CHAPTER 7 - Conclusions

"La science n'a pas de patrie."

LOUIS PASTEUR, Discours d'inauguration de l'Institut Pasteur, 14 novembre 1888

7.1. Summary

The main objective of the present work was twofold. First, we wanted to determine whether the manufacturing industries' R&D activities are associated with similar rates of return across the G7 countries. Second, we suggested that three factors might potentially explain why R&D outlays are associated to different degrees of efficiency across countries and, in some cases, why they do not translate into productivity growth. These factors are related to the degree of government interventionism in the financing of R&D projects, to the extent to which knowledge diffuses across industries, and to the extent to which knowledge spills over national borders. Part I (chapters 2 and 3) focused essentially on the first objective, Part II (chapters 4 to 6) on the second.

The empirical analyses offer a number of original approaches with respect to the existing literature. Three characteristics, which appear in most chapters, deserve to be mentioned. The first one is that we allow for a homogeneous international comparison of the returns to direct and external R&D, as well as of the effectiveness of government support to R&D. This is particularly advantageous for cross country comparison of various policy issues. Furthermore, the literature focuses essentially on US industries, whereas we introduce six other countries into our analysis. The second characteristic is that many facets of the economic analysis of technological change are investigated within a homogenous empirical framework, therefore allowing for inter-chapter complementarity and feedback. The third particularity is that all chapters rely on time series cross section data sets, whereas most existing investigations rely on cross sections of industrial sectors. Although the use of panel data emerged widely in the early nineties (with a few exceptions), it is still far from being generalized amongst the empirical analyses of technological change.

By tackling a myriad of technical and conceptual issues, Chapters 2 and 3 clearly distinguish themselves from the existing studies that focus on the rate of return to direct R&D. To our best knowledge, there is literally no study that attempts to test for the sensitiveness of the estimated returns to all the measurement issues related to the computation of R&D capital stocks (e.g., R&D depreciation rates and lag) and of total factor productivity growth indexes (e.g., relaxing the hypotheses of constant returns to scale and perfect competition and correcting for the double counting of R&D outlays). Important methodological implications emerge from this starting empirical analysis.

First, allowing alternatively - i.e., testing - for free returns to scale, imperfect competition, improperly measured labor cost shares, productivity indicators corrected for double counting and expensing of R&D expenditures, and alternative R&D deflators, does not affect the estimated impact of R&D substantially. These results suggest that the total factor productivity growth approach is much more robust than would have appeared at first sight. We do not deny that important factors such as scale and markup effects generally occur, they are all but negligible. But what matters is that they do not affect markedly the estimated relationship between R&D and productivity growth.

Second, if the estimates are relatively stable with respect to the various total factor productivity growth measurement issues, the reverse is true with regard to the main measurement issues related to the computation of the R&D variable and to the estimation procedure. The rates of return to R&D are more sensitive to the assumed R&D depreciation rates, to the assumed lags, to the presence of a few outlying observations, and to the studied period. However, despite this sensitivity, the ranking of the estimated parameters across countries stays sufficiently stable.

Third, there is strong *prima facie* evidence that the rates of return to R&D vary substantially across countries. Japan takes the lead, with a return to R&D of about 250%. Then come France and Germany, with a R&D impact of about half the one of Japan. The US and Italy are associated to relatively low returns, whereas no significant impact of R&D is estimated for Canada and the UK. This ranking of the seven countries with respect to the relative efficiency of R&D is corroborated by most macro-level studies, except for France which is generally associated with a return to R&D lower or similar to that of the US.

The first potential reason put forward to explain this international variability in the efficiency of R&D is related to the subsidization of R&D activities. Government-financed R&D has the reputation of being less efficient than privately-financed R&D, and R&D subsidization rates vary to a great extent across countries. Chapter 4 focuses essentially on this public policy aspect of the economic analysis of technological change. Three basic questions are asked: *i)* Is the rate of return to total R&D higher or lower in highly subsidized industries? *ii)* Do R&D subsidies contribute to improve productivity growth to the same extent that private R&D does? and *iii)* Do R&D subsidies have an indirect impact on productivity growth, via the stimulation or the inhibition of private R&D investments?

Our empirical results regarding these three questions do not validate the suspicious stance taken up in the literature against R&D subsidies. Contrary to our expectations, they appear to be much more optimistic. We find that highly subsidized industries benefit from higher returns to R&D than lowly subsidized industries, which is consistent with the idea that government support to R&D induces stronger intra-industry (i.e., interfirm externalities within an industry) spillovers. In addition, we do not reach the conclusion that the impact of privately-funded R&D is significantly higher than that of publicly-financed R&D. In fact, we argue that disaggregating total R&D into its two main sources of funds as separate determinants of productivity growth is not a reliable approach; mainly because « *a dollar is a dollar, irrespective of source* », whatever the data aggregation level.

The third question concerns the effectiveness of publicly-financed R&D in stimulating privately-financed R&D. The results suggest that R&D subsidies either stimulate or inhibit private R&D expenditure, depending on the country and the industry considered. Nevertheless, the observed substitution effects are never complete, which means that R&D subsidies always contribute to raise total R&D investments, and perhaps productivity growth. Two important complementary findings also appear. The first one is that negative interindustry effects are likely to be at work. Subsidizing an industry might stimulate its own private R&D investment but might also crowd out the R&D investments in other, closely related, industries. The second result is that the cross-industry and cross-country differences in the private R&D investment response profile to R&D subsidies may be explained, at least partly, by the degree of volatility of the 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 summary, our results do not corroborate the idea that government support to R&D can partly explain the observed international differences in the ability to translate research activities into productivity growth.

The second factor put forward to explain these differences is linked to the diffusion of an industry's innovations towards other industries. More precisely, the idea is that strong inter-industry R&D spillovers might induce lower returns to R&D, but at the benefit of higher social returns. Chapter 5 contributes to the literature on interindustry R&D spillovers in several respects. First, a large number of weighting matrices of different types and geographical origins are gathered together. Second, it scrutinizes the weighting components of these matrices through various statistical techniques that allow to visualize the similarity of these matrices. Third, it provides a first insight into the relative efficiency of three types of interindustry R&D spillovers in contributing to productivity growth.

The main conclusion emanating from Chapter 5 is that it is not possible, with the present availability of supporting matrices, to provide homogenous estimates of interindustry spillovers across countries, except for input-related rent-spillovers. Indeed, the various input-output matrices, which are highly homogenous, are not similar enough to be used alternatively in different countries. By transitivity, the procedure regularly applied in the literature, that consists in using a single technology flows matrix for different countries, is not reliable. Some other findings emerge as well. For instance, the interindustry links profiles characterizing rent-spillovers (i.e., derived from input-output matrices) are clearly distinct from those characterizing knowledge-spillovers (i.e., derived from technological proximity matrices). The technology flows matrices are in an intermediate position but appear to be closer to the concept of rent-spillovers than to the concept of knowledge-spillovers.

Industry-specific peculiarities also appear. For instance, low-tech industries benefit from outside knowledge more through the channel of patent-flows whereas high-tech industries benefit more from their technological proximity to other high-tech industries. Upstream industries further produce the highest social returns embodied in input transaction profiles. The social rates of return to R&D differ substantially across countries according to the transmission channel considered. The cumulated social and direct returns to R&D are relatively high in Japan, France, Germany, and Italy. Keeping in mind that the estimates of external returns to R&D might be seriously biased due to data limitations, one cannot reach the conclusion that countries with relatively poor performances of direct R&D enjoy more acute interindustry R&D spillovers. According to our results, Italy is the only country where interindustry R&D spillovers seem to compensate for the relatively weak return to direct R&D.

If knowledge diffuses across industries, there is no reason for it to be confined to national borders. International R&D spillovers are the leitmotiv for Chapter 6, which aims at testing whether the diffusion of R&D across countries might explain why countries such as Japan benefit from a relatively high return to R&D as compared to others, such as the UK. Three potential channels of international R&D spillovers are taken into account in this analysis: imports, inward foreign direct investments, and technology sourcing. This investigation can be seen as pioneering in two respects. First, we somehow reconcile the literature on international R&D spillover with the literature on the impact of inward FDI by properly incorporating a technological component into FDI flows. Second, we provide a first evaluation of the extent to which a country's outward FDI may contribute to raise its own productivity through the sourcing of the host countries' technological base. In addition, we re-examine Coe and Helpman's methodology concerning an aggregation and an indexation bias. A more accurate - both theoretically and empirically - model is proposed to evaluate how the R&D performed by other countries might affect domestic output and productivity via trade flows.

The empirical results show that outward FDI flows and import flows are two simultaneous channels through which technology spills over and benefits other industrialized countries. We therefore provide credence to the hypothesis of technology sourcing associated with MNEs' activities abroad. This 'technological boomerang' feature associated to outward FDI emerged mainly during the eighties and was much weaker during the seventies. Besides, and contrary to frequent conjectures, inward FDI flows do not contribute to improve the technological base of host economies. Other interesting findings also emerge concerning the relative importance of international R&D spillovers for small countries and for the countries that are open to trade.

This last chapter provides some explanation for the observed paradox concerning the link between R&D and productivity growth. The US and the UK benefit respectively from weak and zero returns to their own R&D activities, but they contribute much more than other countries to international output growth, especially through the sourcing of their own technological base.

7.2. Common drawbacks and open fields

A number of criticisms could be raised against the empirical analyzes developed in the previous chapters. Both the quality of the data and the empirical analyses can be extended and improved. However, before listing the most important imperfections that subsist, it should be kept in mind that these shortcomings are not specific to our analyzes; they are applicable to most of the existing literature in this sphere of research.

About the need for more reliable data, Chapter 3 clearly highlights a crucial need for reliable approximation of R&D lags and depreciation rates, reinforced by the fact that the optimal lags and depreciation rates may not be convincingly determined by a best fitting strategy, at least with industry level data. We use industry-specific R&D depreciation rates and lags computed for Japan. Although we were mainly interested in the cross industry variability of these figures, it is still unclear whether strong international differences are at work for each of these manufacturing sectors. Further, there is no serious indications about the real effect that reliable capacity utilization rates and industry-specific R&D deflators would have on the observed rate of return to R&D.

Another lack of robustness might stem from the data used in Chapter 4. Missing data on R&D subsidies are interpolated and it is difficult to validate the quality of these interpolations. Moreover, it has proven very difficult to estimate the indirect contribution of R&D to other industries via spillovers. The current quantitative understanding of this whole process remains seriously flawed. No clear improvement should be expected in the future without a major extension and revision of data concerning interindustry technology flows matrices. They should be computed within a homogeneous methodology for several countries. However, a feasible extension of Chapter 5 is to incorporate the exchange of investment goods between industries, as an indicator of knowledge-spillovers. Such data are easier to compile and would suffer much less from methodological heterogeneity across countries.

Besides these conventional shortcomings due to data limitations, a number of empirical extensions would be worthwhile. For instance, the fourth chapter focuses exclusively on the efficiency of R&D subsidies. It does not deal with the alternative policy tool aiming at fostering private R&D investment: fiscal incentives (i.e., R&D tax credits and depreciation allowances). Although no study, to our knowledge, incorporates both types of incentives in a single empirical framework, one might legitimately wonder if important interactions between these policies are at work. If so, the estimated stimulation effects of government-financed R&D might be biased by the failure to incorporate R&D tax incentive into the models.

In addition, more attention needs to be devoted to the characteristics and mechanisms of the intersectoral diffusion and adaptation of innovation. The understanding of the extent to which R&D spillovers take place and of the relative efficiency of different types of spillovers is rather incomplete. Chapter 5 does not consider the services industry. This industry has the reputation of doing little research but benefits largely from outside knowledge - i.e., the knowledge generated by manufacturing industries. In this respect, our estimated social returns to R&D are clearly underevaluated. The value added of the services industry in the US, the UK, and Japan, accounted for respectively 70%, 68%, and 56% of GDP during the eighties. These figures reflect the potential size of our underevaluation, especially for the UK and the US.

Further research should also focus on international R&D spillovers measured at the industry level. The aggregate estimates of Chapter 6 are averages. In the present context of technological specialization in industrialized countries, industry level analyses would allow to get a clearer insight into the process of international R&D spillovers. More precisely, it would be interesting to infirm or confirm the role of technology sourcing practices at a more disaggregate level of analysis. Concerning inward FDI, they might be an efficient channel of international knowledge spillovers for some particular industries, and not for others, which would corroborate our non significant estimates at the macro level.

Finally, although we provide some ‘quantitative’ explanations of the observed international differences in the productivity of R&D, it should be kept in mind that key explanatory factors are to be found through the *institutional* stream of analysis. Abramovitz (1952) already suggested that searching for the understanding of technology and technical advance quickly leads to the need to understand the internal structure of the business firms and of the institutions that surround them. Indeed, a main theme that has not been unfolded here is the institutions within which technology develops, and the contrasting influences on innovation of governmental, military, commercial and other kinds of organizations. Systemic differences need to be taken into account, keeping in mind that policies or institutional arrangements that are efficient in one country might not work elsewhere.

For instance, we used total government-funded R&D performed by business firms, but we do not know the extent to which R&D subsidies, and even private R&D is oriented towards public goods, such as defense objectives. These types of contracts are reputed to induce management sclerosis and a depletion of economic might. Another major issue is the role played by universities, especially in basic research, and the way it is transmitted to industry. In Japan more basic research is done within the industry, whereas it is more implemented by universities in the US. Our R&D figures in the previous chapters ‘only’ encompass the research activities performed by business firms. Therefore, since basic research is at the root of technological change, it would be worthwhile to take into account this kind of research performed by universities and to trace its transfer towards industries, at least in countries like the US. These two examples show that, again, the availability of data draws the limits of the quantitative analysis of technological change. If it were possible to dissociate total R&D investments of industries by socio-economic objectives and/or by type of research (i.e., basic research, applied research, and development), one would probably be able to provide additional information on why the return to R&D varies across countries.

7.3. Some implications for S&T policies

In spite of the need to extend further the economic analyses presented in the previous chapters, several policy issues emerge. First and foremost is the understanding that R&D alone does not necessarily crystallize into an improved economic performance. Does it mean that R&D activities should not be sustained? Certainly not. At least because the estimated returns to R&D are either positive or zero, but never negative. The fact that these returns are never significantly negative is an indication that R&D allows *‘to stay were we are and to prevent us from sleeping back’*. [1] In other words, although R&D activities seem to be a necessary (but not sufficient) condition for productivity growth, they might be a sufficient condition against a productivity deterioration. Besides, R&D generates positive externalities and is therefore useful from a societal point of view. Nevertheless, it seems that both the private and social return to R&D vary to a large extent across countries.

[1] *Cf. Griliches (1974, p. 61)*

A first potential explanation of this R&D-productivity paradox is that government support to R&D, despite its devotion to correct for market failures, might generate inefficiencies. This hypothesis has to be rejected, at least in some respects. There is no evidence that government R&D is less efficient than private R&D in contributing to productivity growth. On the contrary, in each country, the relatively highly subsidized industries benefit from higher rates of return to total R&D, probably because of more acute intra-industry spillovers generated by a stronger presence of publicly-financed R&D. Further, 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. Yet it is still unclear why the industries that operate in countries with little government support to R&D, such as Japan and Germany, are characterized by the highest rates of return to R&D. Of course there is no clear causality here. Government R&D could induce lower return through particular mechanisms. Conversely, public authorities could subsidize business R&D to compensate for weaker returns. The only factor that could deter subsidization policies is perhaps related to their particular objectives. If a large share of government support is driven by specific mission-oriented policies, namely defense R&D, one should not expect significant payoff, at least on private markets, simply because the target is not, *a priori*, economic growth.

However, it should be kept in mind that the effectiveness of subsidization policies might be improved. Remember firstly that risk - the uncertainty inherent to research activities - is one of the main reason for firms to underinvest in R&D. Unstable subsidization rates would probably not contribute to temper the risks faced by firms. The empirical evidence supports this presumption. The industries and the countries that benefit from stable subsidization rates are more eager to be stimulated by R&D subsidies. Second, it seems that government support to a particular industry crowds out private R&D investments in others. These indirect effects of R&D subsidies should be properly identified since they might have a clear incidence on the global efficiency of resource allocation profiles adopted by public authorities. The two aforementioned factors - i.e., stability and indirect effects - clearly show that governments, by attempting to correct for market failures, might themselves be subject to, or provoke, some kinds of failures. Measures aimed at improving the way markets work can actually be detrimental for technological change. These arguments do not dismiss the necessity of government support to business R&D, but they have to be taken as a warning against inadequate policies.

The noticeable impact of interindustry R&D spillovers should also be taken into account when evaluating the effectiveness of government support to R&D. Indeed, even if a dollar of subsidy does not automatically produce an equivalent increase in private R&D, the modest increase in total R&D might still be at the source of important internal and social returns. These returns ought to be confronted to the forgone dollar of subsidy for a proper evaluation. The evidence that both rent and knowledge spillovers contribute to output growth also underlines the importance of policies towards industrial competition. A higher degree of competition inside an industry would reduce prices, and therefore raise the potential effects of rent spillovers. Although R&D leaks out towards other industries, this indirect effect does not appear to explain convincingly why R&D might be unsuccessful.

The presence of important inter-industry spillover effects confirms the *'market failure'* justification for government support to business R&D, from a societal point of view. Nevertheless, these spillovers also reduce the solemnity of the issue at work, at least for the industries that take advantage of external knowledge at relatively low costs. One may therefore wonder whether the gain generated by the absorption of outside knowledge compensate for the loss due to imperfect appropriability. In this respect, efficient financial incentives should target the R&D projects implemented by the industries that generate relatively high R&D spillovers and that benefit from weak externalities and/or private return to R&D.

Governments should induce the capacity to adopt innovations emanating not only from other industries, but also from other countries. Indeed, the new international economic environment seems to reduce the ability of any one national economy to appropriate the economic returns from R&D performed within its boundaries. The results of chapter 6 suggest that government policies supporting the adoption and utilization of foreign technologies would yield a high social payoff. R&D diffuses internationally, probably inducing higher returns in the countries of destination (the imitators) and lower returns in the countries of origin (the innovators).

In this context of international diffusion of R&D, countries with relatively open economies and with small domestic markets face quite different problems than large countries in formulating technology policies. In small countries, foreign R&D has a greater impact on productivity growth than the R&D performed within their borders. Such countries might therefore be well advised to "free ride" on the scientific work performed in the largest countries, because the result of such work is disseminated rapidly and cheaply. Trade and outward FDI appear to be two efficient channels of international R&D spillovers.

The more a country is open to trade, the more it is likely to benefit from foreign R&D. This is especially true if the countries of origin are highly intensive in R&D. Trade policies might therefore influence a country's rate of technological change substantially. Outward FDI flows, which reflect partly technology sourcing practices, also allow a country to benefit from foreign R&D. In this respect, the strategic investment policies adopted by foreign governments towards multinational enterprises has a clear role to play in the international diffusion of technologies.

Governments should adopt a global perspective in reaction to the ongoing globalization of economy and technology. The research activities of foreign firms and foreign nations clearly need to be monitored more carefully through active participation in such activities and continual scanning of scientific and technological horizons. One appropriate policy, though *a priori* counterintuitive, is to aim at fostering investment abroad.

The intensification of international R&D spillovers might also affect governments' willingness to foster domestic R&D investments through direct support or tax incentives. On the one hand, R&D subsidies that benefit other countries might be less easily justified. On the other hand, exploiting foreign knowledge bases might prove to be more advantageous than trying to reinforce the domestic knowledge base through intensive research activities. A recent theoretical analysis by Muniagurrie and Nirvikar (1997) tackles this issue.[2] They find that if domestic profits increase (decrease) with higher foreign R&D - i.e., if the spillover (competition) effects dominate, a tax (subsidy) to domestic R&D is appropriate. Their verdict would be applicable if spillovers appeared by magical zero costs. However, Spillovers, especially knowledge-spillovers, do not fall like *manna from heaven*. Absorptive capacity and adaptative R&D efforts have to be developed in order to benefit from external knowledge. Therefore, taxing domestic R&D when international spillovers are prominent would probably reduce their potential effect on domestic productivity growth. Rather, this issue underlines the role of the educational system, more particularly universities, in providing a highly skilled labor force to industries.

[2] Their paper is an extension of Spencer and Brander's (1983) theoretical analysis of countries' strategic incentives to subsidize domestic R&D. A key property of their model is that increases in foreign R&D lower domestic profits.

These implications suggest that science and technology policies are certainly not the only force affecting technological change. A nation's policies concerning economic growth and investment, openness to trade and foreign direct investments, taxes and competition, and education and infrastructure, have substantial effects on its rate of innovation. Further, with the present phenomenon of globalization, national innovative performances might be influenced by other countries' policies towards science and technology. Science and technology policy is one aspect of economic policy-making and not an entirely separate subject. As suggested by Mowery and Rosenberg (1994), the wrong mix of economic policies can lead to a failure of any specific policy targeting science and technology, no matter how ingeniously conceived.