CHAPTER 4 -
R&D SUBSIDIES

"Pour progresser, il ne suffit pas de vouloir agir, il faut d'abord savoir dans quel sens agir."

Gustave Le Bon, Hier et demain.

4. 1. Introduction[1]

During the eighties, R&D subsidies in Japan accounted for a tiny fraction, less than 2%, of the total manufacturing industries' outlays devoted to research activities. In the United States, Canada, the UK, Italy and France, the fraction is above 23%.[2] Germany occupies an intermediate position, with a subsidization rate of about 14%. Since it is often claimed that government R&D is less efficient than private R&D, one might wonder to what extent these figures would explain the international differences, observed in the previous chapter, in the rates of return to R&D. Indeed, Japan and, to a lesser extent, Germany are weakly subsidized and benefit from relatively high rates of return to R&D. On the other hand, some of the most subsidized countries such as the US, the UK, and Canada, are associated with relatively weak, if not non existent, returns. France is the exception, it is highly subsidized and its rate of return to R&D is similar to the one of Germany. Such broad generalizations are easy enough to make, but in reality the issue is certainly more complex. It merits closer examination in order to be validated.

The basic economic justification for science and technology policies, and more particularly R&D subsidies, is linked to the issue of '*market failure*'. Due to imperfect appropriability of innovations, or spillover effects, the social return to research activities implemented by firms is higher than the private return. Since firms do not take these positive externalities into account, their amount of R&D is lower than what would be desirable from a societal point of view. Indeed, the optimal amount of R&D is theoretically reached when the marginal social cost is equal to the marginal social benefit; and firms consider only their own marginal profit.

[1] This chapter is an extension of Van Pottelsberghe (1995), Panitch and Van Pottelsberghe (1997), and Capron and Van Pottelsberghe (1997a, 1997b).

[2] These figures are taken from Table A4.4 in the appendix.

This is the central argument justifying government support to business R&D.[3] In short, most government offer incentives to alleviate this market failure in the allocation of resources devoted to technological activities. R&D subsidies is one of the two main policy tools - fiscal incentives being the other one - at governments' disposal.

Whether these subsidies substantially contribute to improve productivity at the industry level has been quite controversial in the existing literature. Empirical studies on the effects of R&D subsidies fall into two main categories. The first one estimates the direct impact of R&D subsidies' on output growth. The ubiquitous finding that emerges from this literature is quite pessimistic: 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 rather indirect, via the stimulation of private R&D investments. In this case, the empirical evidence is more optimistic, although far from unambiguous, depending on the methodological framework and/or the studied countries and industries. This stresses the need for more empirical tests and analyses concerning the interrelationship between R&D subsidies, the private decision to invest in R&D, and productivity growth; especially in other countries than the US, which have so far been the center of interest.

The two main objectives of the present chapter lie within the scope of these two categories of investigations. The first objective aims at assessing whether R&D subsidies have a substantial and positive direct impact on productivity growth. In the light of the previous chapter we intend to provide an homogeneous international comparison of the rate of return to government and private R&D in the G7 countries. The second objective is to assess whether or not government R&D has stimulated private R&D investments, both at the aggregate manufacturing level and for 22 disaggregated manufacturing industries. Furthermore, as it is conjectured that the impact of government R&D on private R&D may substantially vary across industries, we put forward some of the potential factors, including the stability of R&D subsidization policies, which may explain the estimated response profiles of private R&D investors to subsidies.

The chapter is structured as follows. The existing quantitative literature on the effectiveness of R&D subsidies is surveyed in the next section. Section 4.3 concentrates on the evaluation of the direct impact of R&D subsidies on productivity growth. In this respect we first compare

[3] A second argument is that firms might even underinvest in R&D with respect to their own optimal level. Four factors might be at the source of underinvestments in research: *(i)* asymmetric information between lenders of funds and performers of R&D often leads to financial constraints, especially for SMEs; *(ii)* the risk aversion which might induce firms to enter into safer investments than R&D; *(iii)* the weak availability of qualified researchers; and *(iv)* a too intense evanescence of the knowledge generated. See chapters 2 and 3 of Adam and Farber (1994) for a theoretical formalization of the first and the second factors.

the rates of return to total R&D in highly and lowly subsidized industries. Then we present an evaluation of the rates of return to government and private R&D in the seven countries. In section 4.4 the attention is driven towards the evaluation of the influence that R&D subsidies might have on the private decision to invest in R&D. A particular feature of this section is that it generalizes and extends the existing empirical models by properly allowing for an adjustment process and testing for the presence of long term effects of R&D subsidies on private R&D investments. We submit and test the hypothesis that the stability of R&D subsidization policies may explain the variability in the estimated response profiles of private R&D investors to subsidies, either across countries or across industries. Finally, the conclusions including some suggestions related to the design of public investment policies are drawn in section 4.5.

4. 2. State of the Art: Evidence and Ambiguities

4.2.1. The direct impact of R&D subsidies: Evidence

One of the two methodologies used in the empirical literature in order to assess the efficiency of R&D subsidies is to estimate their *direct* impact on output or productivity growth. Consider the following production function of a Cobb Douglas type. In this function the total R&D input *RT* is disaggregated into its two main components (or sources of funds): private R&D (*RP*) and government R&D (*RG*).

$$Q = A \exp(\lambda t)\, SRP^{\alpha_1}\; SRG^{\alpha_2} \prod_k X_k^{\beta_k} \tag{4.1}$$

Q denotes real output; *SRP* and *SRG* stand for respectively the stock of private R&D and the stock of government R&D. *X* characterizes the *k* traditional inputs: labor, fixed capital stock, intermediate inputs, and energy. From this function, one may either estimate the output elasticity of the two R&D variables or their rates of return.[4] Should we expect to find a difference between the direct effects of publicly- and privately-financed R&D? Or, in other words, is α_1 different from α_2 ? *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 a strong government support to R&D in an industry may favor

4 Cf. equations (2.7) and (2.9) in Chapter 2.

externalities and limit appropriability opportunities for the companies in this industry. This is probably why most studies that attempt to estimate a direct effect of R&D subsidies have been done at the aggregate industry level.

Table 4.1 summarizes the results of the empirical literature which differentiates the impact of private R&D from the impact of R&D subsidies on output growth. While in other countries such exploration has been quite unheard-of, the conclusions drawn in the few US applications stay quite controversial. It emerges from the analyses at the industry level that private R&D is associated with a substantial and significant effect on the growth of productivity which is greater than the impact of total R&D. Government R&D does not seem to have any significant direct effect. What may be seen as controversial is that the sole procedure which allows to estimate a positive and significant direct impact of government-financed R&D on productivity growth is to withdraw some sectors - generally R&D subsidies intensive - from the data set.

By excluding Electrical equipment & communications and Aircraft & missiles from his sample, Leonard's (1971) estimations show a positive correlation between R&D subsidies and the growth of value added. Similarly, Reiss (1990) argues that the non significant rate of return to publicly-financed R&D estimated by Griliches and Lichtenberg (1984) is principally due to the presence of outlying industries. His results, based on a non outlying sample taken out of the one previously used by Griliches and Lichtenberg (1984a), yield a significant estimate of the rate of return on private R&D (26%) and a significant rate of return on government R&D (18%). The Missiles and spacecraft sector is one of the four outliers suppressed by Reiss (1990). Therefore, the impact of R&D subsidies on output growth is likely to differ across industries. This is corroborated by Levy and Terleckyj (1989), who concentrate on the US telecommunication industry over the period 1958-85. They estimate a statistically significant output elasticity of government R&D of 0.04% which is, however, much lower than the output elasticity of private R&D (26%).

At the micro-economic level, Griliches (1980a) confirms his *a priori* statement that there should not be a superiority of company-financed R&D over federally-financed R&D in affecting the productivity growth of firms. This confirmation ensues from the observation, over 883 US firms, that the output elasticities of total R&D are similar to the output elasticities of private R&D. However, from the derivation of the rates of return to private R&D, the author notices that companies in highly subsidized industries - Aircraft and Electrical equipment - yield the lowest rates of return to private R&D (17% and 3%, respectively) while companies in four other industries yield rates of return to private R&D ranging from 26% to 103%.

Table 4.1.
The Rates of Return (or output elasticities) to Total[1], Private, and Government R&D in the literature

Authors	Country - period	Dependent variable	R&D variable	ρ/ ε	Data	*RT*	*RP*	*RG*
Industry-level								
Leonard (1971)	USA - 16 industries 1957-63	V.A. growth;	R&D/V.A.	ρ	C.S.		.75*	
		correlations						.04
	14 industries (no outliers)							.77*
Terleckyj	USA - 20 industries 1948-66	TFP growth - sales	R&D/V.A.	ρ	C.S.	.12*		
(1980a, b)							.27*	-.05
Griliches and	USA - 27 industries	TFP growth - sales	R&D/sales	ρ	C.S.			
Lichtenberg	1959-68					.03*		
(1984a)							.09*	.01
	1964-73					.01		
							.20*	-.01
	1969-76					.06*		
							.34*	.01
Levy and Terleckyj (1989)	USA - telecom industry 1958-85	Cobb-Douglas - sales	R&D stocks	ε	T.S.		.26*	.04*
Reiss (1990)	USA - 23 industries 1969-76, Deletion of 4 outliers	TFP growth - sales	R&D/sales	ρ	C.S.		.26*	.18*
Firm-level								
Griliches (1980a)	USA - 883 firms - 1957-65	Labor productivity	growth of R&D flows	ε	C.S.			
	Pooled data	growth - sales					.06*	
	Chemicals & petroleum						.09*	
	Metals & machinery						.09*	
	Electric equipment						.06*	
	Motor vehicles						.14*	
	Aircraft						.03	
	Other						.05*	
Griliches (1986)	USA - 386 firms	Cobb-Douglas - V.A.	R&D stocks; premium approach	ε	C.S.	.14*	1.8*	
Lichtenberg and	USA - 2000 firms	TFP growth - sales	R&D/sales	ρ	T.S.C.S.			
Siegel (1991)	1973-85					.13*		
							.35*	.03
	1973-76					.10*		
							.25*	-.00
	1977-80					.19*		
							.42*	.10
	1981-85					.21*		
							.51*	-.01
	1973-85 (no outliers)					.13*		
							.29*	.07*
Crott (1995)	Belgium - 30 firms	Labor productivity -	R&D/labor	ε	T.S.C.S.	.05*		
	1984-87	V.A.					.28*	.00
Country-level								
Levy and Terleckyj	USA - Private business	Labor productivity -	R&D stocks	ε	T.S.			
(1983)	1949-81	sales	*(Gov. R&D)*				.27*	.05
			(Gov. contract R&D)				.27*	.09*
Capron (1992c)	Belgium - 1963-1985	Labor productivity growth - GNP	R&D stocks	ε	T.S.		.64*	.21*
Lichtenberg (1992)	53 countries - 1985	Labour productivity	R&D/GNP	ε	C.S.	.09*		
		- GNP					.07*	.02
	1960-85	Labour productivity growth - GNP	R&D/GNP	ρ	C.S.		.10*	-.15*

V.A. = added value; TFP = total factor productivity; ρ = rate of return to R&D; ε = output elasticity of R&D; T.S. = time series; C.S. = cross section; T.S.C.S. = panel data; *RT* = total R&D; *RP* = private R&D; *RG* = government R&D. * Significant at a 10% probability threshold.

Unlike Griliches (1986), Lichtenberg and Siegel (1991), Crott (1995), and Griliches (1986) depict a relationship between private and government R&D on the one hand, and output growth on the other hand, similar to the one estimated in industry-level studies. With a sample of 2000 US firms, over the period 1973-85, Lichtenberg and Siegel (1991) evaluate a rate of return to private R&D (35%) much higher than the rate of return to total R&D (13%), and no significant rate of return to government R&D. However, when outlying companies are withdrawn from the data set, the rate of return to R&D subsidies becomes significant (7%) but is still very weak when compared to the rate of return to private R&D. Crott (1995) run similar estimates over a sample of 30 Belgian firms. Government R&D has no impact on output growth while private R&D has a significant effect which is, again, stronger than the effect of total R&D investments. With a panel data of about 400 US firms, Griliches (1986) provides empirical evidence, through the use of a premium approach, that the firms that have a higher ratio of private to total R&D are also associated with higher productivity performances. In other words, privately financed R&D expenditures are associated with higher returns than government financed R&D.

Cunéo (1984) adopts a different approach in order to assess the impact of R&D subsidies on the labor productivity of 84 French firms in the heavy industry and 98 French firms in the scientific industry, over the period 1972-77. Instead of disaggregating total R&D into its private and government components, Cunéo differentiates the output elasticity of total R&D in highly and lowly subsidized companies. This is done through the use of a dummy variable which takes the value of one for the enterprises which are subsidized at a rate higher than 1 percent of total R&D. His results show that government R&D contributes significantly to output growth when a company's total R&D per capita exceeds a certain threshold. In the heavy industry, the return to government support is positive for companies whose total R&D per capita ratio is at least twice as high as the average ratio of non subsidized companies. In the scientific industry, the ratio of R&D capital stock per capita in the enterprises receiving government support has to be at least four times as high as in the enterprises without R&D subsidies.

Levy and Terleckyj (1983) perform a US macro-economic level study which focuses on the private business sector, over the period 1949-81. They estimate an output elasticity of private R&D of 27% and an output elasticity with respect to government R&D non significantly different from zero. However, when government R&D is separated into contract R&D and all other government R&D, a larger regression coefficient of 9% is obtained for contract R&D, while the coefficient for all other federally funded R&D is insignificant. Capron (1992) obtains similar results at the Belgian macro-economic level over the period 1963-1985, the estimated output elasticities of private and government R&D being equal to 64% and 21%, respectively. That is, government R&D does contribute to output growth, but to a lesser extent than private R&D.

In the framework of an international comparison, Lichtenberg (1992) takes into account investments in R&D (along with other variables such as investment in physical capital and in human capital) in order to explain differences, across 53 countries, in the level of labor productivity in 1985, as well as international differences in the growth rate of labor productivity from 1960 to 1985. Privately-funded R&D is found to have significant positive effects on both the level and growth rate of labor productivity. The marginal product of Government-funded R&D is insignificantly different from zero in the productivity level equation. However, in the productivity growth equation, the marginal product of government research is negative. The countries with higher R&D subsidies exhibit significantly lower productivity growth. This may be due to the composition of the data set which includes countries with high national security and health expenditures. Such expenditures do not contribute to productivity growth but may contribute to improve national welfare.

A particular type of studies deserves to be briefly described. These studies disaggregate total R&D into basic and applied R&D. Griliches (1986) and Link (1981b), with respectively 400 and 51 US manufacturing companies, and Mansfield (1980) at the US industry-level, tackle the question of whether the basic and applied components of government R&D have a different impact on productivity growth. Mansfield (1980)'s results are quite mitigated. When only total applied research and development investments are disaggregated into private and government source of funds, and basic research is not differentiated with respect to the source of funding, none of the three variables has a significant impact on output growth. When an expected R&D payoff variable is introduced into the econometric model, the publicly-financed applied research and development is associated with a significant rate of return, but the coefficients of total basic research and of privately-financed applied research and development stay insignificant. It seems as if these results have to be considered cautiously because they do not emphasize any positive impact of private R&D.

Link (1981b) also provides some evidence that R&D subsidies may contribute to the productivity growth of US companies and his results are compatible with most of the studies previously analyzed. Four variables, which represent the two components of research activities (basic versus applied research and development) disaggregated with respect to the two sources of funds, are simultaneously introduced into Link's empirical model. Government basic research has a significant impact on productivity which is half the value of the impact of privately-financed basic research. Privately-financed applied research and development have a marginally significant impact but publicly-financed applied research and development are associated with a non significant coefficient. Griliches (1986), with the *premium* approach, also shows that firms which spend a larger fraction of their R&D on basic research are more productive.

The four main findings which ensue this literature overview are that *(i)* privately financed R&D expenditures have a substantial and significant direct effect on the growth of productivity which is greater than the impact of total R&D, *(ii)* whereas public R&D appears to have a weak direct effect, if not insignificant; *(iii)* basic research (and also government financed basic research) is more important as a productivity determinant than the other types of R&D expenditures; and *(iv)* the rate of return to total R&D or to private R&D is lower in the industries which are relatively highly subsidized. Griliches (1980a) argues that this apparently weaker effectiveness of R&D activities in highly subsidized industries might be due to stronger R&D externalities associated with government support. If the appropriability conditions were actually limited by the presence of R&D subsidies, it would mean that government R&D is associated with significant spillover effects. However, it is documented in Appendix A4.1 that there is no empirical evidence supporting or rejecting this hypothesis in case of both intra- and inter-industry spillover effects. The potential evanescence of R&D (or R&D subsidies) may therefore be one explanation for the weaker return to total R&D obtained by the firms in the more subsidized industries.

An other hypothesis which could account for the ostensible poor direct performances of R&D subsidies is that their impact on productivity growth is rather 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 without private cost. The author 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 can not be taken as a validation for the (in)efficiency of R&D subsidies. Using the production function approach, it would not be possible to determine the level of production if there were no publicly-financed R&D.

Consequently, the question that arises is to understand the influence of R&D subsidies upon 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 of 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:

$$RP = \gamma_1 + \gamma_2 \; RG \qquad (4.2)$$

and, for simplicity, take equation (4.1) in the form of total factor productivity growth:[5]

$$\dot{TFP} = \alpha_0 + \alpha_1 \frac{RP}{Q} + \alpha_2 \frac{RG}{Q} \tag{4.3}$$

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

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

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 the growth of productivity will be positive if $\gamma_2 > -\alpha_2 / \alpha_1$. The empirical evidence described here 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 do stimulate private investments 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.

4.2.2. The indirect impact of R&D subsidies: Ambiguities

In this subsection we survey the literature that focuses on the question of whether publicly-funded R&D and privately-funded R&D are *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. The literature on the effects of R&D subsidies on private investments is, as a matter of fact, included in the broader literature on the determinants of R&D investments. More particularly this 'broader' literature has mainly focused on the effects of market structure and/or firm size and, to a lesser extent, on technological opportunity and appropriability conditions on innovation.[6]

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5 Cf. section 2.2. in Chapter 2.

6 R&D investments (or R&D intensity) is one of the main proxies for innovation used in the literature. The variety of measures of innovation may be classified as measures of either innovative inputs or outputs. Measures of innovative output (innovation counts, new product entities, and patent data) are scarce or suffer from inter-industry comparability problems. In the majority of the studies on market structure and innovation, the dependent variable is a measure of input to the innovation process (see Cohen and Levin (1989)) : R&D expenditures orthe number of personnel engaged in R&D.

Our objective here is not to replicate a survey like the one by Cohen and Levin (1989) on this literature which they qualify as the « *second largest body of empirical literature in the field of industrial organization* » [p. 1060]. Their comprehensive survey is concerned with all the determinants of innovations linked to the size of firms, the concentration of industries, technological opportunities and appropriability conditions. Although Cohen and Levin recognize that government is an important, if not the most important, extraindustry factor influencing innovation, they give only a marginal attention to the literature dealing with the impact of R&D subsidies on private R&D. Nevertheless, this latter literature is not so « *modest* ». In what follows, we provide a comprehensive survey of the econometric studies which focus on the question of whether government-funded R&D stimulate private R&D expenditures or not.

Most of the investigations which implicitly test this complementarity assumption between the two main sources of funds for research activities are presented in Table 4.2. Only a few empirical studies analyze manufacturing sectors or macro-economic entities, most of them preferring micro-economic approaches. Eight out of the thirteen micro-level studies support the complementarity assumption, four reject it and one is inconclusive. Concerning the three US sectoral studies the results are also mitigated.[7] Nadiri (1980) and Levin and Reiss (1984) find that private and government R&D are complementary. Lichtenberg (1984) fails to obtain any significant relationship. The three macro-economic studies support the stimulation hypothesis for the USA. However, Levy's (1990) contribution shows that a substitution relationship appears for the UK and the Netherlands, the results are inconclusive for Italy and Switzerland, while in Japan, Germany, Sweden and France there is a complementarity between government R&D and private R&D.

These studies are mostly related to the US economy and the divergences between some studies can be explained to a large extent by differences between time periods, data sources, or regression characteristics. Most of the samples used in the micro-level studies are highly non-random, inducing the potential presence of a sample selection bias. Furthermore, the fourth to the seventh columns of Table 4.2 indicates that the empirical models differ markedly across studies. In addition, studies vary in the degree to which they control for firm and/or industry fixed effect. Therefore, one could wonder whether this divergence among the econometric

[7] 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 coefficient smaller than one reflects an eviction effect of *RG* on *RP*, as presented by Levin and Reiss (1984) and Fölster and Trofimov (1996) in Table 4.2.

results is also consequential to the empirical models' diversity.[8] In this respect, five issues deserve careful thought.

- 1st issue: Heterogeneous behaviors

First, most 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, some empirical clues that the relation between government and private R&D is different from one industry to the other, regardless of the characteristics of the empirical models. Nadiri (1980a) produces evidence that the growth of public R&D capital stock has a statistically significant positive effect on the private R&D capital stock of 10 manufacturing industries. When the data set is subdivided into two groups, the estimated private R&D elasticity of government R&D stays positive for the 5 'nondurables goods' industries, while it is negative and significant for the 5 'durables goods' industries. Shrieves (1978) and Fölster and Trofimov (1996) also estimate a negative coefficient for US firms in durables industries and for Swedish firms, respectively.

It is therefore conceivable that R&D subsidies may either stimulate or hinder private R&D investments, depending on industry-specific features. Another reason which may explain why R&D subsidies can have a negative impact on private R&D investments has been raised by Aghion, Dewatripont, and Rey (1996). They develop a theoretical model of entrepreneurial behavior as regards to the adoption rate of new technologies. One of their findings is that R&D subsidization policies may either foster or hinder the rate of technology adoption, depending on the 'conservative' or 'profit maximizing' management feature of firms. The theoretical results suggest that R&D subsidies are likely to incite technology adoptions (which could be proxied by private R&D efforts) if the firms are characterized by a 'profit maximizing' behavior. On the other hand, government R&D is likely to substitute for private R&D among 'conservative' firms.

- 2nd issue: The adjustment process

The second issue is related to the dynamic feature of the model to be estimated. Only three out of the nineteen studies presented in Table 4.2 adopt a partial adjustment mechanism for R&D investments. On *a priori* grounds, the inclusion of lagged R&D may be seen as an important determinant of present R&D investments. Mansfield (1964, p. 32) notices that *« First it takes time to hire people and build laboratories. Second, there are often substantial costs in*

[8] For instance, Lichtenberg (1984) focuses only on government R&D in order to explain the evolution of private R&D investments across 12 US industries; while Switzer (1987) adds 7 other right-hand side variables.

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 behavior of private investors can best be described in terms of dynamic mechanisms.

It is worth noticing 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 investments. Switzer (1984) also uses a partial adjustment mechanism and does not estimate any significant relationship between government and private R&D. It seems therefore essential to test whether an adjustment process is at work and whether it affects the estimated impact of R&D subsidies on private R&D.

- 3rd issue: Technological competition between firms

The third issue concerns the influence of technological competition, inside a given industrial sector, on the R&D investors' behavior. In Table 4.2, Fölster and Trofimov (1996) is the only study which attempts to comprehend the role of R&D rivalry. Their main finding is that total R&D efforts of several competing firms tend to decline when they receive subsidies. If only one firm benefits from subsidies, its own R&D activities increase but the total R&D by all competing firms is likely to decline. Therefore, it should not be surprising to evaluate an eviction effect at the sectoral level, even if the firms which benefit from subsidies increase their private R&D investments. The potential presence of such a negative impact of government R&D on private R&D at the aggregate (sectoral) level amplifies the requisite for empirical studies at the industry level.

- 4th issue: Exogeneity of government R&D

The fourth issue is related to the assumption, implicitly supported by most studies, that the level of government support is viewed as exogenous in the models of private R&D decision. The relevance of this assumption is rather questionable; 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 do R&D and which already have good innovative ideas.

Table 4.2.
Estimated Marginal Impact (or elasticity- ε) of Publicly-Financed R&D on Private R&D.[1]

Author	Country - years - structure [1]	Sample	RP_{t-1}	Q_t	*C4*	*other*	β
Firm-level							
Rosenberg (1976)	USA - 1963 - C.S.	100 firms		+	+	+	2.35*
Shrieves (1978) ε	USA - 1965 - C.S.	411 firms		+	+	+	
		manufacturing					-.53*
		non-spec. durables					-.89*
		materials					1.26*
		spec. durab. equip.					-1.02*
		consumer goods					-.78
Carmichael (1981)	USA - 1976-77 - C.S.	46 transport firms		+			-.08*
		big firms					-.07
		small firms					-.06*
Link (1982)	USA - 1977 - C.S.	275 firms		+	+	+	.09*
Lichtenberg (1984)	USA - 1972 - C.S.	991 firms - level					.10*
	USA - 1977 - C.S.	level					-.22*
	USA - 1972 to 77 - C.S.	growth rates					-.17*
	USA - 1967 to 77 - C.S.	growth rates					-.26*
Scott (1984) ε	USA - 1974 - C.S.	3387 lines of business		+		+	.08*
Switzer (1984)	USA - 1977 - C.S.	125 firms	+	+	+	+	.08
Lichtenberg (1987)	USA - 1979-84 - T.S.C.S.	187 firms		+			.13*
						Q_g	-.00
Holemans and Sleuwagen (1988) ε	Belgium - 1980-84- T.S.C.S.	59 firms		+	+	+	.30*
Antonelli (1989) ε	Italy - 1983 - C.S.	86 firms		+		+	.37*
Leyden and Link (1991)	USA - 1987 - C.S.	137 laboratories				+	1.99*
Crott (1995) ε	Belgium - 1984-87- T.S.C.S.	30 firms		+		+	.50*
Fölster and Trofimov (1996) [4]	Sweden - 1982 - 90 T.S.C.S.	249 groups	+	+		+	.20*
Industry-level							
Nadiri (1980) ε	USA - 1969-75 - T.S.C.S.	10 industries	+	+		+	.01*
		5 durableS					-.04*
		5 non durableS					.02*
Levin and Reiss (1984) [4]	USA - 1967, 72, 77 - C.S.	20 industries			+	+	.12*
Lichtenberg (1984)	USA - 1963-79 - T.S.C.S.	12 industries					.01
Mamuneas and Nadiri (1996)	USA - 1956-88 - T.S.C.S.	15 industries		+		+	.54*
Country-level							
Lichtenberg (1987)	USA - 1956-83 - T.S.	Macro		+			.33*
						Q_g	.11
Levy and Terleckyj (1983)	USA - 1949-81 - T.S.	Private Business		+		+	.21*
Levy (1990) [3]	9 countries -1963-84 -T.S.C.S.	USA		+			.30*
		UK					-.73*
		Italy					.05
		Japan					.16*
		Germany					.23*
		Sweden					.41*
		Netherland					-.13*
		France					.33*
		Switzerland					.02

1. Summary of the existing studies and their empirical specifications. **2.** T.S. = time series; C.S. = cross section; T.S.C.S. = 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. **3.** The estimates reported for Levy (1990) are taken from Capron (1992a). **4.** These estimates have to be interpreted as a negative relationship between government and private R&D (cf. footnote 6). * Significantly different from zero at a 10% probability threshold.

The fact that a firm's own R&D projects is probably among the main determinants of R&D subsidies may explain the presence of a positive statistical relationship 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 about the exogeneity of R&D subsidies is almost certainly unacceptable. 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. According to Lichtenberg (1984), the adequacy of this assumption depends critically on the level of aggregation under consideration. With time series analyses, with macro level data, and, to a lesser extent with industry level data, the exogeneity assumption is much more acceptable.

- 5th issue: Government sales

The last issue is the one introduced by Lichtenberg (1987) who provides empirical evidence, through both macro and micro US data, that most of the models which estimate regressions of private R&D expenditures on federal R&D funding give an overstatement of the federal R&D coefficient. This misspecification would be a direct implication of the failure to distinguish sales to government from other sales - i.e., to private markets. 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 taken cautiously since they mean that government purchases and government R&D are correlated. Hence, both variables could reflect the degree of government interventionism, rising again the question of whether or not such an interventionism has a stimulating impact on private R&D.

- Synopsis

In a nutshell, there is no clear evidence about the complementary or substitutive relationship between the two main sources of funds for R&D. Despite the heterogeneity of the empirical models used in the literature, which renders hazardous any comparison exercise, the balance seems to tilt towards the recognition of a complementary effect of R&D subsidies on private R&D. However, there are clues that in some industries, or in some countries, government R&D is a substitute for private R&D. Further, it seems that the empirical specification may also influence the sign of the parameter of interest.

To the public authorities' views, a correct answer to this debate is crucial. The two following sections attempt to better understand the interrelations between government R&D, private

R&D, and productivity growth. The empirical analyses will concentrate on 22 manufacturing industries in seven industrialized countries. Homogeneous estimates across these countries will facilitate cross-country and cross-industry comparisons and therefore should give some clues towards the question of whether R&D subsidies either contribute directly to output growth and/or stimulate private R&D investments.

Section 4.3 focuses on the potential direct impact of R&D subsidies on productivity growth. If Levy's (1990) 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 that section. However, we have serious reservations about the idea that government support can be employed at zero wage. In order to benefit from R&D subsidies, firms have to lobby, to prepare R&D projects, and to compete with other firms. All those activities aiming at attracting government support are associated with substantial costs. These costs are undoubtedly lower than the costs of private R&D investments and may partly explain why some studies do estimate positive direct impacts of government R&D on output growth which are much weaker than impacts of privately-funded R&D. The question about the potential « *indirect* » effectiveness of R&D subsidies, via the stimulation of private R&D investments, is dealt with in section 4.4.

4.3. Are R&D subsidies productive?

Section 4.2 underlines that the literature on the direct impact of R&D subsidies on output growth provides pessimistic conclusions: Government R&D has no or little impact on productivity growth and the firms in highly subsidized industries benefit from lower returns to total R&D. The aim of the present section is to re-examine this relationship. More specifically, two main questions are being asked. First, do highly subsidized industries benefit from lower rates of return to total (or private) R&D? Second, do R&D subsidies directly contribute to productivity growth? The singularity of this section with respect to the existing literature is twofold. We provide, to our best knowledge, the first homogenous international comparison of the returns to government R&D at the industry level, and our estimates are the first attempt to distinguish the rates of return to private and government R&D within a panel data framework.

The empirical models which are to be estimated are presented in the first subsection, along with a description of the data on R&D subsidies. A particular attention is given to the interpolation procedure used in order to get continuous series of private and government R&D

expenditures. The second and the third subsections are devoted to the interpretation of the econometric results related to the first and the second question, respectively.

4.3.1. Empirical models and definition of data

The empirical model is similar equation (2.9) presented in Chapter 2 and estimated in Chapter 3. The left-hand side variable is the total factor productivity growth rate, defined as in equation (3.1). The right-hand side variables are industry and time dummies ($\alpha_{0,i,j}$ and λ_t, respectively) and the net total R&D intensity (the increment in the total R&D capital stock divided by added value). The parameter ρ^n in equation (4.4) is the net excess rate of return to total R&D. Two dummy variables D_h (h=1 2) are used in order to differentiate the rates of return to R&D with respect to the degree of government interventionism across the industries of each country. D_1 represents the lowly subsidized industries, it takes the value of one for the industries in which the average R&D subsidization rate along the eighties is lower than the median value of all industries' subsidization rates, and a value of zero otherwise. D_2 stands for the highly subsidized industries and takes a value of one for the industries that are not included in D_1. Equation (4.5) is similar to equation (2.9), with the total R&D capital stock disaggregated into privately-financed R&D (*SP*) and publicly-financed R&D (*SG*).

$$TFPG_{j,t} = \sum_j \alpha_{0,j} + \sum_t \lambda_t + \sum_h \rho_h^n \, D_h \left[\frac{\Delta \, ST_{j,t}}{Q_{j,t}} \right] + \varepsilon_{j,t} \tag{4.4}$$

$$TFPG_{j,t} = \sum_j \alpha_{0,j} + \sum_t \lambda_t + \rho_P^n \left[\frac{\Delta \, SP_{j,t}}{Q_{j,t}} \right] + \rho_G^n \left[\frac{\Delta \, SG_{j,t}}{Q_{j,t}} \right] + \varepsilon_{j,t} \tag{4.5}$$

As in Chapter 3, the balanced panel is composed of about 22 industries at 3 or 4 ISIC-digits in seven industrialized countries (USA, Japan, Canada, France, Germany, Italy, and the United Kingdom). All the variables are expressed in constant 1980 US$. *Q* is the output indicator proxied by value added which is deflated by a sectoral production price index (1980=100).

The disaggregation of total R&D investments in four sources of funds is available in the OECD STI database for the eighties and in various OECD publications for the period 1967 to 1980. The whole period 1967-90 is not complete in the time dimension, depending on the countries and/or the industries. The sources of funds are: private (*RP*), government (*RG*), funds from abroad, and other national funds. Private and government R&D are by far the most important components of total R&D. Then come the funds from abroad and other national sources. The former are generally weak in comparison to private and government R&D, while the latter are negligible.[9] Data availability is not homogeneous across the four sources of funds. There are much more available data on private R&D investments than on government R&D. And data on the two other sources of funds are even scarcer.

The computation of complete time series for private R&D and government R&D relies on one broad hypothesis: total R&D investments are essentially composed of private investments and government subsidies. This assumption allows to estimate R&D subsidization rates from private and total R&D investment data as follows: $(RG^* / RT) = 1 - (RP / RT)$; where RG^* is in fact equal to the sum of R&D subsidies, funds from abroad, and other national sources. Thereby, the amount of available data on subsidization rate is maximized. Then, missing data are interpolated from the available subsidization ratios.[10]

Table A4.2 in the appendix shows that the share of available data varies greatly across countries. More than 65% of the panel data is available for Canada, France, Italy, Japan, and the US. In Germany and the UK, the ratio is equal to 50% and 30%, respectively. The interpolation procedure for missing data is described in appendix A4.6. It works by fitting polynomial curves between the available specified points. Our data did not suggest using any particular order of interpolation. Visual testing of different orders of interpolations over different sectors and countries suggested us to use the quadratic (2-order) interpolation, which allows for abrupt (unsmooth) behavior of government subsidization policies and relies on more information than the simple linear interpolation. The time series of *RP* and *RG* are calculated from the total R&D investment series multiplied by the interpolated subsidization rates, which are expressed in constant 1980 US$ and deflated with GDP deflators as provided in the OECD National Account Surveys.

It should be kept in mind that the two indicators of technological progress might be biased for some industries in particular countries. For instance, Table A4.3 in the appendix shows that other sources of funds accounted for about 22% of total R&D investments in the Canadian aggregate manufacturing industry. It is worth noticing, however, that no study among the ones listed in Table 4.1 and Table 4.2 deals with the presence of funds from abroad in total R&D

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9 During the eighties (averages over available years), the cumulated share of 'funds from abroad' and 'other national funds' in total R&D investments, at the aggregate manufacturing level, varies from less than 2% in the US, Japan, and Germany to about 10% in France, Italy, and the UK. The highest value is reached in Canada, where these two other sources of funds account for about 20% of total R&D investments. These figures are presented in Table A4.3 in the appendix

10 The interpolation procedure could have been realized for the R&D subsidization series computed from the total R&D minus the available private R&D data. However, we preferred to interpolate subsidization rates instead of R&D subsidies in level for two reasons. First, subsidization rates are more stable than the R&D subsidies series. Second, the interpolation of subsidization ratios is not biased by the presence of price effects. Table A4.2 in the appendix gives the percentage of available data on (RG^*/RT)

investments. It seems that the general practice is to consider that the funds from abroad are either non existent or that they are assimilated to private R&D. In the present study, these other sources of funds are assimilated to government R&D by construction. Since R&D financing from international organizations are often assimilated to funds from abroad, it seemed more appropriate to associate the funds from abroad to subsidies.

The total R&D capital stock, *ST*, is computed as in Chapter 2 with the perpetual inventory method on the basis of R&D expenditures, with industry-specific lags and depreciation rates. The same methodology is 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 investments (*RG*) and private R&D investments (*RP*), respectively.

4.3.2. Does the rate of return to R&D vary with the degree of government interventionism?

There are two possible approaches to make the distinction between highly and lowly subsidized industries. The first one is simply to consider an arbitrarily chosen subsidization rate for all countries. Above this threshold, an industry would be considered as highly subsidized, and *vice-versa*. However, in doing so some countries would have only one or two highly subsidized industries (such as Japan) and others would have most of their industries characterized as highly subsidized (such as Canada and the UK). The second approach, which seems more appropriate in the present context of international comparison, is to determine for a given country the industries that are relatively highly subsidized in the economy. Table 4.3 categorizes the 22 industries in each country according to the degree of government interventionism. The highly subsidized (H) industries are those whose subsidization rate is high relatively to the other industries in the country. In each country, the threshold is determined by the median value of the subsidization rates, averaged over the eighties, of the 22 industries. With this procedure, about half the industries in each country are qualified as highly subsidized, whereas the other half are qualified as lowly subsidized.

The econometric estimates of equation (4.4) are presented in Table 4.4. The rates of return to R&D are differentiated according to the degree of high or low government interventionism in the industries. The results are *a priori* surprising. In the light of the survey in the previous section, we expected a higher rate of return to R&D in the lowly subsidized industries. Our estimates for most countries suggest the opposite. A positive and significant impact of total R&D on output growth is found exclusively in highly subsidized industries. In the US, France and Italy total R&D in lowly subsidized industries is associated with higher coefficients than in highly subsidized industries, but they are not significantly different from zero. Further, the lowly subsidized industries in the UK are associated with a counter intuitive negative rate of return to R&D. The last column confirms that the return to R&D, estimated over all countries and all industries, is higher in highly subsidized industries.

Table 4.3.
Highly and Lowly Subsidized Industries During the Eighties

	USA	Canada	Germany	France	Italy	Japan	UK
Food, drink & tobacco	L	L	L	H	H	L	L
Textiles & clothing	L	H	H	L	n.a.	H	L
Wood, cork & furniture	L	n.a.	L	H	n.a.	L	H
Paper & printing	L	H	L	L	L	L	L
Chemicals	H	L	L	L	n.a.	L	L
Drugs	L	L	L	L	n.a.	L	L
Petroleum refineries	L	L	H	H	L	H	H
Rubber & plastics	H	L	L	L	H	L	L
Stone, clay & glass	L	L	L	L	L	H	L
Ferrous metals	H	H	H	L	H	H	L
non-ferrous metals	L	H	H	H	L	H	H
Fabricated meal products	H	H	H	L	L	H	L
Machinery (non-electrical)	L	H	L	H	L	H	H
Office machines & computers	H	H	L	H	H	H	H
Electrical machinery	H	L	H	H	H	H	H
Electronic eq. & components	H	H	H	H	H	H	H
Shipbuilding	n.a.	n.a.	H	H	H	H	H
Motor vehicles	H	L	L	L	L	L	L
Aerospace	H	H	H	H	H	n.a.	H
Other transports	H	n.a.	H	L	H	n.a.	n.a.
Instruments	L	n.a.	H	n.a.	L	L	H
Other manufacturing	L	L	L	n.a.	L	L	L
Unweighted average of the subsidization rates (%):	**16.9**	**26.4**	**16.9**	**15.7**	**21.2**	**3.6**	**24.8**
Median (%)	**10.2**	**25.4**	**10.8**	**7.3**	**16.1**	**1.2**	**25.0**

These dummies are computed from the average R&D subsidization ratio during the eighties, presented in Table A4.4 in the appendix.

Despite the fact that highly subsidized industries are associated with higher returns to R&D, it is impossible to infer some conclusions about the relative efficiency of government and private R&D. The causality is not clear. First, in the case of a 'picking winners' policy, R&D subsidies might be directed towards 'national champions', which are generally high-tech industries with relatively high returns. In Table 4.3, the industries Electrical machinery, Electronics and components, Aerospace, and Office machines and computers are relatively highly subsidized in most countries. Second, government R&D might be more effective than private R&D. However this hypothesis is not corroborated at all by the existing literature surveyed in the previous section.

Third, it should be mentioned that these findings are not inconsistent with those provided by Griliches (1980a). The author observes that companies in highly subsidized industries yield the lowest rates of return to private R&D (as compared to the firms in other industries). The main explanatory factor put forward by Griliches is that stronger R&D externalities might be associated with government interventionism. If this argument were right, one should expect relatively strong intra-industry R&D spillovers within the highly subsidized industries. Since our estimates are run at the sectoral level, they implicitly reflect both the direct return to R&D and the return to intra-industry R&D spillovers. That is, the higher returns to R&D in highly subsidized industries might simply be the validation that the more an industry is subsidized, the more a firm's total R&D diffuses and benefits other firms in the industry. This idea is corroborated by the analysis, presented in Appendix A4.1, of the results obtained by Bernstein (1988) and Bernstein and Nadiri (1989).

Table 4.4.
The rates of return to total R&D in lowly and highly subsidized industries (1980-1990)[1].

	USA	Can.	Germ.	France	Italy	Japan	UK	Total
Highly subsidized	.254 * (.153)	.408 (.274)	1.300 * (.375)	1.196 * (.570)	.420 (.331)	2.877 * (.931)	.006 (.226)	.392 * (.110)
Lowly subsidized	.804 (.744)	-.379 (.469)	.752 (.750)	2.499 (1.640)	1.562 (1.612)	2.186 (1.485)	-2.089 * (.906)	.108 (.320)
nobs	231	198	242	220	198	220	231	1540
Adjust-R^2	.485	.537	.510	.382	.413	.486	.499	.398

1. Within estimates, with time dummies and with a *DIFF* dummy variable for the outlying observations detected in Chapter 3 (cf. the last column of Table 3.5). The estimated models correspond to equation (4.4). The dummy variables for lowly and highly subsidized industries are presented in Table 4.3. Standard errors between parentheses. * the estimated parameters are significantly different from zero at a 10% probability threshold.

Even though such spillovers have certainly a part to play, the question of whether or not R&D subsidies have been more or less efficient than private R&D in improving the growth of output still arises. The next subsection compares the returns to both private and government R&D.

4.3.3. The direct impact of R&D subsidies on productivity growth

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 4.5 (cf. equation 4.5). The net rates of return to total R&D are similar to the ones presented in Table 3.5. They range from non significant estimates for the UK, Canada, and Italy to 272% for Japan. Columns *(ii)* and *(iii)* show the estimates of the rates of return to private and government R&D, respectively. Surprisingly, neither the net private R&D intensity nor the net government R&D intensity seem to contribute significantly to output growth. The only rate of return to private R&D that is significant (i.e., in Germany) is weaker than the rate of return to total

R&D. In the light of the existing estimates of this type one would have expected the estimated rate of return to private R&D to be higher or at least equivalent to the rate of return to total R&D. The estimated rates of return to private R&D, although generally insignificant, are always higher than the rates of return to government R&D. These insignificant results are a very weak confirmation that private R&D is more efficient than government R&D in contributing to productivity growth.

Table 4.5.
The rates of return to private and government R&D (1980–1990)[1].

		(i)	*(ii)*	*(iii)*	*(iv)*
USA,	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)*		.091 *(.340)*
	Government R&D			-.077 *(.366)*	-.103 *(.379)*
	Adjusted R^2	.534	.532	.532	.529
Germany,	Total R&D	1.189 *(.334)* *			
nobs= 242	Private R&D		.904*(.344)* *		.873 *(.352)* *
	Government R&D			-.426 *(.445)*	.199 *(.449)*
	Adjusted R^2	.511	.498	.483	.496
France,	Total R&D	1.322 *(.544)* *			
nobs= 220	Private R&D		.763 *(.488)*		1.444 *(.721)* *
	Government R&D			-.104 *(.363)*	.683 *(.533)*
	Adjusted R^2	.383	.372	.364	.374
Italy,	Total R&D	.470 *(.322)*			
nobs= 198	Private R&D		.527 *(.557)*		.576 *(.604)*
	Government R&D			-.049 *(.309)*	.072 *(.334)*
	Adjusted R^2	.415	.411	.408	.408
Japan,	Total R&D	2.720 *(.859)* *			
nobs= 220	Private R&D		1.385 *(.853)*		1.430 *(.857)* *
	Government R&D			1.049 *(2.07)*	1.328 *(2.07)*
	Adjusted R^2	.488	.468	.461	.466
UK,	Total R&D	-.110 *(.222)*			
nobs= 231	Private R&D		-.379 *(.282)*		-.291 *(.292)*
	Government R&D			.333 *(.227)*	.272 *(.235)*
	Adjusted R^2	.489	.493	.494	.494

1. The estimated models correspond to equation (4.5). All estimates include industry and time dummies; and a *DIFF* dummy variable that annihilates the effects of the outlying observations detected in Chapter 3 (cf. Table 3.5, last column). Standard errors between parentheses.
* indicates the estimated parameters that are significantly different from zero at a 10% probability threshold.

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 in France, Japan, and Germany, whereas the return to government R&D is insignificantly different from zero. For the other four countries none of the two variables is associated with a significant impact on output growth. In all countries, except the UK, private R&D has a larger impact on output growth than government R&D. But this impact is never significantly different from the one of government R&D.

In summary, the estimates do not confirm entirely the main findings which emerge from the existing literature.[11] In general, private R&D has not a higher return than total R&D. On the contrary, it is often smaller and is insignificant in six out of the seven countries. And publicly-funded R&D, as expected, does not seem to contribute directly to the growth of output. Although the amplitude of the coefficients of private R&D is larger than the one of government R&D, one must recognize that these results are far to be as robust as those found in the existing literature. The latter has focused essentially on the US manufacturing industries. In Table 4.5 the US coefficients do not corroborate that private R&D contributes significantly to output growth or that its return is substantially higher than the return to government R&D. In the US, only total R&D is associated with a significant impact. Why are these results different from those presented in the existing literature? Two reasons can be put forward. One is technical, the other conceptual.

First, the estimates presented in Table 4.5 are the first attempt, to our knowledge, to measure the differentiated impact of the two sources of funds on the basis of a cross-section time series database. The literature at the industry-level has exclusively focused on cross-section estimates (cf. Table 4.1). The temporal feature of our data set increases the potential multicollinearity biases between government and private R&D. For instance, the estimated return to private R&D in France is insignificant (76%) when private R&D is the only right-hand side variable. When it is included simultaneously with government R&D, its impact becomes significant and much larger (144%).

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 may 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, and this idea is supported by the results of the previous subsection, 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 subsidized industries. One can hardly imagine that the innovative output of a firm, whatever the rate of subsidization, can be disaggregated into ‘private’ knowledge and ‘government’ knowledge. In this respect, the productivity returns to government R&D are perhaps not smaller than those to private R&D, but are perhaps more difficult to measure.

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[11] Table A4.7 in the appendix presents the results of similar estimates, where the detection procedure for the outlying observations has been run for each regression. These alternative estimates yield conclusions that are similar to the ones drawn from Table 4.5.

The literature almost unequivocally defends the idea that government R&D is less efficient than private R&D. Even though our results are quite mitigated and much less convincing in this respect, one could wonder why R&D subsidies could be less efficient than private R&D. A potential explanation lies in the geopolitical area. The Shipbuilding industry as well as the three high-tech sectors Aerospace, Office machines and computers, and Electrical equipment and components are closely related to national defense activities and are generally highly subsidized. The technological outcome of these industries might not be completely devoted to an efficient production process since it is mainly used by public authorities. Subsidization procedures are often subordinated to government contracting with private firms (see Lichtenberg (1988)). These contracts for technological innovations, oriented towards “social welfare” purposes, may give a feeling of security to the sponsored industries. And, if a firm is secured by public funds for R&D activities and/or by steady sales to government - i.e., the rents are not threatened, the management can adopt a less competitive behavior towards private markets.

This argument is substantiated by Mowery and Rosenberg (1994) in their institutional analysis of the federal R&D system in the United States: «*Military (and space) programs have notoriously subordinated cost considerations to the improvement of performance - often incurring very high costs for very small improvements, few of which are relevant to civilian markets.* » [p. 143]. The less a firm is private market-oriented, the less it will need to maintain competitive pressures and the less it will increase its sales. That is, R&D subsidization might lead to a sclerosis of management: researchers working on large scale government projects may in fact ‘learn’ an indifference to cost in the pursuit of performance improvements. This sclerosis deters government interventionism.

The conceivable inefficiency of publicly-funded R&D in the production process, although less accredited by our results than by the existing literature, still raises the question of whether or not the allowance of such subsidies is necessary. In the next section the hypothesis of an indirect positive effect of government R&D on output growth, through the stimulation of private R&D investments, is to be tested.

4. 4. Publicly-funded R&D as a stimulus for privately-funded R&D

As noted earlier in this chapter, publicly-funded R&D is more likely to contribute indirectly to output growth, via the stimulation of private R&D investments. Two contradictory hypotheses are commonly defended in the literature concerning the relationship between publicly-funded and privately-funded R&D expenditures. Some argue that these two categories of R&D are complementary, hence R&D subsidies should increase the amount of private R&D expenditures. Others suggest the existence of an opposite relationship: private firms would decrease their own R&D expenditures as a consequence of the government support to private R&D projects. Most of the studies presented in the state of the art give evidence of a complementarity relationship (cf. subsection 4.2.2) but we have seen that a substitution relationship might sometimes appear according to either the empirical specification adopted or the industries and countries considered.

In this section we intend to contribute to the empirical literature on the impact of R&D subsidies on private R&D investments. More specifically, three questions are put forward. *(i)* Does a change in the empirical specification - such as the adoption of a dynamic specification - modify the estimated relationship between government and private R&D? *(ii)* To what extent does the impact of R&D subsidies on the private decision to invest in R&D vary across industries or countries? *(iii)* What are the likely determinants of the private R&D investment response profile to R&D subsidies? The section is structured as follows. The data set and various static and dynamic empirical models are described in the first subsection. In the second subsection the econometric results are interpreted with respect to the first two questions. The third subsection analyses further the potential determinants of the private R&D response profile to government R&D.

4.4.1. Empirical specifications, data set, and econometric models

Before presenting the main empirical model, let us recall three out of the five empirical issues which emanated from the survey summarized in Table 4.3 and which can be taken into account in the framework of the present empirical analysis.[12]

[12] The third issue presented in subsection 4.2.2 is related to the first one inthe sense that it provides one of the factors that might induce a substitution relationship between *RP* and *RG*: even if a company is stimulated by R&D subsidies, the other companies of the industry might react negatively and the aggregate industry effect ofa subsidy would therefore be negative. The fifth issue can not be embodied in the present analysis because we can not disaggregate total sales into sales to government and other sales.

1st issue: The sign of the impact of government R&D on private R&D may vary across industries.

2nd issue: Introducing a dynamic feature in the empirical model may modify substantially the sign and the significance of the estimated relationship between government and private R&D.

3th issue: There is most likely a bias induced by the presence, across firms or industries, of simultaneity between government and private R&D.

In order to gauge empirically the link between private (*RP*) and government (*RG*) R&D, we adopt a traditional approach which consists in estimating the impact of R&D subsidies and other determinants on the private decision to invest in R&D activities. It is assumed that private R&D is a (log-additive) multiplicative function of three traditional variables:

$$RP_t = \exp\left[c + \varepsilon_t\right] RP_{t-1}^{\lambda}\; Q_t^{\varphi}\; RG_t^{\gamma} \;, \qquad (4.6)$$

where c is a constant term and ε is the error term. Total sales Q_t seem to be one of the main determinants of private R&D; an increase in output means that more funds may be injected into research activities. In the light of the second issue, we allow for a dynamic specification 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 we may suggest that the inclusion of RP_{t-1} is a parsimonious way to identify the feedback effect of past on current spending.

As in the previous estimates of total factor productivity growth equations, the data is composed of 22 industries at 3 or 4 ISIC-digits in seven countries. The main difference with the data set used in the previous sections is that there is no need for data on gross capital formation, employment, and wage compensations. We have now an available data set for an eighteen years period starting in 1973 and ending in 1990. This higher degree of freedom should allow us to estimate industry-specific effects of the relationship between government and private R&D. In addition, an aggregate industry sector is also available. The linearized version of equation (4.6) for a given industry or for the aggregate industry sector in a particular country is specified as follows:

$$\underset{}{rp_t} = \lambda\, \underset{(+)}{rp_{t-1}} + \varphi\, \underset{(+)}{q_t} + \gamma\, \underset{(+/-)}{rg_t} + \underset{(+/-)}{c} + \varepsilon_t \qquad , \qquad t = 1,\ldots, 17 \qquad (4.7)$$

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 the private R&D elasticities with respect to the three corresponding exogenous variables. The parentheses show the expected sign of each parameter. Previous private R&D investments and total sales should positively influence *RP*. R&D subsidies may have either a positive or a negative impact on *RP*. The sign of the intercept *c* is also unpredictable. It characterizes temporarily stable industry specific features, such as appropriability conditions and technological opportunity. This model can be considered as a generalized version of the private R&D models in Table 4.3. Unfortunately, it was not possible to get valid estimates of the parameters for each industry in each country with our limited sample. The time series are made up with only 17 observations and there are four potential explanatory variables. In order to obtain an adequate number of degrees of freedom it is more convenient to rely on data sets that combine both time series and cross-sections and to impose some restrictions on the parameters across countries or industries. Consequently, the observations for each industry are piled up over the 7 countries, forming a panel data set of 119 observations. The slope parameters λ and φ are constrained to be equal across countries. It modifies equation (4.7) as follows for a particular industry.

$$rp_{i,t} = \lambda\ rp_{i,t-1} + \varphi\ q_{i,t} + \gamma_i\ rg_{i,t} + c_i + \varepsilon_{i,t} \qquad (4.8)$$

$t = 1,...,17$ and $i = 1,...,7$

The subscript *i* represents the seven countries. All the parameters, except the intercept *c* and γ, are now constrained to be equal across countries. How restrictive are the cross-countries equality constraints on the parameters? Concerning the parameters associated with the lagged dependent variable (λ) and to total sales (φ) it is expected that they have similar positive values across countries. The sign of the parameter associated with R&D subsidies, γ, is *a priori* not predictable. Country-specific features are a source of temporally persistent international heterogeneity (such as economic power, culture, and national innovation system) which might act upon the investment decision. As far as these unobserved international differences are stable over time, they are seized by the country fixed effects (c_i).

An alternative way of pooling the time series would be to stack together some industrial sectors in a particular country, as in the previous section and in Chapter 2). This would allow to get country-specific instead of industry specific parameters associated with RP_{t-1} and Q_t. However, the parameters should logically be more similar across countries for a given industry than across industries in a given country. Further, in the sight of the third issue, equation (4.10) avoids any potential simultaneity bias which could have been present in the framework of a cross industry regression in a particular country.

The second issue is still to be discussed. Does the introduction of a dynamic feature into our empirical model modify the relationship between government and private R&D? Two reasons could explain why the parameter γ would change with the introduction - or the removal - of RP_{t-1} in the empirical model. The first one is that the failure to properly take into account an important explanatory variable may lead to a misspecification of the model and bias the estimated parameters associated with other explanatory variables. The second one is that some bias may be induced by the potential presence of multicollinearity among the right-hand side variables. This would be the case if RP_{t-1} were highly correlated with RG_t. It is obviously puzzling to determine whether the first or the second reason, or both of them, are at work. In any case, it is important to be aware of the *a priori* implications underlying the two different specifications. The leading issue is to properly understand how private decision makers choose their optimal level of R&D investment and, as we are concerned with the impact of government R&D, to determine whether R&D subsidies have a long term impact on the level of private R&D expenditures. In the affirmative one could consider that private R&D investment is determined according to the following formula (without total output for simplicity):

$$rp_t = \mu + \gamma\ rg_t + \gamma\ \lambda\ rg_{t-1} + \gamma\ \lambda^2\ rg_{t-2} + \gamma\ \lambda^3\ rg_{t-3} + \ldots + \varepsilon_t \quad , \qquad (4.9)$$

which corresponds to a Koyck scheme of declining exponential weights, the lag operator being a polynomial of the first degree. That is, it is assumed that the coefficients on the *RG*'s are declining exponentially from the start. Therefore, from (4.9) we can write

$$\lambda\ rp_{t-1} = \lambda\ \mu + \gamma\ \lambda\ rg_{t-1} + \gamma\ \lambda^2\ rg_{t-2} + \gamma\ \lambda^3\ rg_{t-3} + \ldots + \lambda\ \varepsilon_{t-1} \quad , \qquad (4.10)$$

and subtracting (4.10) to (4.9) we obtain a model similar to equation (4.8):

$$rp_t - \lambda\ rp_{t-1} = \mu\,(1-\lambda) + \gamma\ rg_t + (\varepsilon_t - \lambda\ \varepsilon_{t-1}) \qquad (4.11)$$

$$rp_t = \mu\,(1-\lambda) + \lambda\ rp_{t-1} + \gamma\ rg_t + (\varepsilon_t - \lambda\ \varepsilon_{t-1}) \qquad (4.12)$$

In this last equation, γ is the estimated short-run private R&D elasticity of government subsidies, λ is the estimated adjustment parameter, and the long-run elasticity is equal to γ / (1 - λ). An alternative way of estimating the elasticity is simply to rely on the following equation, which corresponds to equation (4.8) without the lagged endogenous variable among the explanatory variables.

$$rp_t = \mu + \gamma_{l-r}\, rg_t + \varepsilon_t \quad , \qquad (4.13)$$

where γ_{l-r} is perceived as a long term relationship between to two sources of funds and should be equal to γ / (1 - λ). Another hypothesis would be to consider that the impetus given to private R&D is exclusively short-run. In this case, and allowing for a long-run impact of total sales, equations (4.9), (4.10), and (4.12) become:

$$rp_t = \mu + \gamma_0\, rg_t + \varphi\, q_t + \varphi\, \lambda\, q_{t-1} + \varphi\, \lambda^2\, q_{t-2} + \varphi\, \lambda^3\, q_{t-3} + \ldots + \varepsilon_t \quad , \qquad (4.14)$$

$$\lambda\, rp_{t-1} = \lambda\, \mu + \gamma_0\, \lambda\, rg_{t-1} + \varphi\, \lambda\, q_{t-1} + \varphi\, \lambda^2\, q_{t-2} + \varphi\, \lambda^3\, q_{t-3} + \ldots + \lambda\, \varepsilon_{t-1} \; , \qquad (4.15)$$

$$rp_t = \mu(1-\lambda) + \lambda\, rp_{t-1} + \gamma_0\, rg_t + \gamma_1\, rg_{t-1} + \varphi\, q_t + (\varepsilon_t - \lambda\, \varepsilon_{t-1}), \qquad (4.16)$$

where γ_0 stands for the *spontaneous* (i.e. without any long-run effects) private R&D elasticity of government R&D. If this impact is effectively momentary, estimates of the parameter γ_1 in equation (4.16) should be roughly equal to (-γ_0 λ) and its sign should be the inverse of the sign of γ_0 . Otherwise, it would mean that RG_t has both short-run and long-run effects on RP_t. An analogical reasoning could be applied about the impact of total sales on the decision to invest, which could also be *only* short-run. In this case, the coefficient associated with Q_{t-1}, φ_1, should be equal to (- φ_0 λ).

Consequently, six different types of empirical models may be used to appreciate the impact of R&D subsidies on private R&D. The first one is represented by *Model 1*; it is commonly used in the literature. It does not take into account any adjustment process and is generally taken to estimate elasticities (γ_{l-r}) without clear reference to the timing of effects. The second one, *Model 2*, includes an adjustment process and implicitly considers that government R&D has both short-run and long-run effects on private R&D. *Model 3* includes an adjustment process unrelated to R&D subsidies. It assumes that the impact of government R&D (γ_0) might rather be spontaneous and does not have any long-run effects, while the impact of output is allowed to have long-run impacts on private R&D investments. The fourth model assumes that both *RG* and *Q* would have exclusively a short-run influence on *RP*. The third and the fourth models are subject to a potential multicollinearity bias between the explanatory variables. If *RG* and/or *Q* only have a short-run impact on *RP*, there is, as a matter of fact, a strong potential correlation between the right-hand side variables rp_{t-1} on the one hand, and q_{t-1} and

rg_{t-1} on the other hand. *Model 5* and *Model 6* suppress this potential multicollinearity bias by assuming that the estimated adjustment process of *Model 2* holds.

Model 1: $rp_{i,t} = c_i + \gamma_{l-r,i}\ rg_{i,t} + \varphi_{L-R}\ q_{i,t} + \varepsilon_{i,t}$

Model 2: $rp_{i,t} = c_i + \lambda_2\ rp_{i,t-1} + \gamma_i\ rg_{i,t} + \varphi\ q_{i,t} + \varepsilon_{i,t}$

Model 3: $rp_{i,t} = c_i + \lambda_3\ rp_{i,t-1} + \gamma_{0,i}\ rg_{i,t} + \gamma_{1,i}\ rg_{i,t-1} + \varphi\ q_{i,t} + \varepsilon^3_{i,t}$

Model 4: $rp_{i,t} = c_i + \lambda_4\ rp_{i,t-1} + \gamma_{0,i}\ rg_{i,t} + \gamma_{1,i}\ rg_{i,t-1} + \varphi_0\ q_{i,t} + \varphi_1\ q_{i,t-1} + \varepsilon^4_{i,t}$

Model 5: $rp_{i,t} - \lambda_2\ rp_{i,t-1} = c_i + \gamma_{0,i}\ rg_{i,t} + \gamma_{1,i}\ rg_{i,t-1} + \varphi\ q_{i,t} + \varepsilon^5_{i,t}$

Model 6: $rp_{i,t} - \lambda_2\ rp_{i,t-1} = c_i + \gamma_{0,i}\ rg_{i,t} + \gamma_{1,i}\ rg_{i,t-1} + \varphi_0\ q_{i,t} + \varphi_1\ q_{i,t-1} + \varepsilon^6_{i,t}$

The six models are to be estimated in the framework of panel data methods. The conventional econometric technique is to compute the within transformation by cross section unit to eliminate the fixed effects.[13] However, in a dynamic context, this procedure would yield inconsistent estimates because of the presence of the lagged endogenous variable among the right-hand side variables. Indeed, Nickell (1981) and Keane and Runkle (1992) show that the within transformation introduces, by construction, a correlation between the lagged endogenous variable and the error term. In order to suppress the fixed effects we use the transformation of all variables (x) into orthogonal deviation, as suggested by Arellano and Bover (1995), which consists in computing the deviations of each data point from its future mean, as follows:

$$x_k^* = \sqrt{\frac{t-k}{t-k+1}}\left(\log x_k - \frac{1}{t-k}\sum_{p=k+1}^{t}\log x_p\right) \qquad k = 1,...., t\text{-}1$$

Further, three features related to the empirical models and to the structure of the data set deserve to be tackled. The first one is linked to the potential autocorrelation of the error term due to the dynamic characteristic of the model. The second feature is related to the potential presence of cross-sectional heteroscedasticity due to the fact that the variance of the disturbances might not be constant across the countries that form each panel data. The third one is related to the potential presence of contemporaneous correlation of the disturbances

[13] In our case, this transformation would be to take the deviations from individual means of each observation. This procedure yields econometric results exactly similar to the ones obtained with the data in level and country specific intercepts.

across countries for a given industry. This cross-sectional correlation might be due to important missing data. For instance, a world crisis in the iron and steel industry may be reflected in all countries. Finally, the within group estimators might also be inconsistent in the absence of the strict exogeneity assumption. However, Nickel (1981) demonstrates that the bias recedes rapidly as the number of time periods increases. In the present case the within group bias is expected not to be a major problem because the sample runs from 1973 to 1990.

The estimation procedure has to be corrected for autocorrelation, cross-country heteroscedasticity, and cross-country contemporaneous correlation. We first use Hatanaka's (1974) procedure to correct for autocorrelation in the dynamic specification. The different steps of this instrumental variable (IV) and two stage least square (IV-2SLS) procedure are:

1. Compute the fitted value of rp_t on the exogenous variables in time t and $t-1$.
2. Run IV estimates of the model, using the fitted value of rp_t as instrument for the lagged dependent variable.
3. With the IV error terms, estimate the autocorrelation ρ_i for each country and operate the Cochrane-Orcutt transformation on the variables. If the autocorrelation coefficient is not significantly different from zero at a 10% probability threshold, set $\rho_i = 0$. Run OLS on the transformed variables.
4. Compute the variance-covariance matrix of the new residuals and run FGLS estimates on the transformed variables of point 3.

All these steps are developed in appendix A4.8. 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. Yet, the presence of the 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 (TD-2SLS) that corrects for heteroskedasticity and contemporaneous correlation.

The components of the private R&D equation have been constructed from data drawn out from the OECD databases. All the variables are expressed in constant 1980 US$. Q is the output indicator proxied by total sales which is deflated by a sectoral production price index (1980=100). The data on RP and RG are described in the previous section.

4.4.2. Empirical results

Table 4.6 presents the estimates corresponding to the three behavioral models for the aggregate manufacturing sectors of the seven industrialized countries pooled together. The first column shows the regression results of *Model 1*, without dynamic effect. A similar regression equation has been used in the bulk of the empirical analyses presented in Table 4.2. The coefficient associated with total sales is positive, as expected, and is significantly different from zero. This result is consistent with the general view that technical change responds to economic stimuli. Concerning the impact of government R&D on private R&D, the estimated parameters are positive and significant in the USA, Canada, Germany, Italy, and Japan, which is conform with the hypothesis of complementarity between the two variables at the aggregate level. This hypothesis can not be supported for France where the coefficient supports the view that government R&D is a substitute for private R&D. For the UK the parameter is positive but insignificantly different from zero.

The confrontation of these first estimates for the aggregate US industry with the figures presented in Table 4.2 shows that our results are compatible with their reciprocates provided by Levy and Terleckyj (1983), Lichtenberg (1987), and Levy (1990). These three studies, which used an identical empirical model (i.e., without adjustment process), highlight a significant stimulating effect at the US macroeconomic level. However, the results provided by Levy (1990) are different for three countries. His evaluations are positive for France, negative for the UK and non significant for Italy. Our estimates are negative for France, non significant for the UK, and positive for Italy. These divergent results may partly be explained by differences in the studied periods, or in the data sources.

The results presented in the next columns investigate to what extent some modifications in the empirical specification may change the estimated relationship between private and government R&D. In column [2] the lagged endogenous variable is included among the right-hand side variables. The new variable has the expected positive sign and is highly significant, lending some support for the assumed partial adjustment mechanism of private R&D. Past R&D investments play an important role in the decision process underlying new investments in private R&D. The private R&D elasticity of total sales is not significantly different from the one estimated in column [1].

Table 4.6.
Estimates of the private R&D equation for the aggregated manufacturing sector.

Estimation procedure	IV-2SLS						TD-2SLS	
Model	[1]	[2]	[3]	[4]	[5]	[6]	[3]	[4]
RP_{t-1}		.897 *	.947 *	.950 *	**.897**	**.897**	.691 *	.702 *
		(.033)	*(.037)*	*(.037)*			*(.083)*	*(.084)*
Q_t	.365 *	.319 *	.343 *	.429 *	.438 *	.497 *	.133 *	.200 *
	(.072)	*(.038)*	*(.044)*	*(.056)*	*(.042)*	*(.060)*	*(.055)*	*(.089)*
Q_{t-1}				-.139 *		-.075		-.088
				(.059)		*(.054)*		*(.090)*
RG_t USA	.895 *	.030	.179	.094	.113	.123	.050	.025
	(.055)	*(.049)*	*(.143)*	*(.147)*	*(.145)*	*(.145)*	*(.133)*	*(.132)*
RG_t Canada	.166 *	-.087 *	-.199 *	-.186 *	-.187 *	-.183 *	-.103 *	-.100 *
	(.048)	*(.029)*	*(.033)*	*(.033)*	*(.035)*	*(.035)*	*(.041)*	*(.041)*
RG_t Germany	.792 *	.008	.140	.121	.133	.128	-.049	-.066
	(.193)	*(.079)*	*(.147)*	*(.148)*	*(.162)*	*(.161)*	*(.154)*	*(.156)*
RG_t France	-.192 *	-.081 *	-.206 *	-.202 *	-.185 *	-.188 *	-.224 *	-.221 *
	(.043)	*(.028)*	*(.029)*	*(.028)*	*(.025)*	*(.025)*	*(.028)*	*(.028)*
RG_t Italy	.061 *	-.048 *	-.164 *	-.159 *	-.159 *	-.161 *	-.127 *	-.127 *
	(.029)	*(.026)*	*(.034)*	*(.034)*	*(.025)*	*(.025)*	*(.038)*	*(.037)*
RG_t Japan	.450 *	-.003	-.032	-.025	-.051 *	-.052 *	.048	.043
	(.043)	*(.025)*	*(.035)*	*(.034)*	*(.022)*	*(.022)*	*(.040)*	*(.040)*
RG_t UK	.039	.302 *	.224 *	.187 *	-.075	-.077	.079	.073
	(.140)	*(.070)*	*(.097)*	*(.092)*	*(.113)*	*(.117)*	*(.132)*	*(.133)*
RG_{t-1} USA			-.204	-.111	-.107	-.104	.020	.045
			(.146)	*(.151)*	*(.151)*	*(.150)*	*(.141)*	*(.140)*
RG_{t-1} Canada			.122 *	.122 *	.116 *	.119 *	.095 *	.093 *
			(.035)	*(.034)*	*(.036)*	*(.036)*	*(.040)*	*(.039)*
RG_{t-1} Germany			-.212	-.179	-.189	-.162	-.046	-.035
			(.145)	*(.146)*	*(.152)*	*(.153)*	*(.153)*	*(.154)*
RG_{t-1} France			.225 *	.213 *	.200 *	.199 *	.193 *	.193 *
			(.033)	*(.032)*	*(.025)*	*(.026)*	*(.038)*	*(.038)*
RG_{t-1} Italy			.140 *	.136 *	.141 *	.145 *	.110 *	.113 *
			(.033)	*(.033)*	*(.024)*	*(.024)*	*(.037)*	*(.038)*
RG_{t-1} Japan			-.001	.011	.022	.030	.036	.046
			(.033)	*(.033)*	*(.020)*	*(.021)*	*(.038)*	*(.039)*
RG_{t-1} UK			.053	.120	.284 *	.300 *	.101	.128
			(.098)	*(.096)*	*(.108)*	*(.113)*	*(.128)*	*(.131)*
R^2	.441	.871	.917	.926	.601	.619	.953	.954
Adjusted-R^2	-2.232	.370	.625	.679	-.768	-.606	.861	.869

All variables are expressed in logarithm and transformed into orthogonal deviation. Panel data estimates, including country-specific fixed effects; cf. the econometric methodology in appendix A4.8; for the non-dynamic models, Hatanaka 's procedure is suppressed. *RP* = private R&D expenditures, *RG* = R&D subsidies, *Q* = total sales. The columns' numbers correspond to *Models 1* to *6* in the main text. * indicates the estimated parameters that are significantly different from zero at a 10% probability threshold.

As compared with *Model 1*, *Model 2* shows that the inclusion of an adjustment process may alter both the sign and the significance of the estimated impact of R&D subsidies. The parameters for the US, Germany, and Japan are no longer significant while it is significant for the UK. Further, the point estimates for Italy and Canada are now negative and significant The negative coefficient associated with government R&D in France is the only stable parameter, although its amplitude is somewhat smaller. However, these coefficients are representative of short-run elasticities. If we turn to long term impacts, as measured by taking into account the coefficient obtained for the lagged dependent variable, it appears that the long-run elasticities would not correspond to the elasticities provided by *Model 1*. This may be due to *(i)* the presence of multicollinearity bias, or *(ii)* the specification of the models (do we have to include RP_{t-1} ?). Since there are substantial differences between the two models one may wonder which one is the more appropriate. The high significance of the coefficient of the lagged endogenous variable suggests keeping a dynamic specification. Yet, it implicitly allows for a long-run effect of RG_t on RP_t. What would happen if a dynamic specification were kept without allowing for long-run effects of government R&D?

Model 3 intends to test whether the impact of government R&D is more likely to be spontaneous, with no long-run effects influencing the decision-making process of private R&D investments. Equation (4.16) shows that if the impact of government R&D is momentary and immediate, the estimated private R&D elasticity of RG_{t-1} (γ_1) should be equal to ($-\gamma_0\ \lambda$), the product of the parameter associated with contemporaneous R&D subsidies and with the adjustment process. In other words, the private R&D elasticity with respect to RG_{t-1} should roughly have an opposite sign comparatively with the elasticity of RG_t. The third column of Table 4.6 displays the results linked to *Model 3*. The estimated private R&D elasticities with respect to total sales (.34) and with respect to one-year lagged private R&D (.95) are slightly higher (not significantly so) than the ones obtained with *Model 2*.

It seems that only a short term effect occurs for Canada, France, and Italy. In these countries, the coefficient associated with RG_t, γ_0 , is negative and significant and the coefficient associated with RG_{t-1} (γ_1) is positive and significant. The three negative and significant parameters (γ_0) in *Model 3* have the same sign as in *Model 2* but their amplitude is much higher. This means that since only spontaneous effects are allowed in France, Canada, and Italy, they are larger than the short-run effects estimated through a specification which allows for long-run impacts. Concerning the US, Germany, and Japan the parameters (γ_0) and (γ_1) are both insignificant, corroborating the insignificant estimates of *Model 2*. The spontaneous hypothesis does not seem to hold for the UK aggregate industry because the parameter associated with RG_{t-1} is not significantly different from zero, whereas the parameter associated with RG_t (.22) is positive and significant. That is, in the UK government R&D has a positive and long-run influence on private R&D which can not be evaluated in a procedure that presupposes only short-run effects.

Model 4 investigates whether output has also a spontaneous impact on private R&D by formally including Q_{t-1} among the right-hand side variables. The elasticities of total sales (.43) and one-year lagged total sales (-.14) have opposite signs and are both significant, suggesting that output influences positively private R&D investments only in a short-run perspective. The parameters associated with the government R&D variables are barely affected by the inclusion of the one-year lagged output into the regression equation. Yet, *Model 3* and *Model 4* may be subject to potential multicollinearity bias between the various present and lagged explanatory variables. *Model 5* and *Model 6* take into account this potential bias by assuming that the adjustment parameter estimated in *Model 2* (λ = .897) prevails. This allows us to move RP_{t-1} from the right-hand side variables into the dependent variable, getting rid of the potential multicollinearity bias.

With *Model 6*, the estimated private R&D elasticity of one-year lagged output is no longer significant (as compared with *Model 4*), which shows that output may have long-run effects on private R&D. Therefore, the significant coefficient associated with Q_{t-1} (-.139) in *Model 4* may have been biased by a strong correlation between Q_{t-1} and RP_{t-1}. The results associated with *Model 6* do not support the impulse hypothesis on the impact of output on private R&D. Concerning the estimated private R&D elasticities of government R&D, the two models (5 and 6) lead to similar conclusions. The spontaneous hypothesis is confirmed for the impact of R&D subsidies on private R&D in Canada, France, and Italy. For the US and Germany the estimated parameters are still insignificant. The only striking differences which appear when *Model 3* is compared with *Model 5* are related to Japan and the UK. The impact associated with RG_t is now negative and significant in Japan and insignificant in the UK. Yet, these coefficients can not be taken as reflecting only the short-run impact of R&D subsidies because the parameters associated with the one-year lagged government R&D do not have the expected opposite signs (they should be positive and significant for Japan and insignificant for the UK). That is, in Japan and the UK the spontaneous hypothesis does not seem to hold and the impact of R&D subsidies is more likely to be better approximated through *Model 2*, which allows for long-run effects.

The last two columns investigate whether the inclusion of time dummies into the regression equations modify the estimated parameters. The results are presented for *Model 3* and *Model 4*. For *Model 3*, the adjustment parameter and the coefficient associated with output are much smaller and less significant with time dummies (about .70 and .13, respectively) than without time dummies (.95 and .34, respectively). That is, the time dummies, which can be suspected to capture a common trend effect, reduce the significance of the relationship between private R&D on the one hand and the one-year lagged private R&D and output on the other hand. Concerning the private R&D elasticity with respect to government R&D, the spontaneous hypothesis is preserved for Canada, France, and Italy and the amplitude of the parameters is only slightly modified. For the US, Germany, and Japan, the coefficients are still insignificant in both time *t* and *t-1*, which does not allow to reject the short-run-only hypothesis but highlights a zero impact of R&D subsidies on the private decision to invest in R&D activities. For the UK aggregate manufacturing industry we also obtain insignificant parameters (in time *t* and *t-1*), which does not corroborate the results obtained without time dummies in *Model 3*. The UK is the only country in which the estimated elasticity of R&D subsidies is affected by the introduction of time dummies into the regression equation. These observations are similar for *Model 4*, which further rejects the spontaneous hypothesis on the impact of output on private R&D.

On the basis of the estimated elasticities (γ) presented in Table 4.6 we can derive the marginal impact (η) of government R&D on private R&D as follows: $\eta = \gamma * (RP / RG)$; which is the amount invested by private decision-makers when they receive $1 of R&D subsidies. Table 4.7 presents the marginal impacts of government R&D on private R&D derived from the parameters estimated through *Model* 2 or *Model* 3, depending on the rejection of the spontaneous hypothesis. Since the private R&D elasticities of government R&D are not significantly different from zero for the US, Germany, and Japan, the marginal impacts of R&D subsidies are assumed to be equal to zero. A $1 of R&D subsidies yields a decrease of 47 cents of private R&D investments in Canada, of 57 cents in France, and of 69 cents in Italy. That is, private R&D investors seem to partially substitute R&D subsidies for their own investments in R&D in the three countries.

Table 4.7.
Marginal impact of government R&D on private R&D, at the aggregate industry level[1]

	USA	Canada	Germany	France	Italy	Japan	UK
	Model 2/3	*Model 3*	*Model 2/3*	*Model 3*	*Model 3*	*Model 2*	*Model 2*
Short-run elasticities (γ)	.000	-.199	.000	-.206	-.164	.000	.302
RP / RG	2.06	2.34	5.94	2.75	4.18	57.82	1.83
Marginal impact (η)	.000	-.466	.000	-.567	-.686	.000	.553
Instability	.035	.315	.056	.216	.329	.186	.047

1. The marginal impacts (η) are computed from the estimated short run private R&D elasticities of R&D subsidies (γ) presented in Table 4.6, as follows: $\eta = \gamma * (RP / RG)$. *RP / RG* is the ratio of private R&D on 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 subsidization ratio (*RG / RT*) over the period 1973-90.

As the eviction effects are all smaller than $1, one can conclude that R&D subsidies do contribute to raise the amount of total R&D investments in all countries. In the UK, an increase in government R&D of $1 leads to an increase in private R&D investments of about 55 cents, which implies an increase of $1.55 in total R&D investments. The last row of Table 4.7 gives an indication about the stability of the subsidization rates over the period 1973-90. This indicator is relatively weak for the four countries where government R&D either stimulates or does not affect private R&D investments. In other words, it seems that the more stable a country's subsidization policy, the less R&D subsidies are likely to crowd out private R&D investments.

We now turn to the examination of the econometric results for each of the 22 disaggregate manufacturing industries annexed in Tables A4.9 and A4.10. The focus is principally put on the models without time dummies. As shall be seen in Table 4.8, their introduction into the regression equations mainly affects the significance rather than the signs of the estimated impact of R&D subsidies on private R&D. This is also the case for the coefficients associated with output, which is insignificant for 15 industries out of the 22 industries considered. Without time dummies, the number of insignificant parameters associated with total sales is equal to 2 with *Model 2* and to 4 with *Model 3*.[14]

Table 4.8 summarizes the number of positive, insignificant, and negative estimated private R&D elasticities with respect to government R&D in each country, according to different empirical models. These figures clearly validates our conjecture that the studies which estimate an average impact, either at the aggregate level or across industries, eclipse heterogeneous behaviors from one industry to the other. In each country there are industries characterized by a substitutive behavior towards R&D subsidies and others which are stimulated by R&D subsidies. The distribution frequencies of all industries according to the sign and the significance of their estimated private R&D elasticity of government R&D is quite stable across the different empirical models used. The changes are all due to changes in the significance of the parameters. Take the US for instance, with *Model 2*, the elasticities are positive for 9 industries, insignificant for 10, and negative for 2. With *Model 3*, the numbers are respectively 8, 7, and 6. That is, one positive coefficient has turned insignificant and 4 insignificant coefficients have turned negative from one model to the other.

When time dummies are added in *Model 3* there are many more insignificant elasticities in all countries except Canada. Out of the 141 industries in the 7 countries, 59 are characterized by an insignificant parameter with *Model 3*. This number increases to 80 when time dummies are introduced into the regression equation. Finally, *Model 5*, which suppresses any potential multicollinearity bias, yields similar results as *Model 3*, except for Japan. With the two models, 33% of the 141 industries are characterized by a positive coefficient associated with R&D subsidies, 42% are characterized by a non significant parameter, and 25% are characterized by a negative answer.

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14 With *Model 2* and/or *Model 3*, the coefficients associated with output are insignificant for Ferrous metals, Other transport, Shipbuilding, Petroleum refineries and Food, drink, and tobacco.

Some of the coefficients estimated through *Model 3* are biased in the sense that the spontaneous hypothesis is not verified. Whatever the sign and the significance of the coefficient, the link between government and private R&D is sometimes better evaluated through *Model 2*, which does not impose the only short-run hypothesis. For instance, among the 82 significant coefficients associated with RG_t and estimated with *Model 3*, 53 verify the spontaneous hypothesis - i.e. the coefficients of government R&D lagged one year (γ_1) have the opposite sign of γ_0 and are significant -, 27 suggest that a long-run effect should be allowed - the γ_1 are non significant -, and 2 deny the spontaneous hypothesis as well as discredit the imposed adjustment process - both γ_1 and γ_0 are positive and significant -. Among the 59 non significant coefficients of RG_t estimated through *Model 3*, 41 do not reject the spontaneous hypothesis - the γ_1 are also non significant -, and 18 refute it, meaning that a long-run impacts is at work. That is, for the 47 industries where the spontaneous hypothesis has been rejected, *Model 2* is more appropriate because it allows for longer-run effects of R&D subsidies.

Table 4.8.
Number of positive, insignificant, and negative private R&D elasticities of government R&D; ***Model 2, Model 3, Model 3* + time dummies*; Model 5***

Models	*Model 2* Total	*Model 2* %	*Model 3* Total	*Model 3* %	*Model 3* + TD Total	*Model 3* + TD %	*Model 5* Total	*Model 5* %
USA +	9	43 %	8	38 %	5	24 %	8	38 %
USA 0	10	48 %	7	33 %	11	52 %	7	33 %
USA -	2	10 %	6	29 %	5	24 %	6	29 %
Canada +	3	17 %	2	11 %	3	17 %	3	17 %
Canada 0	12	67 %	12	67 %	12	67 %	11	61 %
Canada -	3	17 %	4	22 %	3	17 %	4	22 %
Germany +	12	55 %	12	55 %	8	36 %	11	50 %
Germany 0	6	27 %	7	32 %	13	59 %	7	32 %
Germany -	4	18 %	3	14 %	1	5 %	4	18 %
France +	1	5 %	2	10 %	2	10 %	1	5 %
France 0	12	60 %	9	45 %	11	55 %	10	50 %
France -	7	35 %	9	45 %	7	35 %	9	45 %
Italy +	4	21 %	4	21 %	3	16 %	2	11 %
Italy 0	7	37 %	6	32 %	9	47 %	8	42 %
Italy -	8	42 %	9	47 %	7	37 %	9	47 %
Japan +	6	30 %	5	25 %	3	15 %	9	45 %
Japan 0	13	65 %	14	75 %	17	85 %	11	55 %
Japan -	1	5 %	1	5 %	0	0 %	0	0 %
UK +	12	57 %	13	62 %	11	52 %	13	62 %
UK 0	6	29 %	4	19 %	7	33 %	5	24 %
UK -	3	14 %	4	19 %	3	14 %	3	14 %
TOTAL +	47	33 %	46	33 %	35	25 %	47	33 %
TOTAL 0	66	47 %	59	42 %	80	57 %	59	42 %
TOTAL -	28	20 %	36	25 %	26	18 %	35	25 %

Source: cf. Tables A4.4 to A4.6 in the appendix.

Table 4.9 provides a more detailed summary of the econometric results estimated through *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* are preferred. This 'combined' summary of the empirical results classifies the point estimates according to the countries and to four sub-aggregate groups of industries. The sub-aggregation reflects the quartile distribution of the mean R&D intensity of each industry across the seven countries.[15] For instance, among the six high-tech industries in the USA, the estimated effect is positive for four industries, insignificant for one, and negative for one. Two comments may sum up these figures.

Table 4.9.
Number of positive, insignificant, and negative private R&D elasticities of R&D subsidies; Combination of *Model 2* and *Model 3*

	High-tech.	Medium-high	Medium-low	Low-tech.	Total	%
USA +	4	2	1	2	9	43 %
USA 0	1	2	1	2	6	43 %
USA -	1	1	2	2	6	29 %
Canada +	1	0	2	0	3	17 %
Canada 0	4	3	0	3	10	56 %
Canada -	0	1	2	2	5	27 %
Germany +	1	3	5	4	13	59 %
Germany 0	1	0	0	2	3	14 %
Germany -	4	2	0	0	6	27 %
France +	0	1	1	0	2	10 %
France 0	2	3	1	4	10	50 %
France -	3	1	2	2	8	40 %
Italy +	1	1	1	2	5	26 %
Italy 0	1	1	2	0	4	21 %
Italy -	4	2	2	2	10	53 %
Japan +	0	3	3	1	7	35 %
Japan 0	5	1	1	4	11	55 %
Japan -	0	0	1	1	2	25 %
UK +	4	3	4	4	15	71 %
UK 0	0	1	0	1	2	10 %
UK -	2	0	1	1	4	19 %
TOTAL +	11	13	17	13	54	
TOTAL 0	14	11	5	16	46	
TOTAL -	14	7	10	10	41	
TOTAL +	28 %	42 %	53 %	33 %	38 %	
TOTAL 0	36 %	35 %	16 %	41 %	33 %	
TOTAL -	36 %	23 %	31 %	26 %	29 %	

Source: cf. Tables A4.9 and A4.10 in the appendix.

15 The High-tech group is constituted by Aircraft, Instruments, Office machines & computers, Electrical machinery, Electronic equipment & components, and Motor vehicles. The medium-tech-high group is composed by Chemicals, Drugs, Rubber & plastics, Machinery, and Other transports. The medium-tech-low group is composed by 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 and printing, Ferrous metals, and Fabricated metal products.

First, focusing on the last column of Table 4.9, a classification of the seven countries into three sub-groups emerges. The UK 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 the two countries the effect of R&D subsidies is negative for only 20% to 27% of the industries. Then comes the group constituted by the USA and Japan, in which the impact of government R&D is insignificant for about half the industries and positive in more than 35%. The last group, composed of Canada, Italy, and France, is characterized by a relatively high percentage (27% to 53%) of negative parameters which is larger than the percentage of positive coefficients. In the three countries, very few industries (10% to 26%) have 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-tech-high and medium-tech-low industries, R&D subsidies have a stimulating impact in 42% to 53% of the industries, which is above the average of 38% for all industries in all countries. It is worth noting that such generalization 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.

The relation between R&D subsidies and private R&D is far from being uniform across countries and/or industries. This shows that although evaluations of impacts at the aggregate level are informative about macro-economic policies, they should not be generalized to all industries. The insignificant impact of the Japanese government R&D at the aggregate level may be explained by the fact that, at the disaggregate level, the impacts were insignificant for more than half (55%) of the industries. Similarly, the negative (positive) impact estimated at the aggregate level for Italy (the UK) is conform to the majority of negative - 53% - (positive - 71% -) coefficients estimated for the Italian (UK) industries. Concerning Germany the estimated parameters at the disaggregate level, which are positive and significant for 59% of the 22 manufacturing industries, do not corroborate the insignificant estimates at the aggregate industrial level. For this country one may wonder whether an aggregation bias may lead to the misjudgment of the R&D subsidization policy's efficiency measured at the aggregate industry level. The next development suggest another explanatory factor.

Table 4.10 displays the marginal impact of government R&D on private R&D. As already highlighted in Table 4.9, private investors may be either stimulated or hindered by R&D subsidies. The lowly subsidized industries (such as the US low-tech industries, and most Japanese industries) are generally associated with marginal impacts with high amplitudes, because the ratio (*RP/RG*) is high. Depending on the countries, some industries have a substitutive reaction towards a $1 of R&D subsidies which is greater than $1. That is, in these industries an increase in government R&D yields a fall in total R&D investments.

Table 4.10.
Amount invested in private R&D in reaction to a $1 increase in R&D subsidies, by industry[1]

	USA	Canada	Germany	France	Italy	Japan	UK
Food, drink & tobacco	.00	.00	.00	.00	-1.38	.00	3.20
Textiles & clothing	36.95	-.78	4.01	.00	*n.a.*	.00	8.38
Wood, cork & furniture	95.23	*n.a.*	12.06	.00	*n.a.*	.00	.65
Paper & printing	.00	.00	2.63	-1.63	2.36	.00	.00
Chemicals	-1.09	.00	-4.88	.00	-.38	8.09	.75
Drugs	.00	-.71	8.05	.00	*n.a.*	8.72	6.55
Petroleum refineries	-2.18	4.00	.43	.48	.47	2.22	2.02
Rubber & plastics	1.18	.00	2.80	-15.5	-.35	36.4	.00
Stone, clay & glass	-1.41	-.57	2.55	-1.60	-.64	8.42	1.44
Ferrous metals	-.17	-.87	.00	-1.44	-1.52	6.61	7.35
non-ferrous metals	.00	-.30	2.19	.00	.00	8.93	-.45
Fabricated meal products	-.79	.00	.62	.00	2.88	-23.5	-.34
Machinery (non-electrical)	.00	.00	-1.97	.00	1.07	.00	2.08
Office machines & comp.	-.47	.11	-1.63	-.54	-.99	.00	-.28
Electrical machinery	.11	.00	.00	.00	-.79	.00	1.22
Electronic eq. & comp.	1.18	.00	-.87	-.83	-.50	.00	1.02
Shipbuilding	*n.a.*	*n.a.*	.27	-6.39	-.36	.00	1.38
Motor vehicles	1.40	.00	3.63	.00	-1.07	.00	1.44
Aerospace	.00	.00	-.16	-.56	.09	*n.a.*	.39
Other transports	1.03	*n.a.*	1.20	4.91	.00	*n.a.*	*n.a.*
Instruments	.63	*n.a.*	-1.11	*n.a.*	**.00**	.00	-.40
Other manufacturing	3.29	1.88	17.14	*n.a.*	.00	-22.3	5.04
Combined averages[2]							
Unweighted	6.42	.15	2.13	-1.16	-.06	1.69	1.97
weights = govern. R&D	**.22**	**.04**	**-.40**	**-.59**	**-.27**	**1.09**	**.94**

1. The marginal impacts (η) are computed from the estimated short run private R&D elasticities of R&D subsidies (γ) presented in Tables A4.9 and A4.10, as follows: $\eta = \gamma * (RP / RG)$. The non significant elasticities have been set to zero. The coefficients of *Model 3* are kept when the spontaneous hypothesis is not rejected. When the elasticities of RG_t and RG_{t-1} are both insignificant in *Model 3*, the marginal impact of *Model 2* is presented. If the spontaneous hypothesis is rejected, the marginal impact are computed from *Model 2* only. **2.** Averages of marginal impacts, unweighted; or weighted with the share of each industry's government R&D in total manufacturing government R&D.

The last row shows the average, across all industries, of the marginal impacts of R&D subsidies on private R&D. Because some industries receive much 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. Again, there is a clear evidence that government R&D contributes to raise total R&D investment in all countries, since there is no substitution effects that are lower than -$1. In France, Italy, and the UK the weighted averages corroborate the marginal impacts computed at the aggregate level (cf. Table 4.7). In Germany, only 6 out of the 22 industries have a negative reaction towards R&D subsidies. These industries account for much more than half the total R&D subsidies granted to German manufacturing industries, which explains why a $1 of government R&D yields, on average, a reduction of 40 cents in

German private R&D investments. This result does not corroborate the insignificant marginal impact evaluated at the aggregate level. A similar observation holds for the US and Japan, where the average private R&D investment reactions towards R&D subsidies are positive, whereas the aggregate industry level estimates do not yield any significant reactions. Moreover, the Canadian industries seem to have a positive average answer to government R&D, although close to zero, which does not confirm the negative impact evaluated at the aggregate level.

It clearly appears from the comparison of the last row of Table 4.10 with the third row of Table 4.7 that the conclusions might substantially diverge according to the considered level of data aggregation (aggregate industrial sector in Table 4.7 *vs* weighted average of disaggregate industries in Table 4.10). A potential explanation would be that important interindustry effects are at work. That is, a large subsidy to a particular industry would either stimulate or inhibit private R&D investments in other industries, and particularly in those which are technologically or economically close to the subsidized industry. According to our results, these indirect impacts would be negative in all countries (the average of the estimates at the disaggregate industry level are larger than the estimates at the aggregate industry level), but France and Germany. In France there is no substantial interindustry impacts of R&D subsidies, whereas in Germany R&D subsidies would have a stimulating impact on other industries. Mamuneas and Nadiri (1996) validate our interpretation for the United States. With a panel data set composed of 15 industries over more than 30 years (1958 to 1988), they find that, for a given industry, government funded R&D performed in other industries and privately funded R&D are substitutes. That is, subsidizing an industry's R&D activities is likely to crowd out private R&D in other industries.

4.4.3. An insight into the determinants of the private R&D investment response to R&D subsidies

At the aggregate level, Table 4.7 suggests that the more stable a country's subsidization policy over time, the less an increase in government R&D is likely to deter private R&D investments. In this last subsection we intend to test whether this is also true across the 22 disagreggate industries in each country. Table 4.11 aims at further investigating the factors which may influence the response schemes of private R&D investments 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. The three explanatory variables put forward are the average R&D subsidization rate, the average R&D intensity, and one indicator of R&D subsidization instability. The indicator of instability for each industry is the standard deviation of the R&D subsidization ratio's annual growth rates over the period 1973-90. The regression equation has the following form for each country:

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

where j denotes the industries, GT is the average R&D subsidization rate ($GT = RG / RT$) for each industry over the period 1973-1990, IR is the average R&D intensity ($IR = RT / Q$), and $STAB$ is an indicator of R&D subsidization instability computed by taking the standard deviation of the annual growth rate of the R&D subsidization ratio over the period 1973-1990. 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 subsidization variable aims at investigating whether there are decreasing returns associated with government R&D. A negative β_1 would mean that the more an industry is subsidized, the less it is likely to be stimulated by additional R&D subsidies. The R&D intensity variable intends to test whether high-tech industries adopt particular response schemes. Finally, we expect a negative sign for the parameter associated with the indicator of R&D subsidization stability. In order to test whether the econometric results are stable with respect to the specifications used, the response schemes estimated through the different models are alternatively introduced as left-hand side variables.

The econometric results presented in Table 4.11 show that the determinants of the private R&D response profiles to government R&D may vary across countries. For instance, the average R&D subsidization rate variable is associated with a significant negative coefficient in France while it is positive in the UK, independently of the alternative models used. In France and Japan (depending on the econometric model for Japan) it seems that the more an industry is subsidized, the more the impact of R&D subsidies on private R&D is likely to be weak or negative. This tends to support the view that R&D subsidies may be exposed to the law of decreasing returns. For the UK the coefficient is positive which means that the more an industry is subsidized, 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 subsidization rate. The R&D intensity variable is associated with a coefficient which is either negative like in the US and Germany, or insignificant like in the other five countries. Therefore, among the US and German industries, the more an industry is R&D intensive, the less it is likely to be stimulated by government R&D.

Table 4.11.
The determinants of the private R&D investments response to R&D subsidies[1]

Estimation procedure	IV-2SLS						TD-2SLS	
Model	[1]	[2]	[3]	[4]	[5]	[6]	[1]	[4]
USA, n = 21								
Instability	-.372 *	-.364 *	-.508 *	-.530 *	-.480 *	-.548 *	-.287 *	-.379 *
	(.177)	*(.148)*	*(.179)*	*(.186)*	*(.182)*	*(.196)*	*(.120)*	*(.165)*
RG / RT	.607 *	.473	.658	.690	.598	.751	.204	.029
	(.324)	*(.314)*	*(.470)*	*(.433)*	*(.472)*	*(.476)*	*(.173)*	*(.311)*
RT / Q	-.008	-.021 *	-.028 *	-.028 *	-.027 *	-.032 *	-.021 *	-.026 *
	(.012)	*(.009)*	*(.015)*	*(.014)*	*(.015)*	*(.015)*	*(.005)*	*(.011)*
Adjusted R^2	.303	.304	.335	.330	.279	.350	.204	.224
Canada, n = 18								
Instability	-.364 *	-.392 *	-.466 *	-.472 *	-.502 *	-.439 *	-.344	-.566 *
	(.187)	*(.147)*	*(.119)*	*(.130)*	*(.183)*	*(.172)*	*(.226)*	*(.167)*
RG / RT	-.350	-.524	-.386	-.424	-.794	-.889 *	-.590	-.115
	(.751)	*(.577)*	*(.268)*	*(.281)*	*(.508)*	*(.537)*	*(.811)*	*(.375)*
RT / Q	.016	.002	-.025	-.020	-.022	-.016	.004	-.036 *
	(.021)	*(.015)*	*(.015)*	*(.015)*	*(.026)*	*(.027)*	*(.020)*	*(.021)*
Adjusted R^2	.146	.274	.456	.415	.505	.475	.000	.432
Germany, n = 22								
Instability	-.051	-.373	-.379	-.351	-.950 *	-.970 *	-.268	.130
	(.355)	*(.421)*	*(.687)*	*(.679)*	*(.582)*	*(.528)*	*(.485)*	*(.701)*
RG / RT	-.879 *	.070	.404	.356	.436	.375	.488	.182
	(.457)	*(.497)*	*(.651)*	*(.653)*	*(.698)*	*(.625)*	*(.850)*	*(.565)*
RT / Q	-.087 *	-.054	-.049 *	-.043	-.061 *	-.053 *	-.075 *	-.043 *
	(.020)	*(.022)*	*(.027)*	*(.027)*	*(.030)*	*(.027)*	*(.033)*	*(.023)*
Adjusted R^2	.657	.201	.051	.015	.180	.165	.252	.144
France, n = 20								
Instability	.044	.027	.023	.019	.053	.043	.146	-.032
	(.192)	*(.110)*	*(.326)*	*(.331)*	*(.338)*	*(.338)*	*(.108)*	*(.365)*
RG / RT	-2.504 *	-1.464 *	-3.159 *	-3.187 *	-3.220 *	-3.198 *	-1.812 *	-3.016 *
	(.875)	*(.531)*	*(1.801)*	*(1.799)*	*(1.858)*	*(1.852)*	*(.825)*	*(1.758)*
RT / Q	.027	.020	.055	.055	.067	.063	.017	.039
	(.039)	*(.024)*	*(.085)*	*(.085)*	*(.088)*	*(.087)*	*(.039)*	*(.081)*
Adjusted R^2	.659	.637	.371	.379	.345	.350	.543	.373
Italy, n = 18								
Instability	-.296 *	-.239 *	-.172	-.192	-.187 *	-.181 *	-.208	-.153
	(.146)	*(.100)*	*(.110)*	*(.119)*	*(.107)*	*(.106)*	*(.143)*	*(.105)*
RG / RT	-.848	-.833	-.838	-1.133	-1.051 *	-.924	-.377	-.869
	(.642)	*(.658)*	*(.608)*	*(.844)*	*(.554)*	*(.626)*	*(.805)*	*(.687)*
RT / Q	.031	.013	.039	.056	.037	.032	-.013	.034
	(.051)	*(.050)*	*(.051)*	*(.066)*	*(.048)*	*(.051)*	*(.063)*	*(.057)*
Adjusted R^2	.129	.188	.084	.099	.178	.107	.000	.047
Japan, n = 20								
Instability	-.040	.000	-.034	-.018	-.037	-.012	.044	-.000
	(.075)	*(.046)*	*(.032)*	*(.027)*	*(.026)*	*(.024)*	*(.117)*	*(.037)*
RG / RT	-1.807 *	-.755	-.232	-.220	.062	-.215 *	-5.585 *	-2.056 *
	(.964)	*(.531)*	*(.284)*	*(.261)*	*(.114)*	*(.106)*	*(1.899)*	*(.750)*
RT / Q	-.015	-.008	-.005	-.007	-.015 *	-.015	.014	.001
	(.011)	*(.007)*	*(.008)*	*(.006)*	*(.008)*	*(.006)*	*(.022)*	*(.009)*
Adjusted R^2	.391	.190	.000	.000	.143	.150	.789	.720
UK, n = 21[2]								
Instability	-.613 *	-.657 *	-1.265 *	-1.379 *	-1.249 *	-1.315 *	-.462 *	-1.057 *
	(.218)	*(.150)*	*(.269)*	*(.312)*	*(.278)*	*(.293)*	*(.235)*	*(.308)*
RG / RT	-.003	.503 *	.926 *	.880 *	.795 *	.805 *	.951 *	.926 *
	(.997)	*(.257)*	*(.276)*	*(.388)*	*(.263)*	*(.284)*	*(.500)*	*(.401)*
Adjusted R^2	.049	.382	.577	.511	.615	.596	.152	.405

1. The dependent variables are the estimated private R&D elasticities of R&D subsidies. OLS estimates, standard errors are heteroskedastic-consistent. *RG/RT* is the average R&D subsidization 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 subsidization ratio. These explanatory variables are computed over the period 1973-90 for each industry. **2.** For the UK, the R&D intensity has been removed from the regression because of a strong correlation with the R&D subsidization ratio. * the estimated parameter is significantly different from zero at a 10% probability threshold.

Concerning the instability variable, its influence on the response profiles is more homogenous across countries. The estimated parameters are negative and significant for the USA, Canada, Italy, and the UK, which gives an additional indication that the more an industry's R&D subsidization rate is timely unstable, 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. These observations are reinforced by the fact that they are robust with respect to the empirical model considered (compare the columns of Table 4.11). It can therefore be recognized that, on average, the more an industry's subsidization rate is volatile, the weaker the efficiency of R&D subsidies. This finding is compatible with the results obtained by Hall (1992), who shows that in the United States the effect of R&D tax incentives has been growing over time, as it appeared that the fiscal scheme was to be maintained in the future.

4. 5. Concluding summary

This chapter attempted to better understand the interrelations between government R&D, private R&D, and productivity growth. More precisely, the focus has been put on two basic questions: *(i)* Do R&D subsidies contribute to improve productivity growth? and *(ii)* Do R&D subsidies have an indirect impact on productivity growth, via the stimulation or the inhibition of private R&D investments?

The survey of the literature on this area of research provides some useful preliminary insights towards these two questions. Concerning the first one, it is generally agreed that government R&D has little or no effects on productivity growth, as compared to private R&D. This quite pessimistic view is further worsened by the observation that firms operating in highly subsidized industries benefit from weak returns to their R&D activities. Concerning the second question, the existing evidence is more optimistic, although more ambiguous. The common assertion is that government R&D boosts private R&D investments. However, there is some clues that government R&D may substitute for private R&D, depending on the industries and the countries considered, and on the empirical model adopted. In the framework of an homogenous international comparison and on the basis of panel data, we intend to contribute to this existing literature.

In the matter of the first question our empirical strategy, which is based on 22 industries across seven industrialized countries during the eighties, is twofold. First, we investigate whether the rates of return to total R&D vary across industries with respect to the subsidization rate R&D. Second, we test whether R&D subsidies are associated with a rate of return similar to the one of private R&D. In both cases our empirical results do not validate the suspicious stance taken up in the literature against R&D subsidies. On the contrary, they appear to be quite more optimistic.

First, we find that highly subsidized industries benefit from higher returns to R&D than lowly subsidized industries. However, this finding is not as surprising as it might appear at first sight because our estimates implicitly incorporate intra-industry spillovers effects. It is in fact consistent with the idea that companies in highly subsidized industries benefit from lower returns to R&D. These lower returns are due to the fact that the presence of government R&D induces strong interfirm R&D spillovers. Consequently, the higher returns to R&D in highly subsidized industries might simply be the validation that the social (intra-industry) return emanating from a firm's R&D activities is substantial and largely offset the lower returns to direct R&D.

Second, our estimates of the direct impact of R&D subsidies on productivity growth do not confirm the findings of the existing literature. On average, private R&D is not associated with higher or equivalent returns than total R&D. Further, we cannot reach the conclusion that the impact of privately-funded R&D is significantly higher than the impact of publicly-financed R&D. These results are not really in accordance with those provided in the literature. They engender a much less severe mind about the effectiveness of R&D subsidies. In our view, this suggests that disaggregating total R&D into its two main sources of funds is not a reliable approach; mainly because « *a dollar is a dollar, irrespective of source* ». Although it has been argued that returns to private and government R&D might differ because of more acute spillovers generated by the latter, we submit that total R&D - instead of private or government R&D - is subject to such spillovers. Indeed, one can hardly imagine that the innovative output of a firm could be disaggregated into private and government knowledge.

Having no strong evidence on the relative effectiveness of R&D subsidies in contributing to productivity growth, we shift towards the question of whether R&D subsidies stimulate private R&D investments. To this end, and thanks to a broader availability of data which range from 1973 to 1990, the empirical analysis concentrates on both the aggregate (macro) manufacturing sector and 22 disaggregate manufacturing industries in the seven industrialized countries. Our results lead to the following methodological and policy implications.

First, the estimated impact of government R&D on private R&D is sensitive to slight modifications of the empirical model. More particularly, the inclusion of an adjustment process may modify both the sign and the significance of the parameters of interest, provided one holds for the effect of output. Therefore, one may infer that the discrepancies observed among the results obtained in the existing literature are, at least partly, the consequence of heterogeneous and sometimes contrasting empirical specifications.

Second, the estimation results suggest that, at the aggregate industrial level, government R&D has a crowding out effect on private R&D investments in Canada, France, and Italy while in the UK R&D subsidies stimulate private R&D expenditures. No significant relationship is estimated for the US, Japan, and Germany. However, the estimates at the aggregate level should not lead to generalized conclusions for all industries. Estimates across the 22 disaggregate industries confirm this statement. In each country, R&D subsidies do foster the private R&D effort of some industries. Further, in all countries there is no complete substitution effects of private R&D towards government R&D. In other words, R&D subsidies always contribute to raise total R&D investments.

Third, the impact of R&D subsidies on private R&D investments evaluated at the aggregate level is lower than the weighted average of the impacts measured for all disaggregate industries, suggesting that important negative interindustry effects are at work. That is, subsidizing an industry might stimulate its own private R&D investment but might also influence the R&D investments in other, closely related, industries. Fourth, the cross-industry and cross-country differences in the private R&D investment response to R&D subsidies may be explained, at least partly, by the degree of volatility of the subsidization policy. The more a subsidization rate is unstable, the less an increase in R&D subsidies is likely to stimulate private R&D investors.

In a nutshell, we do not provide any evidence that government R&D is less efficient than private R&D in contributing to productivity growth. On the contrary, highly subsidized industries benefit from higher rates of return to total R&D, probably because of more acute intra-industry spillovers. Since R&D subsidies are always associated with a rise in total R&D investments, we are more inclined to support the idea that such subsidies are worthwhile. However, it should be kept in mind that their effectiveness might be improved upon, for instance through a higher stability and through an appropriate identification of the potential indirect effects that R&D subsidies might have on other industries.

Do we have to disregard the idea, suggested in the introduction of the present chapter, that the inverse relationship observed between a country's rate of return to R&D and its subsidization rate is due to a weak effectiveness of government R&D? According to the present chapter, the answer would be yes.