private R&D investment.

Some new evidence in the light of the integrated assessment scheme

The impact of R&D subsidies on the productivity growth of industries

The left-hand side variable in our empirical model is the total factor productivity growth rate. The right-hand side variables are industry dummies ($\alpha_{0,j}$) and time dummies (λ_t) and the ratio of the increment of the total R&D capital stock to value added. The parameter ρ^n in equation (5) is the net excess rate of return to total R&D. Equation (6) is similar to equation (5), with total R&D disaggregated into *SP* and *SG* which stand for the private R&D capital stock and the government R&D capital stock, respectively.

$$\dot{TFP}_{j,t} = \sum_j \alpha_{0,j} + \sum_t \lambda_t + \rho_h^n \left[\frac{\Delta ST_{j,t}}{Q_{j,t}}\right] + \varepsilon_{j,t} \quad (5)$$

$$\dot{TFP}_{j,t} = \sum_j \alpha_{0,j} + \sum_t \lambda_t + \rho_P^n \frac{\Delta SP_{j,t}}{Q_{j,t}} + \rho_G^n \frac{\Delta SG_{j,t}}{Q_{j,t}} + \varepsilon_{j,t} \quad (6)$$

The estimation of these models are based on balanced panels composed of about 22 industries at the 3 or 4 ISIC digit level in seven industrialised countries (the United States, Japan, Canada, France, Germany, Italy and the United Kingdom). All the variables are expressed in constant 1980 US dollars. *Q* is the output indicator proxied by value added and is deflated by sectoral production price indices (1980=100). The total factor productivity growth (*TFPG*) of each industry *i* at time *t* (t = 1980, ..., 1990) is computed as follows:

$$TFPG_{it} \equiv \ln V_{it} - \ln V_{it-1} - \hat{\alpha}_{it} (\ln L_{it} - \ln L_{it-1}) - (1 - \hat{\alpha}_{it}) (\ln K_{it} - \ln K_{it-1}) \quad (7)$$

V, *L*, and *K* are respectively value added, number of employees and fixed capital stock. α is the share of total labour compensation in value added. These variables have been constructed from data drawn from the OECD's STAN database. All the variables (except for the number of employees) are expressed in constant 1980 US dollars. Value added is deflated by country- and industry-specific production prices which are also available from the OECD STAN database. *K* is fixed capital stock generated by the perpetual inventory method. The annual flows of fixed investments are deflated by national gross fixed capital formation deflators (1980=100) as presented in the OECD's National Account Surveys. Industry- and country-specific depreciation rates come from Blades (1991). The average annual growth rate, which precedes the benchmark year, covers the period 1973-78.

We have applied the perpetual inventory method to estimate *ST*, the total R&D capital stock, on the basis of R&D investments, deflated by the Gross Domestic Product Price Index (1980=100) of countries as established by the OECD's National Account Surveys. The R&D investment series come from the OECD's ANBERD database. The majority of empirical studies do not consider any lag and most use a zero per cent depreciation hypothesis or, to a lesser extent, a 10 to 20 per cent depreciation rate common across industries, despite the fact that industries can be expected to face different R&D depreciation rates. Consequently, we have assumed that different depreciation rates prevail in each sector. Further, industry-specific lags between R&D activities and the productivity growth they cause are taken into account. To do that, we have used the industry-specific lags and depreciation rates that have been published for the Japanese industries in 1985 by the Japan Science and Technology Agency. The same methodology has been used in order to compute the government R&D capital stock (*SG*) and the private R&D capital stock (*SP*) from the series of government R&D investment and private R&D investment respectively.[3]

The impact of total R&D and the differentiated impacts of privately funded and publicly funded R&D on the growth of total factor productivity are displayed in Table 2. The net rates of return to total R&D range from non-significant estimates for the United Kingdom, Canada and Italy to 272 per cent for Japan. Columns *(ii)* and *(iii)* show the estimated rates of return to private and government R&D, respectively. Surprisingly, neither net private R&D intensity nor net government R&D intensity significantly contribute to output growth. Given the existing empirical evidence of this type one would have expected the estimated rate of return to private R&D to be higher than, or at least equivalent to, the rate of return to total R&D. The estimates of the impact of private R&D, although generally insignificant, are always higher than the estimates of the impact of government R&D.

These insignificant results are a very wthat of government R&D. When the two variables are included simultaneously into the regression equation, column *(iv)* shows that the private rate of return to R&D is high and significant only in France and Japan, whereas the return to government R&D is non-significantly different from zero. For the other five countries none of the two variables is associated to a significant impact on output growth.

Table 2. Net rates of return to total, private and government R&D (1980-90)[1]

		(i)	*(ii)*	*(iii)*	*(iv)*
US,	Total R&D	.275 *(.150)**			
nobs= 231	Private R&D		.428 *(.286)*		.390 *(.299)*
	Government R&D			.184 *(.216)*	.102 *(.224)*
	Adjusted R^2	.486	.483	.479	.481
Canada,	Total R&D	.214 *(.241)*			
nobs= 198	Private R&D		.068 *(.328)*		.047 *(.335)*
	Government R&D			-.321 *(.357)*	-.334 *(.371)*
	Adjusted R^2	.534	.532	.544	.542
Germany,	Total R&D	1.189 *(.334)**			
nobs= 242	Private R&D		.543 *(.337)**		-.045 *(.348)*
	Government R&D			-.704 *(.446)*	-.694 *(.453)*
	Adjusted R^2	.511	.512	.508	.506
France,	Total R&D	1.322 *(.544)**			
nobs= 220	Private R&D		.278 *(.494)*		1.360 *(.715)*
	Government R&D			-.547 *(.363)*	.210 *(.256)*
	Adjusted R^2	.383	.351	.369	.383
Italy,	Total R&D	.470 *(.322)*			
nobs= 198	Private R&D		-.286 *(.547)*		-.546 *(.587)*
	Government R&D			-.364 *(.304)*	-.391 *(.321)*
	Adjusted R^2	.415	.434	.415	.436
Japan,	Total R&D	2.720 *(.859)**			
nobs= 220	Private R&D		1.314 *(.853)*		2.839 *(.907)*
	Government R&D			.845 *(2.08)*	2.422 *(2.20)*
	Adjusted R^2	.488	.470	.455	.397
UK,	Total R&D	-.110 *(.222)*			
nobs= 231	Private R&D		-.380 *(.282)*		-.291 *(.292)*
	Government R&D			.333 *(.227)*	.272 *(.235)*
	Adjusted R^2	.489	.493	.494	.494

1. Within estimates, including time dummies. The estimated models correspond to equations (5) and (6). For each regression, 4 to 9 outlying observations have been identified through a bounded influence procedure, their potential effect on the estimates is cancelled through an appropriate dummy variable [*cf.* Van Pottelsberghe (1997) for more information on this procedure]. Standard errors between parentheses. * the estimated parameters are significantly different from zero at a 10% probability threshold.

In short, the average estimates do not confirm the main findings which emerge from the existing literature. Indeed, we observe that private R&D does not have a higher impact than total R&D on productivity growth. However, as expected, publiclyfunded R&D does not seem to contribute directly to the growth of output. Why are these results different from those presented in the existing literature? A first explanation might relate to the fact that the estimates presented in Table 2 are, to our knowledge, the first attempt to measure the differentiated impact of the two sources of funds on the basis of a cross-section time series database. The temporal dimension of our data set is a potential source of multicollinearity bias between the government and private R&D variables. The literature at the industry level has exclusively focused on cross-section estimates, and is therefore less subject to these biases.

Second, disaggregating total R&D into its two main sources of funds is probably not an optimal approach when evaluating the relative efficiency of government R&D, because "a dollar is a dollar, irrespective of source". Griliches (1979) suggests that at the industry level one might expect some differences in the rates of return to private and government R&D because of the more acute spillovers generated by government R&D. However, the total knowledge – rather than government knowledge – generated through the total R&D activities of a firm is more likely to spill over and benefit other firms in highly subsidised industries. Indeed, one can hardly imagine that the innovative output of a firm, whatever the subsidisation rate, can be radically split into "private" knowledge and "government" knowledge. The conceivable inefficiency of publicly funded R&D in the production process, although much less accredited by our results than by the existing literature, still raises the question of whether or not such subsidies are necessary. In the following sub-section we test the hypothesis of an indirect positive effect of government R&D on output growth, through the stimulation of private R&D investment.

The impact of R&D subsidies on private R&D investment

In this sub-section we analyse the econometric results obtained by Capron and Van Pottelsberghe (1997*b*). Three of the five empirical issues proposed in the survey summarised in Table 1 have been taken into account in the present study.[4] First, the sign of the impact of government R&D on private R&D may vary across industries. Second, introducing a dynamic feature in the empirical model may substantially modify the sign and the significance of the estimated relationship between government and private R&D. Third, there is most likely a simultaneity bias, across firms or industries, between government and private R&D.

In order to gauge empirically the link between private (*RP*) and government (*RG*) R&D, a traditional approach has been adopted. It consists in estimating the impact of R&D subsidies and other determinants on the private decision to invest in R&D activities. The main difference with the data set used for the production function approach is that there is no need for data on gross capital formation, employment and wages. The available data set covers an 18-year period beginning in 1973 and ending in 1990. This greater degree of freedom allows the estimation of a relationship between government and private R&D for each industry. In addition, the aggregate industrial sector is available. The regression equation has the following form for a given industry or for the aggregate industry sector of the seven countries:

Model 2: $$rp_{i,t} = c_i + \lambda \ rp_{i,t-1} + \gamma_i \ rg_{i,t} + \varphi \ q_{i,t} + \varepsilon_{i,t} \tag{8}$$

where c is a constant term and ε is the error term. The lower case letters *rp*, *q*, and *rg*, are the natural logarithm of private R&D, total sales and R&D subsidies. t indexes the years 1974 to 1990. The parameters λ, φ and γ are, respectively, the adjustment coefficient and the private R&D elasticities with respect to the two corresponding exogenous variables. Total sales seem to be one of the main determinants of private R&D; an increase in output means that more funds may be injected in research activities. In accordance with the second issue, a dynamic specification has been adopted because R&D activities are obviously a continuous process. Therefore, the amount invested in year t should depend, at least partly, on the amount spent the previous year, RP_{t-1}. R&D projects last several years so that the inclusion of RP_{t-1} appears to be a parsimonious way of identifying the feedback effect of past on current spending. This model can be considered as a generalised version of the private R&D models in Table 1. The observations for each industry have been grouped for the seven countries, forming a panel data set composed of 119 observations. All the parameters, except the intercept c and γ, are constrained to be equal across countries.

How restrictive are the cross-country equality constraints on the parameters? In the case of the parameters associated with the lagged dependent variable (λ) and total sales (φ), they would be expected to have similar positive values across countries. However, in accordance with the first issue, the sign of the parameter associated with R&D subsidies is *a priori* not predictable. Concerning the intercepts, we can suspect that there is an international heterogeneity, temporally persistent, generated by country-specific features (such as appropriability conditions and technological opportunity, economic power, culture and the national innovation system) which may act upon the investment decision. As far as these unobserved country differences are stable over time, they are taken into account by the country fixed effects.

In brief, four alternative empirical models have been used to evaluate the private R&D elasticity with respect to R&D subsidies.[5] The first, *Model 1*, is the most often used in the literature; it does not take into account any adjustment process and is generally used to estimate long-term elasticities. The second, *Model 2* [*cf.* equation (8)], includes an adjustment process and implicitly considers that government R&D has both short-term and long-term effects on private R&D. *Model 3* includes an adjustment process unrelated to R&D subsidies. It hypothesises that the impact of government R&D is rather spontaneous and does not have any long-term effects, while the impact of output is allowed to have long-term impacts on private R&D investment. The fourth model assumes that both *RG* and *Q* have exclusively a short-run influence on *RP*.

The four models have been estimated with panel data techniques. We used an instrumental variable procedure that allows for: *i)* the potential autocorrelation of the error term due to the dynamic characteristic of the model; *ii)* the potential presence of cross-sectional heteroscedasticity due to the fact that the disturbance variance might not be constant across the countries that form each panel data set; and *iii)* the potential presence of contemporaneous correlation of the disturbances across countries for a given industry. An alternative specification, which consists in adding time dummies into the regression equations, has the advantage of withdrawing the autocorrelation bias and reducing the cross-country heteroscedasticity and contemporaneous correlation of the error term. However, the presence of time dummies may also reduce the significance of the estimated parameters. This second econometric procedure, which incorporates time dummies, is limited to the two-stage least squares procedure that corrects for heteroscedasticity and contemporaneous correlation.

Capron and Van Pottelsberghe (1997*b*) provide a detailed summary of the econometric results estimated using *Model 3* or *Model 2*. When the parameters do not support the spontaneous hypothesis underlying *Model 3* for a given industry, the estimates obtained with *Model 2* have been preferred. This “combined” summary of the empirical results classifies the estimates according to the countries and to four sub-aggregate groups of industries. The sub-aggregation reflects the quartile distribution of the average R&D intensity[6] of each industry across the seven countries. For instance, among the six high-tech industries in the United States, the estimated effect is positive for four industries, insignificant for one, and negative for one. Two comments may sum up these figures.

First, a classification of the seven countries into three sub-groups emerges. The United Kingdom and Germany are the two countries in which R&D subsidies stimulate private R&D in more than half of the 22 manufacturing industries. In both these countries the effect of R&D subsidies is negative for less than 30 per cent of the industries. Then comes the group constituted by the United States and Japan, in which the impact of government R&D is insignificant for about half of the industries and positive in more than 35 per cent. The last group, composed of Canada, Italy and France, is characterised by a relatively high percentage (27 to 53 per cent) of negative parameters which is larger than the percentage of positive coefficients. In these three countries, very few industries (10 to 26 per cent) show a positive impact of R&D subsidies on private R&D. Second, different reaction patterns also appear across the four sub-groups of industries, independently of the country of origin. In the medium-high- and medium-low-tech industries, R&D subsidies have a stimulating impact in 42 to 53 per cent of the industries, which is above the average of 38 per cent obtained for all industries in all countries. It is worth noting that such a generalisation is subject to variation across countries. On average, however, one may infer that R&D subsidies are more likely to be efficient in stimulating private R&D when they are directed towards medium-tech industries.

Do these estimates at the disaggregate industry level corroborate macroeconomic estimates? Table 3 provides some clues: it presents the computed marginal impact of R&D subsidies on private R&D investment derived from the private R&D elasticities of R&D subsidies estimated at the aggregate manufacturing sector in Capron and Van Pottelsberghe (1997*b*). These values are the average amount invested by private decision makers when they receive a $1 of R&D subsidies.

Since the private R&D elasticities of government R&D are not significantly different from zero for the United States, Germany, and Japan, the marginal impacts of R&D subsidies are also assumed to be equal to zero. The first row shows that $1 of R&D subsidies yields a decrease in private R&D investments of 47 cents in Canada, of 57 cents in France, and of 69 cents in Italy. In the three countries, private R&D investors show a propensity to substitute R&D subsidies for their own investment in R&D. Yet, these crowding-out effects are smaller than $1, which means that R&D subsidies do contribute to raise the amount of total R&D investment. In the United Kingdom, an increase in government R&D of $1 leads to an increase in private R&D investment of about 55 cents, which implies an increase of $1.55 in total R&D investment.

The complementarity between private and government R&D is a particular feature of the United Kingdom, as compared to the six other countries. This particularity might be an indication that an asymmetrical relationship, or a partial complementarity, is at work between private and government R&D. Since the early 1980s, R&D subsidies in the United Kingdom have substantially decreased. Therefore, it could be that when subsidies fall, private R&D investors also decrease their investment levels. This positive relationship disappears, or is much less straightforward, when public support increases. This suggests that further research is needed to better understand the relationship between private and government R&D. Differentiated impacts should be tested according to the increasing or decreasing feature of R&D subsidies.

Table 3. Marginal impact of government R&D on private R&D, at the aggregate industry level[1]

	United States	Canada	Germany	France	Italy	Japan	United Kingdom
Marginal impact (η) at the aggregate industry level	.00	**-.47**	.00	**-.57**	**-.69**	.00	.55
Weighted average of marginal impacts of the 22 industries	.22	**.04**	-.40	**-.59**	**-.27**	1.09	.94
Instability	.035	**.315**	.056	**.216**	**.329**	.186	.047

1. The marginal impacts (η) are computed from the estimated short-run private R&D elasticities with respect to R&D subsidies (γ) in Capron and Van Pottelsberghe (1997*b*), as follows: $\eta = \gamma * (RP / RG)$. *RP / RG* is the ratio of private R&D to government R&D, averaged over the period 1973-90; the instability variable is the standard deviation of the annual growth rate of the R&D subsidisation ratio (*RG / RT*) over the period 1973-90.

The second row shows the weighted average, across all industries, of the marginal impacts of R&D subsidies on private R&D. Because some industries receive far more subsidies than others, the marginal impacts are weighted by the share of each industry's government R&D in total government R&D to all industries. In France, Italy and the United Kingdom, the weighted averages corroborate to some extent the signs of the marginal impacts computed at the aggregate level. In Germany, only six of the 22 industries have a negative reaction towards R&D subsidies. These industries account for much more than half of the total R&D subsidies granted to German industries, which explains why $1 of government R&D yields, on average, a reduction of 40 cents in German private R&D investment. This result does not corroborate the insignificant marginal impact evaluated at the aggregate level. A similar observation holds for the United States and Japan, where the average private R&D reaction towards R&D subsidies is positive, whereas the aggregate industry level estimates do not yield any significant reactions. Furthermore, the Canadian industries seem to have a positive average response to government R&D which, although close to zero, does not confirm the negative impact evaluated at the aggregate level.

It is clear from a comparison of the first two rows of Table 3 that the conclusions may substantially diverge according to the level of data aggregation (aggregate industrial sector *vs.* weighted average of disaggregated industries). A potential explanation would be that there are important interindustry effects. In this case, a large subsidy to a particular industry would either stimulate or inhibit private R&D investment in other industries, and particularly in those which are technologically or economically close to the subsidised industry. The results presented in Table 3 would therefore suggest that there are important interindustry effects of R&D subsidisation, and that these effects are negative in all countries (the weighted estimates at the disaggregated industry level are larger than the estimates at the aggregate industry level), except France and Germany. In France there is no substantial indirect impact of R&D subsidies, whereas in Germany R&D subsidies have a stimulating impact on other industries. Mamuneas and Nadiri's (1996) results validate our interpretation for the United States. Indeed, within a panel data framework of 15 US industries, they find that externally performed publicly financed R&D and privately financed R&D are substitutes.

The last row gives an indication of the stability of the average subsidisation rates over the 1973-90 period. This indicator is relatively weak for the four countries where government R&D either stimulates or does not affect private R&D investment at the aggregate industry level. This means that the more stable a country's subsidisation policy is, the less R&D subsidies are likely to supplant private R&D investments. Would this observation hold across the industries of a particular country?

Table 4 aims to further investigate the factors which may influence the responses of private R&D investment to R&D subsidies. For each country, it presents regression parameters estimated across the 22 industries with the estimated private R&D responses to government R&D as dependent variable (*i.e.* private R&D elasticities with respect to government R&D for each industry). The three explanatory variables are the average R&D subsidisation rate, the average R&D intensity and an indicator of R&D subsidisation instability. The indicator of instability for each industry is the standard deviation of the R&D subsidisation ratio's annual growth rates over the period 1973-90. The regression equation for each country is expressed as follows:

$$\gamma_{0,j} = c + \beta_1\ GT_j + \beta_2\ IR_j + \beta_3\ STAB_j + \varepsilon_j, \qquad j = 1, ..., 22 \qquad (9)$$

where j denotes the industries, GT is the average R&D subsidisation rate ($GT = RG / RT$) of each industry over the period 1973-90, IR is the average R&D intensity ($IR = RT / Q$), and $STAB$ is an indicator of R&D subsidisation (in)stability computed by taking the standard deviation of the annual growth rate of the R&D subsidisation ratio over the period 1973-90. γ_0 is the estimated private R&D elasticity of government R&D and the βs are sensitivity parameters of the response profiles to government R&D with respect to the three explanatory variables.

The R&D subsidisation variable is included in order to determine whether there are decreasing returns associated to government R&D. A negative β_1 would mean that the more subsidised an industry is, the less it is likely to be stimulated by additional R&D subsidies. The R&D intensity variable is used to test whether high-tech industries adopt particular response schemes. Finally, we would expect a negative sign for the parameter associated with the indicator of R&D subsidisation stability. In order to test whether the econometric results are stable across the different specifications retained, the response schemes estimated through the different models were alternatively introduced as left-hand side variables (For the sake of space, only the results obtained with *Model 2* will be presented).

The econometric results, presented in Table 4, show that the determinants of the response profiles to government R&D may vary across countries. For instance, the average R&D subsidisation rate variable is associated with a significant negative coefficient in France, while it is positive in the United Kingdom. The more subsidised a French or Japanese industry is, the more the impact of R&D subsidies on private R&D is likely to be weak or negative (in the case of Japan, the result is dependent on the choice of empirical model). This tends to support the view that R&D subsidies may be exposed to the law of decreasing returns (or effectiveness). For the United Kingdom, the coefficient is positive which means that the more subsidised an industry is, the more R&D subsidies are likely to be efficient in stimulating private R&D. In the other four countries, no inference can be made regarding the link between the response profiles and the subsidisation rate. The R&D intensity variable is associated with a coefficient which is either negative as is the case in the United States and Germany, or insignificant as is the case in the other five countries. Therefore, among US and German industries, the more R&D intensive an industry is, the less it is likely to be stimulated by government R&D.

Table 4. Determinants of the response of private R&D investments to R&D subsidies[1]

	United States	Canada	Germany	France	Italy	Japan	United Kingdom[2]
number of industries	21	18	22	20	18	20	21
Instability	-.364 *	-.392 *	-.373	.027	-.239 *	.000	-.657 *
	(.148)	*(.147)*	*(.421)*	*(.110)*	*(.100)*	*(.046)*	*(.150)*
RG / RT	.473	-.524	.070	-1.464 *	-.833	-.755	.503 *
	(.314)	*(.577)*	*(.497)*	*(.531)*	*(.658)*	*(.531)*	*(.257)*
RT / Q	-.021 *	.002	-.054	.020	.013	-.008	
	(.009)	*(.015)*	*(.022)*	*(.024)*	*(.050)*	*(.007)*	
Adjusted R^2	.304	.274	.201	.637	.188	.190	.382

1. The dependent variables are the estimated private R&D elasticities with respect to R&D subsidies obtained by Capron and Van Pottelsberghe (1997*b*) for each industry, according to *Model 2* estimated with IV-2SLS, an instrumental variable and two-stage least squares procedure. These parameters are obtained through OLS estimates, standard errors are heteroscedastic-consistent. *RG/RT* is the average R&D subsidisation rate, *RT/Q* is the average R&D intensity; the instability parameter is the standard deviation of the annual growth rate of the R&D subsidisation ratio. These explanatory variables are computed over the period 1973-90 for each industry. 2. For the United Kingdom, the R&D intensity has been removed from the regression because of a high correlation with the R&D subsidisation ratio. * the estimated parameter is significantly different from zero at a 10% probability threshold.

Turning now to the instability variable, its influence on the response profiles is more homogenous across countries. The estimated parameters are negative and significant for the United States, Canada, Italy and the United Kingdom, which gives an additional indication that the more unstable an industry's R&D subsidisation rate is, the less R&D subsidies in this industry are likely to be efficient in promoting private R&D investments. In Germany and Japan the parameters are also negative but insignificant, and in France it is insignificantly positive, which does not allow for any policy prescriptions. We may infer that, on average, the more volatile the R&D subsidisation rate, the weaker the efficiency of R&D subsidies. This observation holds with other empirical models and estimation procedures [see Van Pottelsberghe (1997)].

Policy recommendations

The econometric analysis presented in this paper leads to four main conclusions which do not validate the suspicious stance generally taken up in the literature towards R&D subsidies:

◊ We cannot reach the conclusion that the impact of privately funded R&D on productivity growth is significantly higher than the impact of publicly financed R&D. Further, private R&D is not associated with higher, or even equivalent, returns than total R&D. In fact, only total R&D is associated with significant rates of return. In the context of a production function framework, these results suggest that the disaggregation of total R&D into its two main sources of funds might not be an appropriate approach when panel data are used, because *a dollar is a dollar*...

◊ R&D subsidies may stimulate or inhibit private R&D investment depending on the countries and/or the industries considered. In any case, they always contribute to raising total R&D investment.

◊ R&D subsidies are more likely to be efficient in stimulating private R&D when they are directed towards medium-tech industries

◊ The impact of R&D subsidies on private R&D investment evaluated at the aggregate level is lower than the weighted average of the impacts measured for all disaggregated industries, suggesting that important negative interindustry effects are at work: R&D subsidies provided to a particular industry are likely to reduce other industries' incentive to invest in research activities.

◊ The cross-industry and cross-country differences in the private R&D investment response profile to R&D subsidies may be explained, at least partly, by the degree of volatility of the subsidisation policy. The more unstable the subsidisation rate, the less an increase in R&D subsidies is likely to stimulate private R&D investors.

NOTES

1. Some studies define the dependent variable as total R&D investment, without subtracting R&D subsidies. This means that the estimated coefficient associated with government R&D has to be interpreted differently. Assume that *RT=RG + RP*, then the impact of *RG* on *RT* is equal to $((\Delta RP / \Delta RG) + 1)$. Therefore, a positive coefficient that is smaller than 1 would reflect an eviction effect of *RG* on *RP*, as presented by Levin and Reiss (1984) and Fölster and Trofimov (1996) in Table 2.

2. For instance, Lichtenberg (1984) focuses only on government R&D to explain the evolution of private R&D investment across 12 US industries, while Switzer (1987) adds seven other variables.

3. *Cf.* Van Pottelsberghe and Panitch (1997) for a description of the evaluation procedure for missing data.

4. The third issue presented in the second section is related to the first one in the sense that it gives one of the factors which may induce a substitution relationship between *RP* and *RG*: even if one firm is stimulated by R&D subsidies, the other firms in the sector might react negatively and the aggregate industry effect of a subsidy may therefore be negative. The fifth issue is not taken into account in the present analysis because we cannot disaggregate total sales into sales to government and other sales.

5. *Cf.* Capron and Van Pottelsberghe (1997*b*) for a description of the various empirical models and their implications.

6. The High-tech group includes Aircraft, Instruments, Office machines & computers, Electrical machinery, Electronic equipment & components, and Motor vehicles. The medium-high-tech group is composed of Chemicals, Drugs, Rubber & plastics, Machinery, and Other transports. The medium-low-tech group is composed of Petroleum refineries, Stone, clay & glass, Non-ferrous metals, Shipbuilding, and Other manufacturing. The low-tech group includes Food, drink, & tobacco, Textiles and clothing, Wood, and wood products, Paper & printing, Ferrous metals, and Fabricated metal products.

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