I. Introduction

SUMMARY

This introductory chapter delimits the scope of the thesis within the exciting and fast developing area of the economics of technological change. The main objectives of this research as well as the motivations behind this project are addressed. The outline of the thesis can be summarized as follows. The second chapter discusses the main determinants and outcomes of technological change. The importance of technological activities is illustrated and some issues related to its measurement are addressed. The third chapter describes the main features as well as the construction of the dataset used for the empirical analysis. The next three chapters are the core components of the thesis. These empirical chapters are organized in a similar way: each chapter starts by presenting the methodological and econometric framework used to perform the corresponding analysis. Then, after a review of the most prominent related studies, the main results are discussed. In the fourth chapter the number of patents applied by firms is explained by current and lagged levels of R&D expenditures and technological spillovers. The fifth chapter explores the contribution of R&D to productivity performances of firms. The last empirical chapter goes deeper into the analysis by measuring the impact of technological spillovers on productivity increases. Finally, the conclusion summarizes the main empirical findings and discusses the economic and methodological implications of the thesis. Suggestions for the future research agenda are also exposed.
1.1. THE CONTEXT

Economics teaches us that the endowment of natural resources and production factors like labor force, physical capital and knowledge capital are important factors which determine the production possibilities frontier of a country. It has now become clear that besides elements such as economies of scale, industrial organization, and quality of the labor force, technological change plays a considerable role in shifting this frontier upwards. Judging by the amount of resources allocated by firms to Research and Development (R&D) investments and by the publicly-financed funds mobilized in the ‘industrialized’ countries to support and promote research, these activities are without doubt a major source of economic prosperity and welfare growth. Indeed, the results of these activities are not only vital for firms to maintain their competitiveness, but by creating new goods and services or improving existing ones, they also contribute to a better satisfaction of individual and collective needs, e.g. health, job creation, communication technologies or defense. Yet, it remains undeniably true that if research and development are key elements in the process of scientific and technological innovations, they are not the only ones. A wide range of other factors are required to nourish innovative activities and to turn them into effective welfare improvements.

For instance, the recent discussion initiated by the European Commission among the various actors in private and public organizations has identified a certain number of fundamental objectives as essential ‘routes’ to foster innovation1. First, the research efforts need to be better targeted towards innovation by increasing the capacity to anticipate technical evolution, markets and competitors or by better coordinating technological projects as well as assessing their relevance for innovation. Second, the human resources for innovation need to be reinforced. This goal could be achieved by further developing formal and vocational training and by strengthening the links between higher education institutions and firms. Third, the conditions for the financing of innovation should be improved. Better access to private capital and more favorable fiscal regimes are two examples. A fourth objective is to improve the existing legal and regulatory environment, e.g. adapting and promoting the regulation with regards to standards, intellectual and industrial property rights, or the legal ways of

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cooperation. Finally the role and the modalities of public intervention regarding innovation should be adapted by ensuring its coherence and coordination, simplifying administrative procedures. Actions to promote new technological activities and their absorption may also be reinforced. Ultimately, the most fundamental factor is a state of mind, a culture towards innovation that associate creativity, entrepreneurship and willingness to take calculated risks.

To put the whole matter in a nutshell, innovation covers a variety of aspects and the process underlying this activity is an extremely complex one. This leads to the need of a better understanding of the process of technological innovation and the necessity to develop tools and methods allowing to assess the impacts of the technological activity upon the economy. These measurement tools should help managers and policy makers to appraise and to direct present and future science and technology policies. Among the potential tools available to economists, econometrics and economic modelling appear to be privileged methods and hence, they are advisable.

This thesis attempts to analyze one small part of the problem: the relationship between the determinants of the activity of innovation carried out by large international manufacturing firms and the success of this activity in terms of technological and economic performances. Before to understand more precisely the ins and outs of this work as well as the framework adopted to implement it, it is worth placing some emphasize upon the motivations behind this research as well as its purposes.

1.2. RESEARCH OBJECTIVES OF THE THESIS

The research performed throughout this dissertation aims at implementing quantitative methods in order to assess economic and technological performances of firms, i.e. it tries to assess the impacts of the determinants of technological activity on the results of this activity. For this purpose, a representative sample of the most important R&D firms in the world is constituted. The micro-economic nature of the analysis, as well as its international dimension are two main features of this research at the empirical level.

By way of introduction we address some general issues associated with the concept of technological activity of innovation. “What do we mean by technological activity of the firm?”, “What is the order of magnitude of these activities in comparison to other economic ones?”, “What are the forces that induce these activities or for what reasons do firms engage in such activities?”, “What are the impacts of these activities on firms’ technological performances?” or “What role can public authorities play in order to support and promote these activities?”. The consideration of these questions will clarify the subject of the thesis and outline some of the limits of the formalization of the links between technological and economic activities.
One of the objectives pursued in this work is the analysis of the effect of research and development on the success of innovative activities as measured by patent applications. Indeed, a number of recent studies have found a rather contemporaneous relationship between R&D and patenting activities\(^2\). Since it can be expected that R&D takes some time to be expressed into new products and processes, and as result in patents, this finding seems somewhat puzzling. In order to check this conclusion, it is useful to replicate a similar analysis on the basis of a different dataset, for instance by considering patents from the European Patent Office rather than from the US Patent Office.

Another question of interest is related to the importance of knowledge externalities generated by technological activities of other firms. These technological spillovers arise because of the imperfect appropriability of the outcomes of technological activities. Hence, if firms can benefit to some extent from the research output of other firms, these benefits can be expected to have a positive impact on the firms’ own research activities. Yet, in the theoretical literature, a negative effect of spillovers has also been brought to the fore\(^3\). These spillovers, of a competitive nature, have a negative rivalry effect on a firm’s probability to apply for a patent first, since the more there are active competitors in a given research area, the less a firm is likely to be the first to invent. Though it is not simple to disentangle between both effects, it may be interesting to estimate which effect prevails. The timing of spillovers effects needs to be addressed as well. Here also, because of the presence of lags in the diffusion of these effects, their impact on patenting is unlikely to be immediate and it is worth giving attention to their precise timing.

As it has been argued in the beginning of this introduction, the resources engaged by firms of industrialized countries into research and development activities are far from being negligible. This brings us to the question of the economic effectiveness of these activities. One prime objective of this research is to quantify the contribution of R&D activities to economic performances as measured by productivity increases. Thanks to the international dimension of this analysis, such an exercise should improve our understanding of the extent to which this contribution varies across firms in different countries. In a similar vein, we wish to know whether this contribution changes significantly from one industrial sector to the other, or according to the size or R&D intensiveness of firms. Another question of interest is whether this contribution has changed over time. In order to answer these questions, the conventional methodology of growth accounting at the micro level is implemented\(^4\). This framework, which is by essence neo-classical, hinges on the production function concept and is not exempt from any criticisms. So, before assessing the changes in real output resulting from changes in the traditional inputs, i.e. labor and physical capital, and the stock of R&D capital, we need to

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\(^2\) See Hall et al. (1986) for instance.

\(^3\) See Reinganum (1989) and Crépon and Duguet (1993) for a discussion.

\(^4\) See Griliches (1979) for a discussion of this framework, in particular the method for measuring the R&D capital.
address the main conceptual issues of the productivity residual methodology and present their possible remedies.

Several quantitative methods for evaluating the effectiveness of technological activities have been proposed in the literature\(^5\). Although, no method can claim to be superior to others, the choice of the econometric one has been laid down by the use of the production function framework. As we shall see, one main advantage of using this quantitative tool, is that it allows to deal with some issues associated with this framework\(^6\). One of these issues is the omission of important factors explaining the productivity performances. These effects are missing because of a lack of relevant data. A second problem is the simultaneity which may arise between the decision to devote resources to R&D activities and the resulting output. In order to circumvent these issues, the analysis performed in this work makes use of recently developed econometric techniques in the context of panel data.

The last topic investigated in the thesis is concerned with the formalization of technological spillovers in order to measure the importance and the direction of such effects through the economy and in particular their impact on firms’ productivity. One motivation behind this assessment exercise is the observation that some firms seem to be better in appropriating the fruits of their research activities than others. Hence, it is interesting to examine to what degree, firms of different geographic areas benefit differently from such phenomena. For instance, we can decompose the available spillover pool into its national and international components and then measure to what extent changes in these components contribute differently to productivity increases. We can also dissociate the impact of spillovers according to technological similarities characterizing firms from which they emanate. Since the diffusion of knowledge is socially desirable, a better understanding of the direction and the magnitude of these effects should be helpful for policy makers to target their science and technology policies. Yet, in order to explore these questions we need a conceptual framework that characterizes and allows one to formalize these externalities. One major objective of the thesis is to further explore this question. In particular, the main issues associated with this measurement exercise have to be identified. This is achieved by carefully examining the alternative approaches reported in the literature\(^7\). In a further step, suggestions are proposed and implemented to extend and enrich some of the existing approaches\(^8\). Finally, the implications of these alternative formalization schemes are assessed by exploring the sensitivity of results with regard to the spillover impacts on productivity.

\(^5\) Among these methods we can distinguish between the assessment by peers, questionnaires, or interviews; scoring methods, systemic approaches, e.g. multicriteria and relevance trees analysis; financial methods, e.g. cost-benefit, cost-effectiveness analysis; technological forecasting methods, e.g. scenario methods; science and technology quantitative indicators and econometric methods. For a review of the main characteristics, strengths and weaknesses of these methods, see Capron (1992).

\(^6\) See Mairesse and Mohnen (1995) and Griliches and Mairesse (1995) for a discussion of these issues.

\(^7\) For a review, see Griliches (1995) and Mohnen (1996).

\(^8\) To this end, the methodology suggested by Griliches (1979) and developed empirically by Jaffe (1986, 1988) is used.
Some of the main questions addressed in the thesis are illustrated in Figure 1.1. This figure helps to understand the links between the main objectives pursued and the structure of the thesis.

The numbers in the scheme refer to the following questions:
1. What are the main technological activities?
2. What is the importance of these activities across countries, time periods,...?
3. How do we define the underlying process characterizing the creation of knowledge?
4. What role public authorities can play to foster technological activities and knowledge creation?
5. What are the main determinants that induce this process?
6. What are the technological and economic outcomes of this process?
7. How do we measure these variables?
8. What is the impact of R&D and spillovers on firms' technological performances as measured by patents?
9. How to quantify the link between technological activities and determinants and knowledge creation and which econometric models are the most relevant?
10. What are the firms' economic performances as measured by productivity changes?
11. What are the issues associated to the productivity residual methodology?
12. How can we circumvent some of these issues?
13. How spillovers can be formalized?
14. What is the impact of spillovers throughout the economy?
1.3. OUTLINE OF THE THESIS

The second chapter illustrates the importance of R&D investments, patenting activities and other measures of technological activities performed by firms over the last 10 years. Since most of the subsequent empirical analysis uses these indicators, it is important to address some issues related to their measurement. The process underlying technological change embraces several dimensions. Some light can be shed on these dimensions by defining concepts such as fundamental research, experimental development or invention, innovation and diffusion. As it has been emphasized, research and development is one of the activity characterizing the process of innovation. In order to have a better appraisal of the share of R&D in innovation, it is worth examining other technological activities undertaken by firms. For instance, the absorption of external technologies require certain competencies that can be developed through own R&D. But firms may learn about new processes and products through other methods. Reverse engineering or conversations with employees of innovating firms are two examples. Another dimension of innovative activities regards their financing. Here also, it is interesting to see what are the different financial sources to which firms have access. After recalling the main characteristics of knowledge as an economic good, the main determinants that influence innovation are reviewed. Besides the effects of size and market concentration upon innovation, other determinants such as technology-push and demand-pull factors are considered. In particular, the role of technological opportunity, technological spillovers and appropriability conditions in determining the effort to innovate are discussed. Firms may also pursue R&D activities to enhance their market share. Consequently, some words need to be said on the strategic behaviors adopted by firms under technological competition. Finally, as policy intervention has increased in the recent period, it is interesting to review the instruments adopted by public authorities in order to enhance and support innovative activities. The last section of the chapter addresses the main economic and social effects of technological activities and presents a figure summarizing the main determinants that influence innovation.

The third chapter describes the main features as well as the construction of the database. The raw data sample consists of comparable detailed micro-level data on 2676 large manufacturing firms from several countries. These firms have reported important R&D expenditures over the period 1980-1994. The chapter begins by defining the variables contained in the database as well as the data sources. A particular attention is paid to the procedure matching the patents from the European Patent Office to the firms in the database. Then, the construction of different variables is discussed. Finally, some descriptive statistics of three different datasets derived from the raw sample are presented. These datasets are used for the empirical analysis in the subsequent chapters.
The next three chapters are the core components of the thesis. These chapters have a common structure. First, an outline of the methodological and econometric framework is presented. Then the most prominent findings reported in the related literature are reviewed. Finally, the empirical section interprets the main results.

The fourth chapter explores the dynamic structure of the patent-R&D relationship by considering the number of patent applications as a function of present and lagged levels of R&D expenditures. R&D spillovers as well as technological and geographical opportunities are taken into account as additional determinants in order to explain patenting behaviors. The estimates are based on recently developed econometric techniques that deal with the discrete non-negative nature of the dependent patent variable as well as the simultaneity that can arise between the R&D decisions and patenting. The results show evidence of a rather contemporaneous impact of R&D activities on patenting. This suggests that the decision to apply for a patent occurs in an early stage of the knowledge production process. Hence, patents have to be regarded as an intermediate output of this process. As far as R&D spillovers are concerned, these externalities have a significantly higher impact on patenting than own R&D. Furthermore, these effects appear to take more time, three years on average, to show up in patents. Finally, the econometric tests lead to the conclusion that R&D spillovers are exogenous. This finding supports the view that these effects are a result of exogenous technological factors on the supply side of innovation.

The fifth chapter explores the contribution of own stock of R&D capital to productivity performance of firms. To this end the usual productivity residual methodology is implemented. The main issues, both conceptual and technical, related to this methodology are addressed and their possible remedies discussed. Among the problems, we can already mention the extreme heterogeneity characterizing the firms in the sample, the pattern of variability of data which exhibits important differences between the cross-sectional and temporal dimension of data, measurement errors in the variables, the presence of non-observed effects correlated with the regressors and the predeterminency of these explanatory variables. A survey of some selected empirical studies illustrates these problems and their consequences with regard to the interpretation of the results. The reviewed findings give an order of magnitude of the contribution of R&D. This is useful when comparing our results with these benchmarks. The empirical section presents a first set of results which replicate the analysis of previous studies and tries to assess the robustness of the findings with regard to the above issues. Then, further results, based on different sub-samples of the dataset, investigate to what extent the R&D contribution on productivity differs across firms of different industries and geographic areas or between small and large firms and low and high-tech firms. The last section explores more carefully the simultaneity issue. On the whole, the estimates indicate that R&D has a positive impact on productivity performances. Yet, this contribution is far from being homogeneous across the different dimensions of data or according to the various assumptions retained in the productivity model.
The last empirical chapter goes deeper into the analysis of firms’ productivity increases, by considering besides own R&D activities the impact of technological spillovers. The chapter begins by surveying the alternative ways proposed in the literature in order to assess the effect of R&D spillovers on productivity. The main findings reported by some studies at the micro level are then outlined. Then, the framework to formalize technological externalities and other technological determinants is exposed. This framework is based on a positioning of firms into a technological space using their patent distribution across technological fields. The question of whether the externalities generated by the technological and geographic neighbors are different on the recipient’s productivity is also addressed by splitting the spillover variable into a local and national component. Then, alternative measures of technological proximity are examined. Some interesting observations emerge from the empirical results. First, the impact of spillovers on productivity increases is positive and much more important than the contribution of own R&D. This confirms previous findings of related studies as well as the results obtained in Chapter 4. Second, spillover effects are not the same according to whether they emanate from firms specialized in similar technological fields or firms more distant in the technological space. Finally, the magnitude and direction of these effects are radically different within and between the pillars of the Triad.

The conclusion summarizes the main empirical findings and discusses the economic and methodological implications of the thesis. In particular the stress is put on the main limits and pitfalls of the current formalization of the links between technological activities and economic performances at the micro level. Finally, some aspects deserving further attention are discussed and some ideas for the future research agenda are suggested.