The Organization of R&D - Sourcing Strategy, Financing and Relation to Trade

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2012

The Organization of R&D

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Lund Economic Studies Number 166

Distributed by the Department of Economics
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www.nek.lu.se

ISSN 0460-0029

Printed in Sweden by Media-Tryck, Lund University
Lund 2012

To Johan

Acknowledgments

When I started the PhD programme five years ago, I did not really know what I was getting myself into. I only had some vague idea of what writing a PhD thesis actually meant. Many compare the writing of a thesis to a journey, but I think it is more like a roller coaster ride. And I do not really like roller coasters! When going on one I always wonder several times what I am doing there, and when the train slowly goes uphill I really just want to jump off. But when the circuit is finished I feel great and very content with the ride. During my time as a PhD student I have sometimes felt like those hills were enormous, but somehow I got over them, and now that the end is approaching it actually feels quite good. On a roller coaster it is the train that keeps you on track all the time. For me, writing a thesis, that train has consisted of a number of people that have helped me and supported me along the way. I would therefore like to take this opportunity to express my deepest gratitude to them.

First of all I would like to thank my main supervisor, Pontus Hansson. I have often gone into his office thinking that what I was working on was really bad and that I had no idea of how to make it work, but after a little time with him I would leave his office with lighter steps and many ideas of how to proceed. Moreover, he always has some fun stories about all kinds of things that have nothing to do with economics. I would also like to thank him for giving me the opportunity to be a teacher on the course in introductory macroeconomics. Being a teacher is one of the best and most developing experiences that I have had during these five years.

My assistant supervisor, Klas Fregert, has always had time for me and he never tires of answering my questions about macroeconomics.

Olof Ejermo helped me get started on the thesis work by co-authoring the second chapter of this thesis. He also asked me to be a part of a project for VINNOVA, which was very interesting and educational. What is more, he has given me access to the data that is used in two of the chapters in this thesis. I am very grateful for all of the above.

I am indebted to Martin Andersson, who commented on the draft for my thesis at my final seminar, for very valuable comments that have helped improve this thesis.

I also thank all the people in the seminar group for macroeconomics and econometrics at the Department of Economics for giving me comments and suggestions on the various chapters in this thesis, especially David Edgerton and Fredrik NG Andersson for comments on econometrical issues.

A big thank you goes to my roommate, Johan Blomquist, for being a lot like me in the sense that he prioritizes many other things in life over the thesis work, that he does not in general work on weekends or in the evenings and that he likes to take breaks to discuss things other than work; and for *not* being like me in the sense that he is a very good econometrician and therefore can answer all my stupid questions on the matter, which he always does with endless patience.

Writing a thesis can be very lonely and frustrating at times, but it has always been enjoyable to go to work every day thanks to wonderful colleagues. Wolfgang Hess, despite having his office far away at Alfa, has often enjoyed a coffee or lunch at EC. He is also one of the most guest friendly people I know, and has showed me Bavarian traditions like the Feuerzangenbowle. At EC, Margareta Dackehag, Pernilla Johansson, Åsa Ljungvall, Therese Nilsson, Martin Nordin, Maria Persson, Eric Rehn and Emma Svensson have kept their doors open for small chats. They have also made the lunches interesting, be it of discussions about economics or questions about whether rice cookies are actually made of rice or not.

Other fellow PhD students that have contributed to my well being are Elvira Andersson, Jens Dietrichson, Lina Maria Ellegård, Gustav Engström, Thomas Eriksson, Olle Grünewald, Peter Karpestam, Gustav Kjellsson and Ida Lovén.

Over the years, many administrative and computer issues have come up. Thank you Mariana Anton, Jörgen Ellberg, Ove Hagerbo, Agnetta Kretz, Paul Linge, Ann-Charlotte Sahlin, Peter Schüller, Nathalie Stenbeck and Karin Wandér for help with these matters.

Outside of the Department my friends and family have helped me to take my mind off the thesis work. Sara, my 'sister', thank you for being there. You always have time to talk, on the phone, over countless Saturday lunches or on Wednesdays when watching Grey's Anatomy together. When you tell me about your work, I am very happy about my own, because I would never manage yours.

I am very grateful for the breaks in the weekly routine offered by my friends in the book club and the cooking club. We have read many good books over the years, even though some have been more challenging than others, and experimented with new recipes. But the most important is just to meet and talk about all kinds of things. And Pär – thank you for being a great lunch companion.

Special thanks go to Katarina and Martin for being such superb party organizers and taking the initiative to organize many enjoyable dinners, even if some of us (on different occasions) have fallen asleep on the couch for a while. But that is OK, and that is what is so great about it.

Even if my family have not really understood what it is that I have been doing for the last five years or why I have been doing it, they have always supported me and, in various ways, helped me to keep my mind off economics. My mother Lena gives me French books. My father Arne makes the best 'Lufsa' and 'Flundror' in the world. My brother Johan is my running companion even though we live 600 km apart. We discuss training plans and we challenge each other. My other brother, Jakob, never stops trying to educate me in the natural sciences e. g. with books about Newton, but he also picks out books in the genres of science fiction or fantasy for me.

I would also like to express my gratitude to my ‘nearby parents’, my aunt and uncle, Erna and Sigge, for help with different matters and good Sunday dinners.

Finally, thank you Johan. While writing this thesis my mood has not always been the best, but you have always been able to put a smile on my face, no matter the problems I have been facing. I do not know what I would do without your love and support and I just hope that I can give them back to you. I love you.

Lund, January 2012

Karin Bergman

Contents

Chapter 1

Why Study the Organization of R&D?

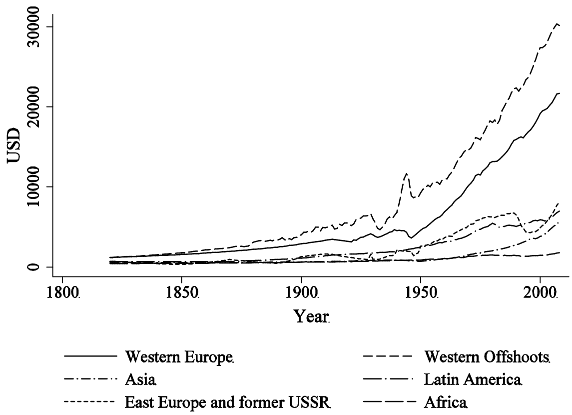
1.1 Introduction

Understanding the relevance of the question of how research and development (R&D) should be organized, requires an understanding of the role R&D plays in generating economic growth. By looking at the economic development in the world and reviewing the theories explaining economic growth in the long run, we may see the importance of R&D in this process.

During the last 200 years income levels have diverged among the regions of the world. Figure 1.1 shows the gross domestic product (GDP) per capita for different regions from 1820 to 2008. We see that these regions were very close in terms of income levels in the beginning of this period. Thereafter, the Western Offshoots[1] and Western Europe increased their GDP per capita much more than the other regions. Output per inhabitant in the Western Offshoots went from being three times higher than that of Africa in 1820 to being 17 times higher in 2008. In other words, in 2008 it only took a little more than 20 days for the average worker in the Western Offshoots to produce as much as the average worker in Africa produced in an entire year.

[1] Western Offshoots are Canada, U.S., New Zealand and Australia.

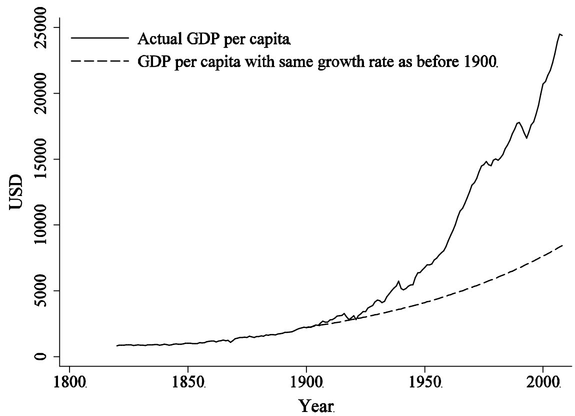
Figure 1.1. GDP per capita 1820-2008 (in 1990-year prices)



Note: Western Offshoots are Canada, U.S., New Zealand and Australia.
Source: Maddison (2010).

If we only look at the economic development in Sweden we see, in Figure 1.2, that Sweden's GDP per capita was 30 times lower in the year 1820 than it is today (Maddison 2010). Economic growth really took off in Sweden in the 20th century. From 1820 to 1900 the average growth rate was only 1.2 percent whereas it was 2.2 percent from 1900 and onwards. If the economy had continued to grow at the pre-1900 growth rate, Sweden would only have attained a level of GDP per capita that is a third of its actual value in 2008. This level of income is comparable to those for Latvia and Belarus today. Hence, only a one percentage point difference in annual growth rate creates this difference in income levels over a 100-year period.

Figure 1.2. GDP per capita for Sweden, 1820-2008 (in 1990-year prices)



Source: Maddison (2010) and own calculations.

How can we explain this higher growth rate for Sweden in the 20th century? And how can we explain the differences in growth rates between the different regions in the world? In general, we can say that total output, i.e. GDP, is produced with two input factors, labour and physical capital. Hence, increasing either of these will increase GDP, but with decreasing returns to scale. Moreover, it is not possible to continue increasing these factors indefinitely. Instead, the economy has to develop by making more productive use of labour and capital, which can be achieved either by increasing the skills of the labour force or by having capital that is 'better' in the sense that we can get more output from a given unit of capital.

Robert Solow and Trevor Swan showed, in theoretical models in the 1950s, how economic growth in the long run is given by the rate of technological progress (Solow 1956, Swan 1956). That is, the only way to increase income levels in the long run is to become more productive. However, Solow and Swan treated technological development as an exogenous factor, something that occurred independently of what happened in the economy. It was not until the end of the 1980s, in what has come to be called new growth theory, that technological change was considered as an endogenous factor, i.e. something that can be affected by economic forces (Romer 1986, Lucas 1988). These theoretical models show how long-run growth is generated by allowing for positive externalities from knowledge and human capital that offset the diminishing returns of physical capital. The next step was to actually incorporate a theory for technological change (Romer 1987, 1990, Grossman and Helpman 1991, Aghion and Howitt 1992) by deviating from the assumption of competitive markets that had been a standard assumption in earlier models. In this new setting, innovations, and thereby technological progress, are the result of research activities, and the incentives to perform R&D are based on the prospect of earning monopoly rents on the new innovation.

The possibility of earning these monopoly rents or daring to invest in a long-term education program depends, according to Hall and Jones (1999), on the social infrastructure. By social infrastructure they mean the institutions and rules that determine the economic environment. When the social infrastructure is favourable, both firms and individuals will be willing to acquire new skills and devote resources to trying to come up with new innovations. Hall and Jones add that a favourable economic environment is characterized e.g. by the existence and upholding of property rights, economic and political stability and a well functioning financial system.

1.2 The organization of R&D

Once the general economic environment is favourable to investment in productivity enhancement (i.e. investment in R&D), we can start discussing how R&D activities should be organized. From a policy perspective there is an interest in this question because there is a belief that the market economy will result in less investment in R&D than is socially optimal (Arrow 1962). The reason for this underinvestment is the nature of the innovation process. Because the outcome of R&D is uncertain and the marginal cost of spreading new knowledge is zero, it is difficult for an inventive firm to fully appropriate the returns from its R&D investment. Due to the market's underinvestment in R&D, there is a long tradition of government funding of R&D. Hence, we are interested in where these government funds make the best contribution and whether there are any specific R&D policies that should be promoted. This thesis deals with questions on this topic.

The second chapter investigates an old research question in the literature – whether small or large firms have better opportunities to perform R&D. This question is usually investigated by examining whether the size of the firm affects the amount of R&D expenditures; size being often measured by sales or the number of employees. Chapter 2 extends this literature by dividing sales into domestic and foreign sales to see if these different kinds of sales affect R&D expenditures differently.

The third and fourth chapters deal with productivity effects of R&D. It is a rather common strategy in the literature to first calculate or estimate a measure of total factor productivity (i.e. the part of output that is not brought about by the amount of labour and capital), and then try to investigate the effect of R&D on productivity. It is also a well documented fact that a firm's or an industry's R&D efforts have a positive effect on productivity (Wieser 2005, Hall et al. 2009). The third and fourth chapters deal with extensions of this literature where the interest is to investigate the productivity effects of different kinds of R&D. Chapter 3 investigates whether there are differences in the effects of a firm's own R&D compared to the R&D that it contracts out to other firms. Chapter 4 looks at the different productivity effects that arise depending on whether the R&D is funded by the private or the public sector.

A possible criticism against both chapters 3 and 4 is that it is debatable if total factor productivity is an appropriate measure or not. An individual firm probably measures its progress by its profits, returns on assets or returns on equity. But in some sense these measures mirror the productivity effects and as a researcher this is the measure of interest since GDP is increased by increasing productivity.

The following subsections summarize the different chapters in more detail.

1.2.1 Are exports different from domestic sales?

Chapter 2 investigates whether different types of sales – domestic and foreign – affect R&D expenditures differently on the firm level. There are several reasons why firms competing internationally are more likely to do R&D. For example, foreign sales provide a way for firms to spread fixed costs incurred by R&D. Moreover, as stressed by recent literature (Keller 2010), by learning from exporting, firms may enter virtuous circles where exports enhance the productivity effects of R&D, which induce further R&D and so on. The chapter further expresses the view that there is a qualitative difference between manufacturing and service sectors as the former can more easily separate R&D activities from production. Service development is not easily standardized, as solutions need to be more adapted to local conditions. Hence, scale effects from R&D should be more pronounced in manufacturing.

The study in this chapter uses data on Swedish firms for the period 1991-2001 and the findings are in line with previous research in that they support a proportional relationship between total sales and R&D. Furthermore, they generally support the idea that foreign sales are more important than domestic sales in determining R&D. This result suggests that open trade policies aimed at stimulating competitiveness are an effective way to raise R&D expenditures at the firm level. In addition, as expected, the effect is more pronounced for manufacturing than for service sector firms.

1.2.2 Do it yourself or contract it out?

Should there be specialized R&D firms that sell their R&D to other firms, or is it better for firms to perform their own R&D? This issue is discussed in chapter 3 where in-house R&D is labelled internal R&D and contracted R&D is labelled external R&D. The focus is on whether the productivity effects of internal R&D are different from those of external R&D. The study uses a sample of Swedish manufacturing firms in the period 1991-2004, and is one of the few studies to look at the amounts of R&D expenditures and not only at a qualitative measure of the firms' strategy of only doing R&D themselves, only buying R&D, or both.

There are several reasons for outsourcing R&D (Den Hertog and Thurik 1993, Cassiman and Veugelers 2006). It allows firms not to take all the risks of R&D themselves and to get around financial constraints. In addition, the firm may benefit from technological spillovers from the R&D performing firm. However, there is a risk of information spilling out from the firm as well.

Moreover, Cohen and Levinthal (1989, 1990) discuss the importance of a firm's 'absorptive capacity' for experiencing positive productivity effects from external R&D. By 'absorptive capacity' they mean the ability to understand and use external information; an ability that depends on the firm's prior knowledge, which is influenced by the employees' knowledge and the firm's own investments in R&D. In this way internal and external R&D are complementary.

The findings in this chapter give some support to the notion of complementarity between internal and external R&D, especially in industries with high R&D intensities. There is also some evidence of the importance of the employees' level of education for the firm's capabilities to absorb the external R&D. However the total effect of external R&D on productivity is often found to be negative in the investigated sample. This negative effect could be due to the short time horizon of the study, or on firms using external R&D to counteract declining profits (Antonelli 1989), or on the outsourcing strategy being occasional, which implies that the firm might not have the appropriate routines (Johansson and Lööf 2008).

1.2.3 Should the government care?

One of the most basic questions is if the government actually should fund R&D at all. In this context, chapter 4 examines whether privately and publicly funded R&D have different productivity effects. The study is performed on the industry level, using data from 13 OECD countries, and studies productivity effects of R&D performed in the private sector but with different funders.

Following the reasoning of Arrow (1962), the public funder of R&D should aim at projects with higher risks, longer time to completion and basic research rather than applied, since it is more difficult for private firms to appropriate the returns to such projects. Jaffe (1998) further argues that there is often a difference between the private and the social returns to R&D due to the existence of spillovers. Therefore, the public funder of R&D should target projects where there are large spillover gaps. If this strategy is followed by the public funder, we may expect lower private returns for publicly funded R&D than for privately funded R&D, but larger spillover effects. However, as David et al. (2000) point out, it could be that the public funder of R&D actually funds the projects with higher private returns in order to ensure success of the public funding program.

The findings in the chapter confirm the importance of privately funded R&D for productivity. However, publicly funded R&D is generally found to have a negative effect, but sometimes it is not significant. The results concerning differences in spillover effects are less robust, but there is some evidence of positive spillover effects from privately funded R&D, whereas spillovers from publicly funded R&D have an insignificant or a negative effect on an industry's productivity growth. Contrary to the suggestion by Jaffe (1998), it does not seem that the public funder of R&D manage to find the projects with the largest spillover gap. Neither does it seem to find the projects with the highest private rates of return. However, it could be that the government, when funding business R&D, primarily has goals other than increasing productivity like improving health care or national security (Bönte 2004), or supporting competence building and networking (Georghiou 2004).

1.3 Concluding remarks

This thesis deals with the organization of R&D from a micro perspective in order to get a better idea of how to generate economic growth in the long run. What kind of R&D policies should be promoted? This thesis contributes to the existing literature by investigating other data sets than before, by using more modern econometric techniques and by extending the investigated variables.

The thesis confirms earlier findings of the existence of a proportional relationship between R&D and sales and of the importance of a firm's or an industry's own R&D for productivity. It further shows that foreign sales are more strongly connected to R&D than domestic sales, and that firms should only use an outsourcing strategy if they already conduct a considerable amount of own R&D and have well educated workers. The finding in chapter 4 of a negative or insignificant effect from publicly funded R&D is also in line with previous findings in the sense that the government needs to think thoroughly about the objectives of their funding and how that funding should be designed.

This thesis only covers some aspects of the organization of R&D. There are of course many more questions we could ask. What kind of R&D seems to be the more effective? Should we put resources into inventing large radical innovations that make the economy 'jump', or into generating a development process with small continuous improvements? And for developing countries that grow by assimilating the existing technologies, how can we affect the diffusion of technology and the possibility of acquiring the new technology? Hence, there is still much to be done in this research area and, with longer and better data sets, we might be able to get clearer results and thus provide policy makers with better guidelines.

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Chapter 2

Swedish Business R&D and its Export Dependence

Co-authored with Olof Ejermo

2.1 Introduction

Sweden's research and development (R&D) expenditures, as a share of GDP, is among the highest in the world with business R&D being the most important constituent. The trend towards such a high business R&D ratio originated in the mid-1980s (Table 2.1) and continued at least throughout the 1990s. Other countries, especially among the Nordic group, have seen similar upward trends, but this trend has been more pronounced in Sweden than elsewhere.

Parallel with this rising trend there has been a shift in terms of the Swedish economy's dependence on trade. Trade has always been important and for decades Sweden has had an unusually high concentration of multinationals; of 12 European countries Sweden actually had the highest share of large firms in 1988-91 (Henrekson and Johansson 1999, Henrekson and Jakobsson 2001). From 1950 until the mid-1970s exports as a share of GDP were stable at 20-25 percent. Then, after a series of devaluations in the 1970s and early 1980s, exports temporarily rose above 30 percent. An increasing problem of high domestic inflation forced the government to float the currency in 1992, and the Swedish krona immediately lost 25 percent in value, which seems to have become permanent. At the same time Sweden experienced a permanent shift towards higher levels of trade, in part stimulated by EU membership in 1995. Export and import levels are now firmly established above 40 percent as a share of GDP (Statistics Sweden 2011).

TABLE 2.1

Business R&D as a share of GDP 1981-2008 in selected OECD countries, percent

	1981	1985	1989	1993	1997	2001	2005	2008
Denmark	0.5	0.7	0.8	1.0	1.2	1.6	1.7	2.0
Finland	0.6	0.9	1.1	1.2	1.8	2.4	2.5	2.8
France	1.1	1.3	1.3	1.5	1.4	1.4	1.3	1.3
Germany	1.6	1.9	2.0	1.5	1.5	1.7	1.7	1.9
Israel	..	..	..	1.4	1.9	3.5	3.4	3.8
Japan	1.4	1.8	2.0	1.9	2.1	2.3	2.5	2.7
Netherlands	0.9	1.1	1.2	0.9	1.1	1.1	1.0	0.9
Norway	0.6	0.9	0.9	0.9	0.9	0.9	0.8	0.9
Sweden	1.4	1.9	1.8	2.2	2.6	3.2	2.6	2.7
Switzerland	1.6	..	2.0	..	..	..	..	2.2
United Kingdom	1.5	1.4	1.5	1.3	1.2	1.2	1.1	1.1
United States	1.6	2.0	1.8	1.7	1.9	2.0	1.8	2.0
OECD Total	1.2	1.5	1.5	1.4	1.4	1.6	1.5	1.6

Source: OECD (2010) and own calculations. '..' denotes missing data.

In practice, there could be many reasons for why Swedish firms increasingly chose R&D intensive paths relative to firms in other countries. According to Schumpeter (1934), small firms, more flexible by nature, might derive an advantage from R&D. Large firms, on the other hand, have advantages that stem from such things as scale economies (Schumpeter 1950). Thus, two economies with different size distributions may have different R&D intensities. It is also possible that Swedish firms might have been especially concentrated in sectors where technological opportunities were emerging, or there might have been a supply effect from budding inventors inspired by the higher education system. Another explanation might be that the Swedish wage structure was institutionally compressed compared to other countries, with lower wages among engineers and other highly educated professions compared to, for instance, German workers. These low wages could have induced a higher demand for R&D services.

Yet another explanation might be increased exports. In fact, there are several reasons why firms engaging internationally are more likely to do R&D. Foreign sales provide a way for firms to spread fixed costs incurred by R&D. Moreover, as stressed by recent literature (see e.g. Keller 2010), by learning from exporting, firms may enter virtuous circles where exports enhance the productivity effects of R&D, which induce further R&D and so on.

The purpose of this chapter is to re-investigate the classic size-R&D relationship but with a focus on the size effect of foreign sales. We use data on the firm level for the years 1991-2001 and divide total sales into foreign and domestic to ascertain which is more important for stimulating R&D. As Sweden has continuously increased its trade dependence, we investigate whether the effect of foreign sales on R&D has increased in importance over time. We further argue that there is a qualitative difference between manufacturing and service sectors as the former can more easily separate R&D activities from production. Service development cannot be easily standardized as solutions need to be more adapted to local conditions. Moreover, overseas sales often induce production establishment there. Hence, scale effects from R&D should be more pronounced in manufacturing sectors.

Recognizing the potentially endogenous nature of R&D and foreign sales we pursue our empirical analysis by first examining the extent to which endogeneity is an issue. Moreover, R&D is an activity likely to be carried out in firms of higher quality, while firms of less quality may exit. Thus, samples of R&D performers are likely to suffer from selection bias. Therefore, we estimate two-step Heckman selection equations of the relationship between R&D and size, correcting for sample selection bias. Regression analysis, as specified here, gives us information about the average relationship of size to R&D, but not about whether the relationship differs across the sample distribution. The knowledge of such a difference can offer useful policy advice as it provides information on how trade policies might affect R&D investments for *different* types of firms. Accordingly, we examine the relative role of foreign vs. domestic sales across the distribution of firms in terms of their R&D expenditures in quantile regressions in order to shed further light on the size-R&D relationship studied in the literature.

Our findings generally support the idea that foreign sales are more important than domestic to stimulate R&D, which suggests that open trade policies aimed at stimulating competitiveness are effective ways to raise R&D expenditures at the firm level. We also find, in line with our hypothesis, that this effect is clearly more pronounced for manufacturing than for service sector firms. Although our results cannot decisively support a conclusion that the foreign sales effect has increased systematically in importance over time, foreign sales did increase dramatically during the investigated period. In all, our results imply that R&D increases by about the same proportion relative to foreign sales, but since foreign sales have picked up speed – R&D has as well. However, we find that the distributional differences differ somewhat over time. Our quantile regressions reveal that the sales effect, mainly that of domestic sales, is more important in later years for high level R&D performers than for low level R&D performers.

The chapter proceeds as follows. Section 2.2 provides a literature review where we first summarize the theoretical arguments in favour of small and large firms in innovation processes, which the literature refers to as the Schumpeterian hypotheses. We then also demonstrate the link to the literature on why foreign sales are an important factor determining R&D investments,[1] and discuss recent developments in the literature on export and learning. Section 2.3 contains a description of the database at hand, the empirical strategy and the results of the empirical analysis. Section 2.4 summarizes the results and policy conclusions are drawn.

[1] Formally, R&D expenditures comprise current costs and investments. We use R&D expenditures and R&D investments although our data is always on R&D expenditures.

2.2 Size and innovation – theory and evidence

2.2.1 Why does size matter?

Any attempt to explain the level of R&D conducted in firms should recognize the work of Schumpeter (1934, 1950), which has led to two conflicting hypotheses – 'The Schumpeterian hypotheses' (Breschi et al. 2000). In *The Theory of Economic Development* Schumpeter (1934) discussed how innovations tended to arrive in swarms in the wake of pioneering entrepreneurs. Seemingly in contrast, Schumpeter (1950) noted in *Capitalism, Socialism and Democracy* the efficiency with which large corporations handled their innovation processes in formalized R&D departments. Indeed, the development of firms in western economies seemed to follow trajectories of scale economies from the 1950s to the 1970s.

Theoretical arguments rest ambiguously on whether large firms should have advantages over smaller ones when it comes to the implementation of innovation processes in production. Cohen (2010) surveys the literature and mentions several possible explanations for large firm advantages. These explanations include (i) scale economies in R&D, where higher returns from R&D arise as innovators can spread the fixed costs of R&D over larger volumes of sales, (ii) complementarities between R&D and other activities and (iii) fewer financial constraints due to capital market imperfections. These advantages also suggest that large firms may be inclined to direct their innovative efforts towards incremental, process-oriented innovations, which can be applied to large production volumes. On the other hand, organization theory stresses the inability of large firms to foresee shifts in new modes of production. That is, the same bureaucracies that render large corporations more effective under a regime of gradual innovation, 'static efficiency', inhibit them in situations of fast technological change, where 'dynamic progressivity' is required (Nelson and Winter 1982, Tidd et al. 2005).

2.2.2 The role of foreign markets

In a static product quality setting, process R&D can be seen as having a fixed cost part (e.g. lab equipment) and a variable part that cuts unit costs. As specified in a model by Cohen and Klepper (1996), large-sales firms have an opportunity to spread their fixed costs of R&D, and the marginal effect of an R&D dollar spent is higher than for smaller firms as a cost-cutting effect can be applied on many units. From this perspective, exports are no different from ordinary sales as both would equally induce a size effect given that the *same* good is exported. But export goods are not the same; they are likely to be more competitive than goods intended for a domestic market. Consistent with this idea, Andersson and Ejermo (2008) find that Swedish regions more specialized in certain technologies tend to export goods of higher prices. The home market effect described by Krugman (1980) suggests that countries with initially high domestic demand for a differentiated product produced under monopolistic competition, i.e. subject to scale economies, will tend to export this good later on. This idea has links to that of R&D scale economies. Innovation scholars (e.g. Edquist et al. 2000, Klepper and Malerba 2010) stress the role of demand and cite many case studies of technology where government has played a role in formulating demand for a product. A Swedish example from history is the role of the former government monopoly Televerket, which worked with Ericsson to develop telephone services. Mowery and Rosenberg (1998) describe the development of several industries in the U.S., for instance the aircraft, pharmaceuticals and electronics industries in which innovation development was highly influenced by federal government programs, civilian or military. In the small market of Sweden, domestic competence (and incompetence!) is sometimes developed in firms which are sheltered from international competitiveness, but flourish (or perish) as the economy opens up.

Recent literature (Keller 2010) emphasizes that exported goods are subject to *dynamic* learning effects, in the sense that the product is prone to change when subject to international competitive pressure, and the firm gets feedback from customers and suppliers. By this reasoning, producers, by being active in other markets, learn about product characteristics that appeal to a more diverse set of customers than in domestic markets. This learning effect might stimulate further

R&D that generates more exports and so on. For small countries these dynamic effects may be substantial given their limited potential to exploit domestic scope effects.

Another potential link between R&D and the export market concerns the need to establish production activities in the foreign country to economize on transport costs. Thus, a firm might keep R&D in the home country to exploit scale economies of R&D and apply production techniques overseas. This behaviour might also prevent knowledge from spilling over to foreign competition. The extent to which R&D is kept in the home country is labelled a home bias effect (Belderbos et al. 2011), which results not only from capital used for R&D, but primarily from trained human capital and the need to transfer important (tacit) knowledge within the firm through face-to-face communication. These knowledge attributes tend to lead to path dependence in the location of R&D activities. As it is generally more costly, in terms of transports, to export manufactured goods than services, manufacturing R&D should be more closely linked to a foreign sales effect. This reasoning makes the division between manufacturing and service firms relevant for the study of sales effects. In addition, a sales variable indicating size is likely to be downward biased as production operations opened up abroad and subsequent sales are not included.

2.2.3 Empirical findings

2.2.3.1 The size-innovation relationship

Studies of the size-R&D relationship usually aim to study the size-innovation relationship, but, as innovation is difficult to measure, they tend to rely on R&D as an indicator of innovation. R&D is, however, an input into the innovation process, not necessarily linked to innovation.[2]

As has been discussed, the theoretical motivations for a large firm advantage in innovative activity are mixed, and size-advantages have also been difficult to

[2] Discussions on different innovation indicators can be found in Kleinknecht et al. (2002) and Smith (2005).

establish empirically. Many studies examine the link between innovation and size (see e.g. Scherer 1965, Bound et al. 1984, Cohen and Klepper 1996), where size is usually measured by sales or number of employees and innovation by R&D expenditures. Bound et al. (1984) found that R&D intensity fell slightly with size among the very smallest firms and rose somewhat with size among the very largest firms and Scherer (1965) found that R&D personnel increased more than proportionally with firm size up to a threshold, after which the relationship became proportional. However, the consensus view has become that R&D rises proportionately with firm size among R&D performers, with an elasticity of close to unity (Cohen 1995).

At the same time several studies suggest that the number of innovations per employee declines with firm size (Pavitt et al. 1987, Acs and Audretsch 1990, Acs and Audretsch 1991, Kleinknecht et al. 1993, Santarelli and Piergiovanni 1996), so that small firms account for a disproportionately large share of innovations relative to their size. There are exceptions to this finding; Acs and Audretsch (1990) point out that the pattern varies across industries and Pavitt et al. (1987) suggest that the relationship is somewhat U-shaped.

These results indicate that although there might be scale advantages to R&D, these are in a sense offset by a lowered productivity in terms of product innovations, not giving rise to a general advantage for large firms in innovation. However, not all studies control for sample selection bias, a possible problem as surviving small firms recorded in the samples also tend to be the successful ones (Bound et al. 1984).

A few studies analyze the size-innovation relationship using Swedish data. Wallmark and McQueen (1991) presented the ‘100 most important innovations’ in Sweden 1945-1980. Granstrand and Alänge (1995) examined and extended this data. They found that 20 percent of the innovations originated from autonomous entrepreneurs, 76.5 percent from corporate entrepreneurship and 3.5 percent from state entrepreneurship. After dividing the period into four subperiods, the authors noted that the role of autonomous entrepreneurs increased over time despite the fact that the economic system favoured large firms.

In a Swedish firm-level study focusing on market concentration and R&D, Gustavsson Tingvall and Karpaty (2011) also controls for size in terms of the number of employees and find the elasticity to be clearly above unity, indicating a large firm advantage in R&D.

2.2.3.2 Exports, R&D and productivity

Fors and Svensson (2002) examine how foreign sales affect R&D intensity (R&D/total sales) in Swedish multinationals and find a two-way relationship where a higher intensity of foreign sales increases the R&D intensity, and that a higher R&D intensity increases the foreign sales intensity. They also control for the size of the firm, in terms of employment, in one of their specifications and find a very small insignificant effect indicating a proportional relationship between size and R&D.

With regard to the potential role of export in learning, discussed earlier, and hence in providing a theoretical link that export may foster learning, Keller (2010) reports mixed evidence of a variety of approaches investigating such a link, although later studies tend to find some effects of learning. It is well known that exporting firms are more productive than non-exporting firms, but the fundamental reason could well be that firms self select into exporting. In other words, since they are already more productive than the average firm, they choose to enter the export market. Clerides et al. (1998) examine whether average costs, as a symptom of learning effects, are affected by exports among firms in Columbia, Morocco and Mexico. They control for the selection effect in a first-step equation but find no effect of starting to export. Similar to Clerides et al. (1998), van Biesebroeck (2005) investigates average cost effects of exporting for firms in nine African sub-Saharan countries and reveals a 25 percent productivity boost which is attributable to previously non-exploited scale effects. Hallward-Driemeier et al. (2002) find that South Asian firms that are planning to start exporting invest more resources to raise productivity and quality than non-exporters. Keller (2010), however, argues that such investments should be deducted from any learning effects as they consume real resources. De Loecker (2007) employs a matched firm sample of Slovenian firms and finds that exporting firms become more productive after they start exporting. Andersson and Lööf (2009) differentiate between small and large exporters (in terms of export intensity), and between temporary and persistent exporters among Swedish firms. They find that learning effects require persistent export activity for small and large firms, while large firms also need a high export intensity to be effective. Fryges and Wagner (2010) construct profitability measures rather than productivity measures for German firms, which enables them to distinguish productivity effects from those of rising wages. They find a small statistically significant productivity premium for exporting firms which is not absorbed by higher wages.

2.3 Empirical analysis

2.3.1 Data and variables

The data for our analysis consists of firm-level observations from different databases compiled by Statistics Sweden (SCB). With respect to R&D we have had the choice of two sources of data. One source is the Swedish firm register (Structural Business Statistics – SBS) that has annual R&D data between 1985 and 2002, but data is only given for an interval for firms with R&D expenditures less than 10 MSEK. Another source is the data that forms the foundation for the Swedish official R&D statistics used in reports to the OECD. This data on R&D expenditures is collected from a biennial R&D survey which is more specific. However, it only covers the period from 1991 to 2005 and in practice the time limit is 2001 in order to match it with our other sources of data. This data set covers all firms with reported R&D expenditures over 5 MSEK and a sample of firms reporting less than 5 MSEK. Because the quality of the data from the R&D statistics is higher and more comprehensive, we have chosen this source of data, even though we get a smaller sample. However, the qualitative nature of the main relationships does not change when using annual data instead.[3] The average time span is rather short when using the biennial data; the average number of observations per firm being only 2.4. Hence, panel estimations are of limited use, which is why we have chosen to use cross section estimation methods and present the results for a few specific years (1993, 1997 and 2001).[4] Table 2.2 shows the number of firms in the sample for the investigated years divided by size groups in terms of the number of employees. The sample frame is restricted to firms with more than 50 employees, though the number of employees may have changed from the population frame to the actual sampling, so that a few firms exist in the smallest group. The majority of firms are in the group with at least 200 employees.

TABLE 2.2

Number of firms in the sample per year and size class

	Size class (number of employees)			
Year	< 50	50-199	≥ 200	Total
1993	6 (1.3 %)	195 (43.5 %)	247 (55.1 %)	448 (100 %)
1997	2 (0.6 %)	82 (26.4 %)	227 (73.0 %)	311 (100 %)
2001	5 (1.4 %)	109 (31.1 %)	236 (67.4 %)	350 (100 %)

The sales variables come from the Structural Business Statistics. The foreign sales variable is exports, which is the sum of sales to foreign firms within the corporate group and sales to other foreign customers.

We also include a number of control variables. Since the level of R&D is likely to be affected by the education level at the firm, we have gathered information on the share of employees with any type of post-gymnasium education at each firm.[5] Capital intensity, measured as the book value of capital divided by

[3] Both sources of data on R&D expenditures show a very high correlation on the firm level.
[4] Despite this short time horizon, we ran panel estimations which gave similar results to those in this chapter.
[5] Swedish gymnasium education roughly corresponds to upper secondary education in the American education system (years 10-12).

total sales, is also included on the basis that technological progress is usually interlinked with capital investments.

The nature of R&D and innovation can be expected to differ between sectors, and technological opportunities differ as well. We include industry dummies to pick up some of these differences as well as possible differences in the market structure. Following Ejermo and Kander (2011), firms have been classified as belonging to one of ten sectors. Sectors 1-7 belong to manufacturing, while sectors 8-10 are in services. This division of sectors is based on different R&D intensities. Moreover, as mentioned earlier, we expect R&D in manufacturing firms to be more strongly linked to foreign sales, and therefore conduct estimations for manufacturing and service industries separately.

The R&D activities in large corporations could be organized in sub-parts, or specific firms, of the larger corporation. Thus, in practice the R&D levels could be misleading as one firm within the larger corporate group could draw on investments made elsewhere in the corporation. We have analyzed our main equation using the corporate level as our unit of analysis with no difference in results. Hence, using the firm level does not seem to significantly bias our results.

Another aspect of the organization of R&D activities concerns the possibility of a differential effect between Swedish vs. foreign owned firms. As mentioned earlier, home bias effects in terms of the localization of R&D might induce foreign owned firms active in Sweden to reduce their R&D levels in Sweden relative to sales. To test for this possibility we introduce a dummy variable for foreign-owned firms, hypothesized to impact negatively on R&D levels. However, this variable is only available from 1997 and hence is not included in the regressions for the years before that.

All nominal variables are deflated using an index of civil engineering wages (Ljungberg 1990), and are expressed in 1985-year prices. Table 2.3 shows summary statistics for 1997, which is representative for all years between 1991 and 2001.

TABLE 2.3

Descriptive statistics of variables for 1997 in all sectors, manufacturing and services

	Variable	Obs.	Mean	Sd.	Min	Max
All sectors	R&D	311	75445	254683	1102	2620000
	Foreign sales	311	728111	2460000	37	30800000
	Domestic sales	311	444255	1390000	649	19000000
	Capital intensity	311	0.25	0.46	0	6.93
	Highly educated, share	311	0.31	0.2	0.05	0.89
	Foreign ownership	311	0.38	0.49	0	1
Manufacturing sectors	R&D	261	76324	267451	1102	2620000
	Foreign sales	261	838901	2670000	837	30800000
	Domestic sales	261	351875	666379	649	5800000
	Capital intensity	261	0.23	0.25	0	1.81
	Highly educated, share	261	0.26	0.16	0.05	0.77
	Foreign ownership	261	0.4	0.49	0	1
Service sectors	R&D	50	70860	175464	2885	1130000
	Foreign sales	50	149785	437860	37	2820000
	Domestic sales	50	926477	3090000	682	19000000
	Capital intensity	50	0.31	0.99	0	6.93
	Highly educated, share	50	0.58	0.18	0.12	0.89
	Foreign ownership	50	0.28	0.45	0	1

R&D and the sales variables are in thousands of SEK (1985-year prices).

2.3.2 Time trends in the distribution of innovative activities and exports

Figures 2.1-2.4 summarize trends in R&D expenditures and exports in Sweden, and include the observations for 2003. Figure 2.1 shows that large firms have a somewhat decreasing share of total R&D expenditures. Nonetheless, we should note that R&D expenditures are still extremely concentrated in large firms, since almost 94 percent were in firms with at least 200 employees in 1991, a figure that only dropped to 91 percent in 2003. Figure 2.2 shows that mean R&D expenditure per firm clearly has increased over the period even though it diminished from 1991 to 1993 and from 2001 to 2003.

Figure 2.1. Share of R&D in firms with at least 200 employees

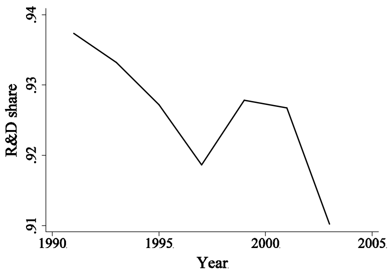


Figure 2.2. Mean R&D expenditure per firm (in 1985-year prices)

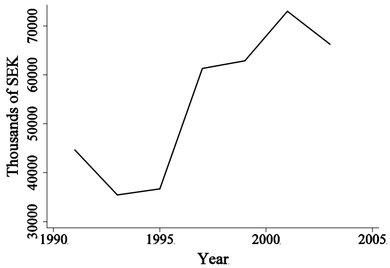


Figure 2.3 shows that R&D still takes place predominantly in the manufacturing sector. Manufacturing firms conduct about 80 percent of total R&D in Sweden, with only slowly increasing shares for service firms. Figure 2.4 shows the development of the export intensity (exports/total sales) for firms with positive R&D expenditures. This intensity increased from 0.43 in 1991 to 0.57 in 2003, showing the increased trade dependency of Swedish R&D performers.

Figure 2.3. Share of R&D in manufacturing and service sectors

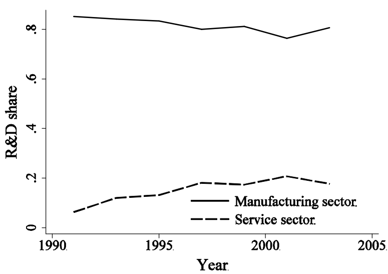
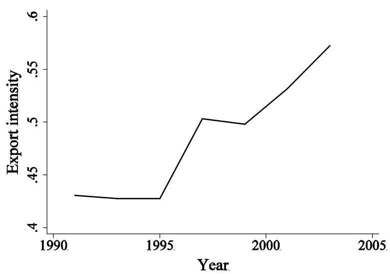


Figure 2.4. Export intensity for R&D performing firms



2.3.3 Regressions on the size-R&D relationship

In this section we conduct the regression analysis, which enables us to sort out the role of the two sales variables – foreign and domestic – in R&D expenditures, while also taking into account effects related to the sample at hand. Equation (2.1) depicts the main estimated equation.

$$\ln RD_{it} = \beta_1 lnS_{it}^F + \beta_2 lnS_{it}^D + \gamma' X_{it} + u_{it}, \quad (2.1)$$

where i is a firm and t denotes year. The dependent variable is the log of R&D expenditures, the explanatory variables of main interest are the log of foreign sales (S^F) and the log of domestic sales (S^D), X is a vector of control variables including capital intensity, the share of highly educated, a dummy for foreign ownership, industry dummies for our ten sectors and a constant, and u is an idiosyncratic error term. For reasons of space we only present regressions for the years 1993, 1997 and 2001, even though we have also run the regressions for 1991, 1995 and 1999. These latter regressions are presented in the Appendix, Tables 2.9-2.11.

If $\beta_1 = \beta_2$ then there is no difference in the effect on R&D expenditures of changes in these two types of sales variables, but if $\beta_1 > \beta_2$ then changes in foreign sales have a larger impact than changes in domestic sales. There would then be evidence of a learning-by-exporting effect or of scale economies in R&D. We expect this latter effect to be more pronounced for manufacturing than for service sectors. Following the literature, we expect $\beta_1 + \beta_2 = 1$ resulting in a proportional relationship between R&D expenditures and size.

Several issues with the estimation of this equation need attention. First, due to the log specification, we exclude non-R&D performers, which might lead to biased results when using OLS estimation. To correct for sample selection bias concerning the R&D variable, we use the Heckman (1979) two-step estimator where, in the first stage, we specify an equation for the probability of engaging in R&D. From this stage, an inverted Mills ratio is estimated and used to correct for selection. Because the R&D data only includes R&D performers, we construct the selection variable with the help of the Structural Business Statistics data set. We believe that zero values can be expected to be accurate from the SBS, and thus complement the data from the R&D statistics. Therefore, the selection variable is created as follows:

$$s(R\&D) = \begin{cases} 1 & if \quad R\&D_{stat} > 0 \\ 0 & if \quad R\&D_{stat} = 0 \\ 0 & if \quad R\&D_{stat} = missing\ and\ R\&D_{SBS} = 0 \\ missing & if \quad R\&D_{stat} = missing\ and\ R\&D_{SBS} = missing \end{cases} \quad (2.2)$$

where $R\&D_{stat}$ is R&D data from the R&D statistics and $R\&D_{SBS}$ is from the Structural Business Statistics.

As we also log the export variable, we exclude the non-exporters who constitute about ten percent of the R&D performers in the data. There is no easy way to control for this exclusion, and hence we just have to acknowledge that this exclusion is a shortcoming, and that our results are valid only for firms with positive domestic and foreign sales.

Second, another major issue is the possibly endogenous relationship between R&D and the sales variables, and specifically the variable for foreign sales. It is rather well documented in the literature that the decisions to perform R&D and to export are made simultaneously (Fors and Svensson 2002, Lileeva and Trefler 2007, Aw et al. 2008). However, Lileeva and Trefler (2007) point out that it is exporting that makes it more profitable to improve productivity (investing in R&D) because it increases the output over which the productivity gains will be spread. We deal with this possible endogeneity problem by using an instrumental variable estimator and instrument foreign sales with its lagged values.

2.3.3.1 Estimation results

First we examine the results from our three estimators, OLS, IV and Heckman, for one specific year, 1997, gauging if there are problems of endogeneity and/or selection bias.

For the IV estimation we use the two-stage least squares estimator where we instrument foreign sales with its first and second lag. Including more than one instrument allows us to test the validity of the instruments using the Hansen test of overidentifying restrictions, a test which our instruments pass. However, whether the first lag of foreign sales is actually an appropriate instrument, despite passing the validity test, is debatable. Therefore, we have also tried with only the second and third lag as instruments but we get no differences in the results or in the validity tests. In addition, we have also instrumented domestic sales and the human capital variable and tested these variables for endogeneity. We conclude that they can be treated as exogenous and do not need to be instrumented.

For the selection equation in the two-step Heckman estimator, all the previously discussed variables are included in addition to variables for competition, total (logged) R&D in the region and metropolitan area. Following the Industrial Organization literature we include a measure of competition to control for effects of market structure (see e.g. Vossen 1999, Aghion et al. 2005, Gustavsson Tingvall and Karpaty 2011). We use the Hirschmann Herfindahl Index (HHI), defined as

$$HHI_k = \sum_{i \subset k} s_i^2, \tag{2.3}$$

where s_i^2 is the squared market share of firm i belonging to sector k.[6] The variable for total R&D in the region is intended to capture the potential for knowledge spillovers measured by the total R&D (minus R&D of the own firm) of the county where the firm has its main workplace. Other firms' R&D may stimulate own R&D investments in order to 'absorb' their results (Cohen and Levinthal 1989), and may make it more profitable to invest in own R&D (Audretsch and Feldman 1996). The metropolitan variable shows the share of employees that reside in one of the counties of Stockholm, Gothenburg or Malmoe. The variable uses the location of the individual rather than that of the firm, as the firm's county judicial seating does not always appropriately reflect the true county of the firm's activity. Both the R&D county and the metropolitan variable are intended to capture the advantages of being located in an agglomeration where much R&D activity takes place, and hence may have a positive influence, a spillover effect, on the probability of engaging in R&D.

[6] The results are mainly unchanged when using the market share of the top four firms (C4) in the sector instead. The HHI index carries information on the dispersion of all firms in a sector whereas the C4 only considers the top four.

Table 2.4 shows the results for the OLS, the IV and the second stage Heckman for the year 1997. The samples for the OLS and the Heckman estimations are limited to only those observations for which the first and second lags of log foreign sales are available, in order to use the same observations as for the IV.

TABLE 2.4

OLS, IV and second stage Heckman, 1997

Dependent variable: Log R&D expenditures	(1) OLS	(2) IV	(3) Heckman
Log foreign sales	0.37***	0.40***	0.60***
	(0.045)	(0.050)	(0.076)
Log domestic sales	0.33***	0.32***	0.43***
	(0.041)	(0.041)	(0.055)
Capital intensity	0.20	0.20	0.19
	(0.319)	(0.311)	(0.283)
Highly educated, share	3.67***	3.65***	5.69***
	(0.481)	(0.467)	(0.739)
Foreign ownership	-0.14	-0.15	-0.10
	(0.111)	(0.108)	(0.123)
Constant	1.43**	1.37**	-2.51*
	(0.726)	(0.653)	(1.318)
Observations	275	275	275
Censored observations			907
R-squared	0.686	0.685	
Lambda			1.31***
			(0.297)
Hansen		0.900	

Standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. Sector dummies not reported. P-value is reported for the Hansen test of overidentifying restrictions. In the IV estimation, the variable for log foreign sales is instrumented with its first and second lag.

We can observe that the estimates are very similar across the OLS and the IV estimations, indicating that there is effectively no problem of endogeneity, even though we reject exogeneity of foreign sales for this year. Thus, we can rely on the

OLS in this sense. Comparing the OLS estimates with those of the Heckman estimator, we see that the Heckman estimates for the sales variables are higher than when we use OLS, especially for foreign sales. The other variable estimates are pretty similar. This higher elasticity in the Heckman estimates indicates the existence of sample selection bias and the lambda coefficient, i.e. for the Mill's ratio, is significantly different from zero. These results show that the sample selection bias is the most important to control for, and the Heckman estimator is therefore our most preferred estimator even though we cannot control for endogeneity. Moreover, in the IV estimations we reject that foreign sales are exogenous only for about half of the years.

Now that our strategy[7] for the estimation has been laid out, we present the Heckman estimates for the first stage, i.e. the selection equation, in Table 2.5.[8] Here, we also differentiate between manufacturing and service sectors.

The results show that both foreign and domestic sales are important determinants for the decision to perform R&D and the coefficient of foreign sales is significantly higher than that of domestic sales in each of the investigated years except for 1991, when firms from both sectors are examined together. Moreover, the coefficient of foreign sales is higher for the manufacturing sector than when all firms are included. For the service sector the results are somewhat more varied. Domestic sales are only significant in 1997 and 2001 and the estimates of the sales variables are much lower than for the manufacturing sector.

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[7] The panel regressions reported on in footnote 4 have been done using an IV fixed effect estimator since no Heckman panel estimator could be found.

[8] In Table 2.8 in the Appendix, we present descriptive statistics of all firms, i.e. including those firms that are only used in the first stage.

TABLE 2.5

First stage Heckman estimates

Dependent variable: s(R&D)	(1) 1993 – All	(2) 1993 – M	(3) 1993 – S	(4) 1997 – All	(5) 1997 – M	(6) 1997 – S	(7) 2001 – All	(8) 2001 – M	(9) 2001 – S
Log foreign sales	0.28***	0.38***	0.10**	0.38***	0.56***	0.15***	0.33***	0.55***	0.13***
	(0.023)	(0.030)	(0.041)	(0.030)	(0.045)	(0.042)	(0.024)	(0.040)	(0.032)
Log domestic sales	0.15***	0.24***	-0.03	0.21***	0.17***	0.16***	0.09***	0.06*	0.08*
	(0.033)	(0.041)	(0.065)	(0.035)	(0.045)	(0.058)	(0.027)	(0.038)	(0.041)
Capital intensity	0.02	-0.02	-0.01	0.10	-0.05	0.16*	-0.06	-0.21*	0.00
	(0.080)	(0.152)	(0.079)	(0.076)	(0.133)	(0.083)	(0.074)	(0.129)	(0.056)
Highly educated,	1.26***	1.14***	1.34***	3.70***	4.47***	2.89***	2.49***	2.24***	2.42***
share	(0.295)	(0.430)	(0.411)	(0.330)	(0.496)	(0.432)	(0.234)	(0.360)	(0.324)
Log county R&D	-0.07*	-0.03	-0.10	-0.02	-0.10**	-0.07	0.04	-0.00	0.04
	(0.035)	(0.041)	(0.071)	(0.041)	(0.044)	(0.074)	(0.032	(0.038)	(0.057)
Metro	0.15	0.18	-0.30	-0.21	-0.01	-0.80**	-0.17	0.09	-0.61*
	(0.122)	(0.134)	(0.352)	(0.144)	(0.163)	(0.163)	(0.152)	(0.181)	(0.332)
HHI sector 10	14.85	-1490.32***	-114.79	-63.15***	-2491.92***	-4078.73***	-75.19***	-3113.25***	-3655.56***
	(0.000)	(156.135)	(228.207)	(9.972)	(204.431)	(1,027.015)	(8.899)	(246.948)	(639.418
Observations	1428	966	462	2185	1176	1009	2398	1297	1101
T-test log foreign sales = log domestic sales (p-value)	0.002	0.007	0.134	0.001	0.000	0.948	0.000	0.000	0.372

Turning to the specification of main interest – the determinants of the amount of R&D conducted at the firm – Table 2.6 displays the second stage Heckman estimates for the three chosen years, 1993, 1997 and 2001 where we now include all available observations.

TABLE 2.6

Second stage Heckman estimates

Dependent variable: Log R&D expenditures	(1) 1993	(2) 1997	(3) 2001
Log foreign sales	0.65***	0.58***	0.60***
	(0.081)	(0.068)	(0.098)
Log domestic sales	0.45***	0.38***	0.29***
	(0.050)	(0.044)	(0.042)
Capital intensity	0.60**	0.46***	-0.12
	(0.255)	(0.112)	(0.174)
Highly educated, share	6.25***	5.59***	5.10***
	(0.577)	(0.614)	(0.696)
Foreign ownership		-0.09	-0.24**
		(0.108)	(0.109)
Constant	-3.80***	-2.60**	-2.27
	(1.251)	(1.266)	(1.719)
Uncensored observations	448	311	350
Censored observations	980	1874	2048
Lambda	1.45***	1.08***	1.37***
	(0.432)	(0.265)	(0.413)
T-test log foreign sales = log domestic sales (p-value)	0.013	0.005	0.001
T-test log foreign sales + log domestic sales = 1 (p-value)	0.365	0.664	0.378

Standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. Sector dummies not reported.

In line with our expectations, the elasticity with respect to foreign sales is again generally higher than for domestic sales. The estimate for foreign sales ranges between 0.47 (in 1991) and 0.65 (in 1993 and 1995), whereas for domestic sales it ranges between 0.29 (in 2001) and 0.45 (in 1991 and 1993). This difference between the estimates of the sales variables is significant and rather constant over the years except for 1991 when the estimates are almost the same. Thus, when studying all firms together, we cannot really claim that Swedish firms increasingly link their R&D behaviour to foreign sales relative to their domestic sales.

The combined elasticity ranges from 0.82 (in 1999) to 1.05 (in 1995), which is very close to one, and we can only reject that it is one for 1999. Thus, on average, R&D expenditures increase at the same pace as sales, and there does not seem to be a large firm advantage in performing R&D.

With regard to the control variables, capital intensity is not very robust. Most of the time it is significant but the size of the estimate changes a lot. On the other hand, the share of highly educated is significant and positive for all years, indicating that, in line with our expectations, having a well educated work force is an important determinant for the amount of R&D undertaken at the firm. As expected, the variable for foreign ownership, which is only available from 1997, is negative for all years, and significant for both 1999 and 2001.

To investigate if the results differ between manufacturing and service sectors, Table 2.7 shows the second stage Heckman estimates for these sectors separately. The first thing to note is that the coefficient of lambda is insignificant for all years except 1999 for the service sector, indicating that the Heckman estimator is not always needed for this sector.

The elasticity for foreign sales ranges from 0.48 (in 1991) to 0.88 (in 2001) for the manufacturing sector. It ranges from -0.03 (in 2001) to 0.23 (in 1997), and is not always significant, for the service sector. The domestic sales elasticity ranges from 0.21 (in 2001) to 0.47 (in 1991) for the manufacturing sector and from -0.27 (in 1991 and not significant) to 0.42 (in 1993) for services. The difference between the estimates for foreign and domestic sales becomes increasingly bigger over the years for the manufacturing sector, indicating that manufacturing firms increasingly link their R&D spending to exports. The post 1994 period is one where Swedish exports have increased dramatically, following a depreciated currency and membership of the European Union. Our results suggest that R&D

has been affected as well by these trends. For the service sector, on the other hand, domestic sales seems to be slightly more important in determining the amount of R&D than foreign sales, although we can only reject equality between the coefficients for two of the years (1999 and 2001).

TABLE 2.7

Second stage Heckman for manufacturing and service sectors respectively

Dependent variable: Log R&D expenditures	(1)	(2)	(3)	(4)	(5)	(6)
	1993 - M	1993 - S	1997 - M	1997 - S	2001- M	2001 - S
Log foreign sales	0.68***	0.15	0.65***	0.23**	0.88***	-0.03
	(0.078)	(0.131)	(0.075)	(0.110)	(0.129)	(0.128)
Log domestic sales	0.46***	0.42***	0.32***	0.24***	0.21***	0.17
	(0.053)	(0.128)	(0.042)	(0.093)	(0.052)	(0.108)
Capital intensity	0.43	0.69*	-0.05	0.45***	0.58**	-0.61**
	(0.316)	(0.415)	(0.272)	(0.176)	(0.296)	(0.247)
Highly educated, share	6.03***	3.67***	5.56***	2.63*	4.37***	1.18
	(0.581)	(1.263)	(0.579)	(1.385)	(0.667)	(2.119)
Foreign ownership			-0.10	-0.05	-0.22	-0.27
			(0.110)	(0.382)	(0.135)	(0.274)
Constant	-7.03***	2.51	-4.77***	2.87	-6.93***	9.60*
	(1.500)	(2.669)	(1.296)	(3.291)	(2.092)	(5.387)
Uncensored observations	398	50	261	50	273	77
Censored observations	568	412	915	959	1024	1024
Lambda	1.25***	-1.16	0.95***	-0.01	1.57***	-1.48
	(0.343)	(0.988)	(0.239)	(0.610)	(0.399)	(1.167)
T-test log foreign sales = log domestic sales (p-value)	0.005	0.222	0.000	0.914	0.000	0.060
T-test log foreign sales + log domestic sales = 1 (p-value)	0.173	0.002	0.729	0.001	0.504	0.000

Standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. Sector dummies not reported.

The combined elasticity ranges from 0.93 (in 1999) to 1.14 (in 1993) for the manufacturing sector and from 0.03 (in 1991) to 0.57 (in 1993) for the service sector, though the sales variables are not always significant. For the service sector we reject that the combined elasticity equals one for all time periods, whereas we never reject it for the manufacturing sector. Hence, for the service sector there seems to be a small firm advantage in R&D.

Turning to the control variables, the capital intensity variable is again shown not to be very robust, it is only significant for two of the years for manufacturing firms and three of the years for service firms, and it shows up with opposite signs. The share of highly educated is positive and significant for all years in the two sectors except in 1991 and 2001 for the service sector. In general, the size of the estimate is also lower for service sectors, but it is clearly important to have a highly educated work force for the amount of R&D. The variable for foreign ownership is still negative for all years but significant only for the manufacturing sector in 1999.

2.3.3.2 Quantile regressions

In this section we report on quantile regressions that allow us to investigate in more detail if and how the estimated effects vary across the distribution of R&D expenditure values. It also allows us to more clearly understand the role of the two sales effects for different levels of R&D performers. This understanding may also be important for policies which try to stimulate R&D. The technique is based on the minimization of the sum of absolute residuals which sorts the dependent variable by size and then changes the weight in the regression depending on which part of the sample is addressed.

Formally, the θth regression quantile of the dependent variable y is the solution to (Buchinsky 1998)

$$\min_{\beta}\left(\sum_{i:y\geq x'\beta}|y_i - x_i'\beta|\theta + \sum_{i:y<x'\beta}|y_i - x_i'\beta|(1-\theta)\right). \tag{2.4}$$

Hence, the estimated coefficients vary as residuals are successively given different weights in the estimation procedure. For the median regression, all residuals receive equal weight. However, when estimating the 75th percentile, negative residuals are weighted with 0.25 and positive residuals with 0.75. The criterion is minimized, when 75 percent of the residuals are negative.[9]

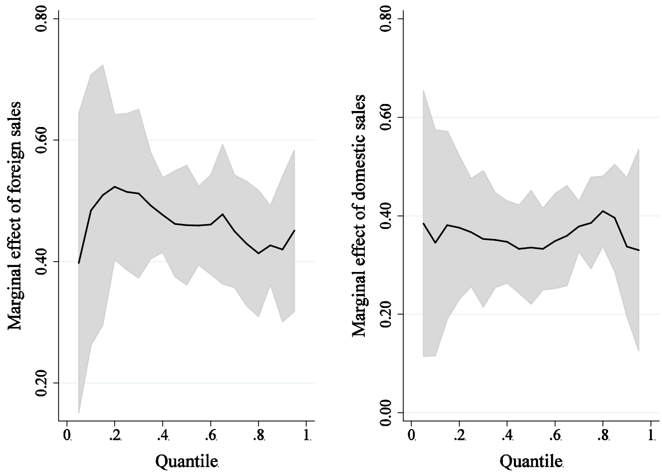
It is not easy to control for sample selection bias in the quantile regressions, even though Buchinsky (1998, 2001) has done some work in this direction. Moreover, it is not evident if the selection bias changes or not with the amount of R&D expenditures. To get some idea of the size of the selection bias over the distribution, we have reestimated our regression separately using only those firms with high R&D expenditures (above the 75th percentile) and those with low R&D expenditures (below the 25th percentile). In these regressions we see that the selection bias seems to be greater for firms with high R&D levels, and the coefficient of lambda is not even significant for the firms with low R&D levels. Hence, if the estimated elasticity differs with the amount of R&D when using quantile regression, it is reasonable to assume that the same pattern would occur if we could control for the sample selection, but that the estimates for high R&D performers would in general be higher.

Quantile regressions are run every fifth quantile (Q5, Q10, … , Q95) for all firms. Quantile regressions are more robust to outliers, but are subject to heteroscedasticity problems. In order to solve potential heteroscedasticity problems, bootstraps with 3000 replications are conducted.[10] The 95 percent confidence band from bootstrapped estimation errors are shown as shaded (grey) areas in the figures. We show results on the marginal effects of (log) sales for 1993 and 2001 in Figures 2.5 and 2.6.

The graph for 1993 is also representative for the situation in 1991 and the graph for 2001 is representative for the distribution of marginal effects for 1995, 1997 and 1999 as well.

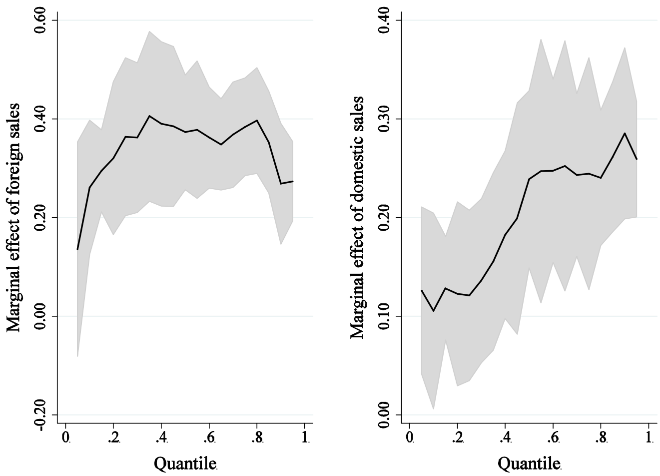
[9] Koenker and Hallock (2001) provide an intuitive explanation.
[10] See Rogers (1993) and Gould (1993). This procedure is automated in the Stata statistical package.

Figure 2.5. Quantile regressions for R&D in 1993



The difference is dramatic; while the marginal effects are fairly stable for both foreign and domestic sales in 1993, the marginal effects for domestic sales rise, as we move to higher values for R&D, from about 0.10 to 0.25 in 2001. This result means that firms increasingly link their R&D expenditures to domestic sales the more R&D they conduct, which is possibly explained by the fact that Swedish customers could be advanced users of new products. As sales start to pick up on the domestic market, they start to stimulate R&D as there is an expectation that the product may take off, possibly also on the international market. In a range of products such as mobile telephones and broadband, Swedish customers have been early to adopt new technology. The elasticity for foreign sales has somewhat of an inverted U-shaped pattern with values ranging from 0.18 to 0.40 and back to 0.25. When R&D expenditures start to increase, they quickly become more and more sensitive to changes in foreign sales, but after a while the level of sensitivity stabilizes and even diminishes to some extent. However, since the sample selection bias seems to be more pronounced for high R&D performers, this stabilization or fall in the estimates should be considered with care. It should also be noted that the foreign sales effect is almost invariably stronger than that of domestic sales for the entire R&D distribution.

Figure 2.6. Quantile regressions for R&D in 2001



Thus, during the 1990s, the sensitivity of R&D expenditures to changes in sales changed over the distribution of firms. In the early 1990s, all firms were more or less equally sensitive to changes in sales, whereas in the later 1990s and early 2000s the firms with high levels of R&D were the most responsive to changes in sales, especially concerning domestic sales. This result shows that, in these later years, the level of sales was not that important as a determinant for R&D expenditures in firms with lower levels of R&D, and that we need to look for other variables to explain the R&D efforts.

2.4 Summary and conclusions

The Swedish economy has undergone dramatic changes in the last decades in terms of openness. This chapter examines whether exports have had an impact on firms' R&D efforts. We divide firms into manufacturing and service sectors and compare effects at different points in time. In line with the 'stylized fact' presented in Cohen and Klepper (1996), we find the average combined elasticity of sales to R&D to be close to one, suggesting a proportionate relationship. This average relationship masks several differences revealed after more detailed analyses. For service firms the elasticity is less than one, which indicates that, among service firms, a small firm advantage is discerned, implying that being small and flexible might be advantageous for service firms. In the words of Breschi et al. (2000) they would belong to the Mark I regime, referring to Schumpeter's (1934) notion of the dynamic young entrepreneurial (and small) firms. Another possibility is that smaller firms cater for the R&D needs of large corporations to a larger extent and R&D is increasingly being conducted by smaller consultancy firms in services. For manufacturing firms there is clear evidence that foreign sales have a stronger effect on R&D expenditures than domestic sales. There are several reasons why foreign markets can be expected to provide more stimulus to R&D. First, learning-by-exporting may have firms enter into virtuous circles of export-R&D-export. Second, we argue that export sales are in a sense a low estimate of the sales effect. In multinational firms with production operations abroad, of which Sweden has many, the exported good is often refined in foreign affiliates and hence the total sales effect becomes underestimated. Third, we have argued that scale effects should be more pronounced in manufacturing firms, as production and R&D can be more distinctly separated. Moreover, for manufacturing firms the weight of goods may make it more economical to establish plants abroad to economize on transport costs. Our results support these hypotheses in general, but our study does not distinguish between the alternative hypotheses explaining the link from exports to R&D; this issue is left to future research.

Neither does our study differentiate between the type of products that are exported or to which markets they are sold, something that could influence the sensitivity to changes in sales. The R&D expenditures of a firm that exports an R&D intensive product are probably more sensitive to changes in the exports of that product than the R&D expenditures of a firm that exports low R&D intensive products. The same reasoning goes for the markets receiving the exports. If the exported goods are sold to R&D intensive countries, then a firm probably needs to put more resources into R&D itself to keep the products competitive, in line with the ‘advanced user’ argument put forward above. Support for these conjectures can be found in Andersson and Ejermo (2008). Deeper exploration of these hypotheses is left to future research.

Over the course of the period investigated here, Sweden experienced a sharp depreciation of its currency (1992-93) and became a member of the European Union (1995). The 1990s was a period of export-led recovery. Some Swedish policy discussions (Braunerhjelm 1998, Edquist and McKelvey 1998) have concluded that Sweden ‘underperforms’ with respect to R&D in terms of innovative performance, exports and growth, at times referred to as the Swedish paradox. Recent contributions examining productivity of R&D in terms of patents suggest, however, a much more positive outlook and a taxonomy based on growth patterns (Ejermo and Kander 2011). Ejermo et al. (2011) demonstrate that it is the growing sectors that are responsible for R&D expenditures, which suggests that growth effects might be undervalued. Our results support this idea; ‘underperformance’ may simply arise from a neglect of accounting for sales effects abroad, i.e. the reasons for investing in R&D depend on the degree of internationalization and exports of the firm. Interestingly, foreign ownership of Swedish firms may result in less R&D being allocated to Sweden, which fuels the discussion of cross-border ownership. Our results also suggest that the export-led growth experienced since the 1990s has led to a two-tiered structure in terms of R&D organization. On the one hand, manufacturing firms’ R&D efforts are to some extent driven by economies of scale. On the other hand, R&D in the service sector has been on the rise, with the R&D efforts appearing to be relatively more linked to domestic sales at the same time as making small firms more important. Again, a clear possibility is that these firms cater for the needs of multinationals at home in the sense that they conduct R&D based on the needs of these large firms. It is also possible that these firms represent increasing dynamics in terms of innovation and entrepreneurship. We believe that these are important avenues for further research.

Acknowledgments
The authors are grateful for helpful comments and suggestions from Martin Andersson, Johan Blomquist and seminar participants at 'The 12^{th} Uddevalla Symposium' in Bari, June 2009, and at the Department of Economics in Lund.

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Appendix

TABLE 2.8

Descriptive statistics for 1997 for all firms that are in the first stage of Heckman

	Variable	Obs.	Mean	Sd.	Min	Max
All sectors	R&D	2185	10738	99509	0	2620000
	Foreign sales	2185	138746	971200	1	30800000
	Domestic sales	2185	190436	727586	379	19000000
	Capital intensity	2185	0.22	0.58	0	11.64
	Highly educated, share	2185	0.22	0.2	0	1
	Foreign ownership	1807	0.23	0.42	0	1
	County R&D (total)	2185	2820000	3050000	15737	8110000
	Metro	2185	0.53	0.41	0	1
	HHI	2185	0.02	0.03	0	0.36
Manufacturing sectors	R&D	1176	16939	129749	0	2620000
	Foreign sales	1176	218659	1300000	5	30800000
	Domestic sales	1176	140291	378478	493	5800000
	Capital intensity	1176	0.23	0.45	0	8.97
	Highly educated, share	1176	0.15	0.13	0	0.77
	Foreign ownership	1031	0.24	0.43	0	1
	County R&D (total)	1176	1810000	2400000	15737	8110000
	Metro	1176	0.42	0.43	0	1
	HHI	1176	0.03	0.04	0	0.36
Service sectors	R&D	1009	3511	41634	0	1130000
	Foreign sales	1009	45608	238654	1	5010000
	Domestic sales	1009	248880	986743	379	19000000
	Capital intensity	1009	0.21	0.7	0	11.64
	Highly educated, share	1009	0.29	0.24	0	1
	Foreign ownership	776	0.22	0.42	0	1
	County R&D (total)	1009	4010000	3290000	15737	8110000
	Metro	1009	0.65	0.35	0	1
	HHI	1009	0.01	0.01	0	0.09

R&D and sales variables are in thousands of SEK (1985-year prices).

TABLE 2.9

First stage Heckman estimates for 1991, 1995 and 1999

Dependent variable: s(R&D)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1991 – All	1991 – M	1991 – S	1995 – All	1995 – M	1995 – S	1999 – All	1999 – M	1999 – S
Log foreign sales	0.31***	0.34***	0.20**	0.27***	0.35***	0.12***	0.38***	0.64***	0.15***
	(0.028)	(0.031)	(0.088)	(0.022)	(0.029)	(0.036)	(0.027)	(0.046)	(0.036)
Log domestic sales	0.26***	0.31***	-0.01	0.12***	0.16***	0.04	0.10***	0.09**	0.07
	(0.039)	(0.043)	(0.105)	(0.030)	(0.038)	(0.031)	(0.031)	(0.042)	(0.051)
Capital intensity	0.50**	0.39	2.38**	-0.05	-0.13	0.70***	-0.08	0.04	-0.07
	(0.245)	(0.256)	(1.064)	(0.051)	(0.176)	(0.269)	(0.097)	(0.134)	(0.123)
Highly educated,	2.64***	2.37***	2.59***	2.54***	2.52***	2.45***	2.94***	3.18***	2.35***
share	(0.430)	(0.541)	(0.849)	(0.296)	(0.461)	(0.399)	(0.268)	(0.400)	(0.352)
Log county R&D	0.01	0.01	0.18	-0.05	-0.03	-0.09	0.02	0.01	-0.04
	(0.038)	(0.040)	(0.161)	(0.033)	(0.038)	(0.064)	(0.040)	(0.048)	(0.068)
Metro	-0.12	-0.05	-1.70**	-0.01	0.04	-0.35	-0.36**	-0.09	-1.00**
	(0.135)	(0.139)	(0.739)	(0.119)	0.130)	((0.338)	(0.155)	(0.187)	(0.313)
HHI sector 10	-3.28	-2156.16***	-1466.79***	21.58	-1124.97***	-583.75**	-30.51***	-3416.29***	-2949.09***
	(0.000)	(187.120)	(549.700)	(0.000)	(124.868)	(253.673)	(5.141)	(296.045)	(898.582)
Observations	1504	1031	473	1564	1049	515	2177	1194	983
T-test log foreign sales = log domestic sales (p-value)	0.297	0.511	0.192	0.000	0.000	0.268	0.000	0.000	0.248

TABLE 2.10

Second stage Heckman for 1991, 1995 and 1999

Dependent variable: Log R&D expenditures	(1)	(2)	(3)
	1991	1995	1999
Log foreign sales	0.47***	0.65***	0.51***
	(0.073)	(0.077)	(0.064)
Log domestic sales	0.45***	0.40***	0.31***
	(0.061)	(0.047)	(0.031)
Capital intensity	0.16***	0.36	0.41**
	(0.047)	(0.267)	(0.202)
Highly educated, share	5.49***	6.27***	4.64***
	(0.659)	(0.702)	(0.464)
Foreign ownership			-0.20**
			(0.089)
Constant	-2.57	-3.66***	-0.40
	(1.629)	(1.347)	(0.982)
Uncensored observations	310	515	341
Censored observations	1194	1049	1836
Lambda	0.97***	1.71***	0.83***
	(0.350)	(0.425)	(0.247)
T-test log foreign sales = log domestic sales (p-value)	0.790	0.003	0.006
T-test log foreign sales + log domestic sales = 1 (p-value)	0.506	0.594	0.012

Standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. Sector dummies not reported.

TABLE 2.11

Second stage Heckman for manufacturing and service sectors respectively, for 1991, 1995 and 1999

Dependent variable: Log R&D expenditures						
	(1)	(2)	(3)	(4)	(5)	(6)
	1991 - M	1991 - S	1995 - M	1995 - S	1999 - M	1999 - S
Log foreign sales	0.48***	0.30	0.66***	0.14	0.66***	0.09
	(0.073)	(0.273)	(0.069)	(0.093)	(0.074)	(0.068)
Log domestic sales	0.47***	-0.27	0.39***	0.23***	0.27***	0.30***
	(0.064)	(0.357)	(0.041)	(0.067)	(0.034)	(0.066)
Capital intensity	0.16***	-0.40	0.38	0.35	0.15	0.69**
	(0.046)	(3.867)	(0.300)	(0.522)	(0.264)	(0.344)
Highly educated, share	5.45***	1.63	5.62***	3.16***	4.55***	2.17***
	(0.635)	(1.636)	(0.539)	(1.222)	(0.425)	(0.841)
Foreign ownership					-0.19**	-0.12
					(0.093)	(0.226)
Constant	-4.02**	6.91*	-5.85***	3.02	-3.84***	5.15***
	(1.686)	(3.549)	(1.277)	(2.371)	(1.193)	(1.760)
Uncensored observations	298	12	447	68	278	63
Censored observations	733	461	602	447	916	920
Lambda	0.92***	0.95	1.22***	0.03	0.92***	-0.96**
	(0.333)	(1.002)	(0.333)	(0.685)	(0.227)	(0.435)
T-test log foreign sales = log domestic sales (p-value)	0.922	0.339	0.000	0.486	0.000	0.044
T-test log foreign sales + log domestic sales = 1 (p-value)	0.644	0.000	0.558	0.000	0.348	0.000

Standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. Sector dummies not reported.

Chapter 3

Internal and External R&D and Productivity – Evidence from Swedish Firm-Level Data

3.1 Introduction

Numerous studies have examined and confirmed the importance of firms' internal research and development (R&D) for firm performance (see Wieser 2005 and Hall et al. 2009 for a review of the literature). However, firms do not carry out their entire R&D themselves; they also acquire external know-how. This acquired know-how can take the form of contracted R&D, collaboration with other firms or organizations, public material like patents or publications, the use of consultants or the hiring out of skilled personnel who then return with new knowledge. Moreover, firms' use of external know-how has increased significantly since the 1980s, making it gradually more important in the innovation process (Arora et al. 2001, Jankowski 2001, Bönte 2003, Howells et al. 2003).

This chapter deals with external know-how in terms of contracted R&D where a firm pays someone else to perform the R&D. This notion of external know-how will henceforth be referred to as external R&D. There are several reasons for firms to use external R&D (Den Hertog and Thurik 1993, Cassiman and Veugelers 2006); for example, it allows firms to avoid taking all the risks of R&D themselves and to get around financial constraints. In addition, there is the possibility of enjoying spillovers, since new knowledge may come into the firm. However, the complementarities to the rest of the production, which it can achieve by doing the R&D itself, do not exist and information can spill out from the firm.

The objective of this chapter is to investigate the productivity effects of internal and external R&D. There are several reasons why we should expect the productivity effects to be equal or to differ. Transaction cost theory stresses the substitutability between internal and external R&D, and points out that outsourcing of R&D is a way for firms to exploit the R&D capabilities of competitors, suppliers and other organizations and thereby enjoy the economies of scale associated with specialization (Pisano 1990). This reasoning would hence yield the same productivity effects from internal and external R&D. Moreover, Rigby and Zook (2002) use case studies to show how an open-market innovation strategy, i.e. a strategy to open up the innovation process to external knowledge flows, can improve the cost, quality and speed of innovation when the pool of ideas to choose from increases for those responsible for innovation. Still, to ensure that the know-how of the R&D project stays with the buying firm and does not leak to competitors, the contract between buyer and seller has to be very clear on which specific technologies the buying firm owns (Pisano 1990). The establishment of such a contract can be very costly, not least because of the uncertainty and complexity of R&D projects. Therefore, Veugelers and Cassiman (1999) argue that outsourcing of R&D is more likely to occur for R&D projects that are of a generic nature and not specific to the firm. In this setting there are possibilities for specialization advantages which imply that outsourcing of R&D occurs for routine research tasks, and process rather than product innovations. If this is the case, then we might expect higher returns to external R&D than to internal R&D, because most studies examining the returns to process and product R&D find higher returns for process R&D (Hall et al. 2009). However, Hall et al. (2009) explain that this result might be due to the poor reflection of quality improvements in the price indices and/or that new products imply adjustment costs that lower productivity in the short run.

Nonetheless, firms are faced not only by the choice between make *or* buy, but also by the choice of make *and* buy. Veugelers and Cassiman (1999) discuss how the combination of internal and external R&D creates extensive scope for complementarities, e.g. in the sense that internal R&D helps to modify and improve the external technology. Moreover, internal R&D capabilities improve the ability of screening the available external projects. Cohen and Levinthal (1989, 1990) discuss the importance of a firm's 'absorptive capacity', the ability to understand and use external information, for the innovativeness of the firm. This absorptive capacity depends on the prior knowledge of the firm, which is influenced by the employees' knowledge and the firm's own investments in R&D. Concerning the employees' knowledge, it is not only how much and what kind of education the employees have that matters, but also their general awareness of where useful information can be found and who possesses the relevant knowledge. The importance of a firm's own investments in R&D is positively dependent upon the pace of technological development in a field, and on the complexity of outside knowledge.

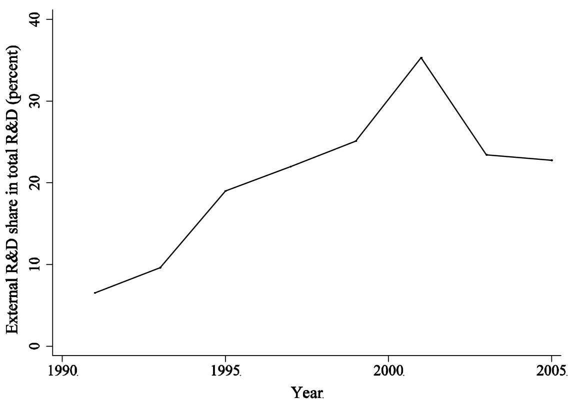
The existing literature on productivity effects from internal and external R&D is quite limited, especially in regard to using the amount of expenditures on internal and external R&D rather than simple dummy variables for having internal and/or external R&D. The study in this chapter uses R&D expenditures in a panel of Swedish manufacturing firms to examine the rates of returns to internal and external R&D. Because human capital is an important factor in determining a firm's absorptive capacity, the effect of the employees' level of education on these returns is also examined. The estimation is performed in two steps; a production function is estimated in the first step in order to calculate a measure of total factor productivity, which is then used in the second step. The findings give some support to the notion of complementarity between internal and external R&D and suggest that the employees' level of education is important for the firm's capabilities to absorb external R&D.

The rest of the chapter is organized as follows. Section 3.2 reviews the empirical evidence on internal and external R&D, section 3.3 describes the empirical analysis, section 3.4 contains the results and section 3.5 concludes the chapter.

3.2 Empirical evidence

Following the international trend, the share of external R&D in total R&D increased in Sweden in the 1990s. This share went from a little over 5 percent in 1991, peaked at over 30 percent in 2001 and seems to have stabilized at around 20 percent in 2005 (see Figure 3.1), indicating a more pronounced role of external R&D.[1]

Figure 3.1. External R&D share in total R&D (percent). Manufacturing sector, Sweden, 1991-2005 (biennial data)



[1] The large drop in the share of external R&D in total R&D from 2001 to 2003 might be a reflection of the dot com crisis which had a large impact in Sweden.

There are two strands of literature on the relation between internal and external R&D. The one strand studies whether internal and external R&D are complements or substitutes by examining a firm's decision to engage in internal and/or external R&D (see e.g. Veugelers 1997, Piga and Vivarelli 2004). The other strand studies the effects of internal and external R&D on a firm's innovative output or productivity (see e.g. Bönte 2003, Cassiman and Veugelers 2006, Lokshin et al. 2008, Schmiedeberg 2008, Santamaria et al. 2009).

In the first strand it is common to find that having internal R&D increases the probability of having external R&D, the interpretation often being that the two are complements. However, the results from the second strand give a more mixed picture of the complementarity issue. Cassiman and Veugelers (2006) find a positive effect on the share of sales from new products, in Belgian firms, for firms having internal and external R&D at the same time, specifically for firms with a high reliance on basic R&D. In contrast, Schmiedeberg (2008), in a study of German firms, finds no significant effect of having both internal and external R&D on either the probability of patenting or the share of sales from new products. Schmiedeberg's (2008) explanation of the lack of support for complementarity is that it might be due to the organization of production in Germany, where innovation strategies are oriented towards continuous, incremental innovation which might lead to a less market-responsive focus of external innovation strategies. Lokshin et al. (2008) use R&D expenditures to examine the impact of internal and external R&D on labour productivity in a six-year panel of Dutch manufacturing firms. They apply a dynamic panel data model that allows for decreasing or increasing returns to scale in internal and external R&D and for economies of scope. When not including squared R&D variables, there is no support for complementarity, but once they are included the interaction of internal and external R&D becomes highly significant and with a rather large estimated impact.

Concerning the direct effects of internal and external R&D on a firm's innovative output or productivity, Schmiedeberg (2008) finds, when examining different kinds of innovative output, that internal R&D is significant in all estimations, whereas contracted R&D is only significant for the probability of patenting, but with a larger estimate than for internal R&D. Cassiman and Veugelers (2006) find in some of their specifications that having only internal R&D gives a positive effect on the share of sales from new products, whereas only external R&D is never significant and shows up with opposite signs. Santamaría et al. (2009) investigate the effects of internal and external R&D on the probability of product and process innovations and on the production of patents. Also, they differentiate the effects in low and medium technology industries from those in high technology industries, and reveal that internal R&D has a positive and significant effect in all estimations except on the probability of process innovations in high technology industries. External R&D only has a small positive effect on the probability of a process innovation in low and medium technology industries, but is as important as internal R&D for the production of patents in high technology industries.

In the paper by Lokshin et al. (2008) internal R&D is significant and positive in all specifications and shows signs of decreasing returns to scale. In general, external R&D is not significant except when squared R&D variables are included in the model, and then only the square of external R&D is significant and with a negative sign. Together with the positive effect of jointly having internal and external R&D, the results indicate that external R&D only has a positive effect when a firm has sufficient internal R&D. In contrast, Bönte (2003) shows, in a panel of West German manufacturing firms, that external R&D has a higher productivity effect than internal R&D. However, for high-technology firms the findings indicate that there are decreasing returns to scale to external R&D, and this result implies that productivity would decrease in his sample if the share of external R&D in total R&D increased.

In sum, the literature on the effects of internal and external R&D on productivity is quite limited and the results are mixed. Sometimes external R&D is found to have a larger productivity effect than internal R&D; sometimes the effect is smaller, and often not significant. Concerning the question of complementarity, the findings are also ambiguous. The results seem to differ depending on which sectors are examined and in what terms productivity is measured.

3.3 Empirical analysis

This section first describes the data that is used in the empirical analysis and then goes on to develop the model to be estimated. It also discusses issues pertaining to the estimation.

3.3.1 Data

The data for this study has been compiled by Statistics Sweden and covers the period 1991-2004. Several data sets have been merged. First, balance sheet data is extracted from the Structural Business Statistics (SBS) which cover most Swedish firms.[2] Second, data on R&D expenditures comes from the R&D statistics that are collected on a biennial basis and includes firms that have reported spending more than 5 MSEK on R&D in the SBS. In addition, this data set includes a sample of smaller R&D performing firms. From 1997 and onwards all firms with more than 200 employees are also included no matter the amount of R&D expenditures. The R&D data consists of 419-687 firms for each available year and covers, despite the sampling procedure, most of the R&D that is undertaken in Sweden.[3] In addition, this dataset allows for the differentiation between internal and external R&D.

[2] Before 1996 this dataset only includes firms with at least 50000 SEK in sales. From 1996 and onward most Swedish firms are included.

[3] When comparing the total amount of R&D in the R&D statistics with the reported R&D in the SBS (this data is only reported in intervals) the differences are very small for the years before 1996. Afterwards, the R&D statistics cover 70-80 percent of total R&D reported in the SBS. Moreover, the sample of R&D performing firms has generally not been affected by the sampling procedure of the SBS since the firms that are covered in the R&D statistics are the types of firms that were also covered in the SBS before 1996.

Third, data on the employees' level of education is taken from the education register.

Only manufacturing firms are used in this study since service firms in general cannot be fitted into a standard production function framework. The firms are grouped into 12 industry groups based on the Swedish standard of industrial classification, SNI 92, which corresponds to the ISIC rev (3) standard of classification. Some industries are on the two digit level and some are grouped together because there are very few firms in some industry classes. The industries that are grouped together are also quite similar in structure in terms of what they do and their R&D intensities.

As shown in Figure 3.1, the share of external R&D in total R&D increased in the 1990s in Sweden, but, as can be seen in Table 3.1, having only internal R&D is still most common for Swedish manufacturing firms and there is no sign of a decreasing trend. Still, even if it is not explicitly shown in the table, it is possible to see that it is also very common to have both internal and external R&D. The small number of firms with only external R&D suggests that internal R&D is an important determinant of having external R&D, in line with previous findings in the literature.

TABLE 3.1

Number of firms with only internal or external R&D

Year	Only internal R&D	Only external R&D	Total number of firms with R&D
1991	171 (50 %)	15 (4 %)	340
1993	257 (57 %)	22 (5 %)	453
1995	261 (53 %)	19 (4 %)	489
1997	132 (45 %)	6 (2 %)	296
1999	165 (54 %)	8 (3 %)	303
2001	190 (60 %)	7 (2 %)	315
2003	189 (60 %)	11 (3 %)	316
Total	1365 (54 %)	88 (4 %)	2512

3.3.2 The model

Output (Y) at time t for firm i is produced using physical capital (K) and labour (L) in a Cobb-Douglas setting:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} \tag{3.1}$$

The variable A is a measure of total factor productivity (TFP) and α and β are the elasticities of output with respect to physical capital and labour. TFP, in turn, is a function of the R&D capital stock (R) at the firm and other external factors affecting productivity (E).

$$A_{it} \equiv TFP_{it} = R_{it}^{\gamma} E_{it}^{\sigma}$$

Taking logarithms and first differencing yields:

$$\Delta \ln TFP_{it} = \gamma \Delta ln R_{it} + \sigma \Delta ln E_{it} \tag{3.2}$$

In order to estimate equation (3.2), a measure of the R&D capital stock is needed. This stock variable is usually calculated using the perpetual inventory method. However, the biennial nature of the Swedish R&D data and the rather short time span make it problematic to employ this method. The calculation of the stock variable is also sensitive to the choices of rates of depreciation and growth of R&D (Hall et al. 2009). Therefore, taking the rate of return to R&D capital, $\rho = (\partial Y / \partial R)$, as the parameter of interest instead of the elasticity, $\gamma = \rho(R/Y)$, the expression $\gamma \Delta ln R_{it}$ can be rewritten as $\rho(\Delta R_{it}/Y_{it-1})$. Assuming no depreciation of R&D, ΔR_{it} can be approximated with the expenditures on internal and external R&D.

$$\frac{\Delta R_{it}}{Y_{it-1}} = f\left(\frac{R\&D_{it-1}^{int}}{Y_{it-1}}, \frac{R\&D_{it-1}^{ext}}{Y_{it-1}}\right) = f\left(r_{it-1}^{int}, r_{it-1}^{ext}\right)$$

The R&D expenditure variables are lagged one period because it is assumed that it takes time for R&D to affect productivity. Whether longer lags should be used is debatable; for instance, Ali-Yrkkö and Maliranta (2006) do not find a significant effect of R&D on productivity until after 3-5 years, but in general there is no consensus on the most appropriate lag structure (Hall et al. 2009). The most common is to use R&D intensity lagged one period only, and to find a significant effect at this level. Whether there should be different lag structures for internal and external R&D, depending on the type of R&D that is contracted out, is also open to debate. If, for example, the external R&D is more directed towards applied research, it could be that the results from external R&D will take more time to implement than those from internal R&D. In addition to the inclusion of the two different R&D variables in the estimation, there will be an interaction term between them to test for complementarity.

The additional set of controls, *E*, is a function of two variables. The first is a lagged TFP variable in order to allow for convergence in productivity levels, in the sense that lagging firms are more likely to be able to record strong productivity growth through technology spillovers (Griffith et al. 2003). The second is a human capital variable, specified as the share of the employees with at least three years of higher education. The latter is also a measure of the absorptive capacity at the firm even if it does not say anything about the positions the educated workers hold. This variable, *H*, is included in the estimation both by itself and interacted with the R&D intensity variables to evaluate if the education level affects the returns to internal and external R&D. There are other factors that may affect the productivity at the firm, e.g. new knowledge spills over to the firm from neighbouring firms or contacts with customers or suppliers (see e.g. Arora et al. 2001), but spillover effects in this sense lie outside the scope of this chapter. Hence, equation (3.2), for the growth rate in TFP, becomes:

$$\Delta \ln TFP_{it} = \phi_0 + \sigma_1 lnTFP_{it-1} + \rho_1 r_{it-1}^{int} + \rho_2 r_{it-1}^{ext} + \rho_3 r_{it-1}^{int} * r_{it-1}^{ext} + \sigma_2 H_{it-1} + \delta_1 r_{it-1}^{int} * H_{it-1} + \delta_2 r_{it-1}^{ext} * H_{it-1} + \mu_i + \nu_j + \lambda_t + \eta_{it}. \quad (3.3)$$

In addition to the extensions to equation (3.2) outlined above, equation (3.3) also includes a firm specific effect, μ_i, an industry effect, v_j, a time effect, λ_t, and an idiosyncratic error term, η_{it}.

If the results show that $\rho_1 = \rho_2$ there is no difference in the productivity effects from internal and external R&D, and it would seem that the same kinds of R&D projects are performed internally and externally. If $\rho_3 > 0$, there will be evidence of complementarity between internal and external R&D in the sense that internal R&D enhances a firm's absorptive capacity.

3.3.3 Estimation

In order to estimate equation (3.3) a measure of TFP is needed. This measure can be obtained from the estimation of the production function in equation (3.1) in logarithms:

$$lnY_{it} = lnA_{it} + \alpha lnK_{it} + \beta lnL_{it}. \quad (3.4)$$

To allow for multilateral comparisons of productivity levels, TFP in one firm is measured relative to another firm. The general practice is to use the average of the other firms in the same industry (Van Biesebroeck 2007). The production function is hence estimated for each industry *j* separately and TFP in firm *i* in industry *j* at time *t* is then calculated as:

$$lnTFP_{ijt} = lnY_{ijt} - \overline{lnY_{jt}} - \widehat{\alpha_j}\left(lnK_{ijt} - \overline{lnK_{jt}}\right) - \widehat{\beta_j}\left(lnL_{ijt} - \overline{lnL_{jt}}\right), \quad (3.5)$$

where a bar over a variable denotes the mean of that variable in industry *j*, and $\widehat{\alpha_j}$ and $\widehat{\beta_j}$ are the estimated parameters from equation (3.4) for each industry *j* separately. The growth rate in TFP is then calculated as:

$$\Delta lnTFP_{ijt} = lnY_{ijt} - lnY_{ijt-1} - \widehat{\alpha_j}\left(lnK_{ijt} - lnK_{ijt-1}\right) - \widehat{\beta_j}\left(lnL_{ijt} - lnL_{ijt-1}\right). \quad (3.6)$$

When the measure of TFP is calculated the effect of internal and external R&D intensity on the growth rate of total factor productivity will be estimated. The reason for not directly including the R&D variables in the first step is the nature of the R&D statistics. Since this data is only collected on a biennial basis, the efficiency of the employment and capital estimates is increased by this two-step procedure. In both steps of the specification it is assumed that there is a firm-specific effect and a time effect and, as previously mentioned, there are also industry effects in the second step.

There are several problems to be considered in both steps of the estimation. First, there are time-invariant firm effects that may be correlated with the explanatory variables. Second, the independent variables are assumed not to be strictly exogenous, and third the panel data set has a short time dimension and a large firm dimension. The literature usually employs GMM methods to handle these problems, especially the difference GMM and more recently the system GMM proposed by Arellano and Bover (1995) and further developed by Blundell and Bond (1998). The system GMM uses a system of equations where lagged levels of variables are used as instruments for an equation in first differences and lagged first differences are used as instruments for an equation in levels. Blundell and Bond (2000) suggest that the system GMM is the most appropriate estimator when estimating first differences with weak instruments, and it has been shown to be a more reliable and robust estimator than the difference GMM when estimating production functions (see e.g. Ballot et al. 2001, Hempell 2005, Lokshin et al. 2008, O'Mahony and Vecchi 2009).

In the first step of the estimation all available data on firms that appear in the R&D statistics is used, even if they are not matched with the balance sheet data for the specific year that they are in the R&D statistics, and hence will not be in the second step of the estimation procedure. In this way the precision of the estimates for the elasticity of output with respect to physical capital and labour can be improved, especially since there are very few firms in some industry classes. In the estimation, output is measured as value added (deflated using industry-specific producer price indices), labour as the number of employees and capital as the book value of plant, construction and equipment (deflated with a construction price index). Due to data limitations, it is not possible to correct labour and capital for R&D expenditures in order to avoid double counting. Both labour and capital could include R&D expenditures in the sense that some employees are R&D staff and some of the capital is used in R&D. Thus, the estimated rate of return to R&D can be interpreted as an excess return. Moreover, this rate of return will also be a gross rate of return since an estimation of the net rate of return implies assumptions about the depreciation rate and growth rate of R&D. Since the depreciation rate can be substantial at the firm level, due to replacement investments, the estimated rate of return will be underestimated (Hall et al. 2009).

Instruments for the estimation in the first step, using the system GMM, differ between the industries because of the results from the serial correlation tests and the Hansen test of overidentifying restrictions. Lagged level variables from t-2 or t-3 and later are used in the difference equation and lagged first differences from t-1 or t-2 are used in the levels equation. The number of lags in the difference equation depends on the number of firms in the estimation. Following the general rule of keeping the number of instruments to be lower than the number of groups in the estimation (see e.g. Roodman 2009b) all available lags are used for some industries and only one lag is used for others. To keep the instrument count down, a collapsed instrument set is used for most industries. With the use of these lags the sample for the estimation in the first step consists of 1110 firms and 11623 observations.

Instruments in the second step of the estimation procedure are first and/or second lagged levels of the right hand side variables in the first difference equations, and first differences dated t-1 or t-3 in the levels equation. Hence, in the second step the sample is reduced to 475 firms and 1740 observations. Table 3.2 shows the 12 industry groups and their respective means of internal and external R&D intensities in percent. The table reveals that internal and external R&D intensities vary quite a lot between industries and that, in general, external R&D

intensities are much lower than internal R&D intensities. The sector including producers of radio, television and communication equipment has the highest internal as well as the highest external R&D intensity. It should also be noted that R&D in Sweden is very concentrated to a few firms, i.e. around two percent of the firms account for about 50 percent of the internal R&D expenditures.

TABLE 3.2

Internal and external R&D intensities (percent), by industry

SNI 92		Obs.	Mean internal R&D intensity	Mean external R&D intensity
15-16	Food, beverages and tobacco	104	7.03	1.13
17-19	Textiles, clothing and leather	28	4.61	0.16
20-22	Wood, paper and publishing	136	11.45	1.55
23-24	Refined petroleum; Chemicals	203	14.41	1.83
25-26	Non-metallic mineral products	119	8.06	0.41
27-28	Basic metals and metal products	139	5.25	0.41
29	Machinery and equipment	445	19.29	0.64
30-31	Computers and electrical machinery	133	24.76	2.38
32	Radio, television and communication eq.	69	63.90	18.07
33	Medical, precision and optical instr.	166	34.74	2.37
34-35	Motor vehicles and other transport eq.	159	31.00	3.97
36-37	Other manufacturing; Recycling	39	5.72	0.03
Total		1740	19.67	2.12

3.4 Results

The estimation of the production function in the first step produces an elasticity between 0.62 and 1.05 with respect to labour and between 0.06 and 0.19 with respect to capital, when significant. It should be noted that capital only is significant for five out of the twelve sectors, and in general the estimate is quite low. However, this result is not that unusual in within estimations (see e.g. Mairesse and Sassenou 1991), and in addition it could be that the book value of capital is not a good measure of the true value of capital at the firm. In the estimation there is no restriction on the returns to scale, but constant returns to scale are only rejected for one of the sectors – basic metals and metal products.

TFP measures have been derived from the first step of the estimation (found in the Appendix) in order to be used in the second step; the mean growth rate is 2.87 percent. Table 3.3 displays descriptive statistics for the variables that are used in the two steps of estimations separately.

TABLE 3.3

Descriptive statistics of variables in both steps of estimation

	Variable	Obs.	Mean	Sd.	Min	Max
First step variables	Value added	11623	266466	925420	41	27300000
	No. of employees	11623	423	1091	1	19134
	Capital	11623	221334	820890	3	16200000
Second step variables	Growth in TFP	1740	0.03	0.32	-2.85	2.63
	TFP (log)	1740	0.11	0.43	-3.29	2.09
	Internal R&D intensity	1740	0.20	0.40	0.00	8.82
	External R&D intensity	1740	0.02	0.17	0.00	6.21
	Share of employees with higher education	1740	0.11	0.11	0.00	0.80

Value added and capital are expressed in thousands of SEK (2000 year prices).

Table 3.4 shows the mean growth rate in TFP divided according to R&D sourcing strategy. The highest growth rate is found among firms with only external R&D, but there are only 34 such observations. It is more interesting to see that the mean growth rate is slightly higher for firms with both internal and external R&D than for firms with only internal R&D.

TABLE 3.4

Growth in TFP by R&D sourcing strategy

	Obs.	Mean	Sd.	Min	Max
Only external R&D	34	0.074	0.196	-0.368	0.404
Only internal R&D	905	0.027	0.323	-2.846	2.180
Both internal and external R&D	801	0.029	0.321	-1.648	2.631

Turning to the estimation results, Table 3.5 displays the results from the second step of the estimation where four different specifications are used in order to allow for comparisons with the existing literature. The first two specifications do not include any interaction variables, the third includes the interaction between internal and external R&D and the fourth also includes the interactions between R&D and the human capital variable.

TABLE 3.5

Second step of estimation

Dependent variable: Growth rate in total factor productivity				
	(1)	(2)	(3)	(4)
$lnTFP_{t-1}$	-0.39***	-0.31***	-0.41***	-0.39***
	(0.120)	(0.091)	(0.111)	(0.107)
r_{t-1}^{int}	0.18***	0.26***	0.08	0.01
	(0.056)	(0.057)	(0.073)	(0.084)
r_{t-1}^{ext}		-0.14	-0.38*	-0.65
		(0.095)	(0.227)	(0.441)
$r_{t-1}^{int} * r_{t-1}^{ext}$			0.05**	0.08**
			(0.028)	(0.037)
H_{t-1}	-0.20	-0.31	0.09	-0.19
	(0.290)	(0.237)	(0.305)	(0.379)
$r_{t-1}^{int} * H_{t-1}$				0.40*
				(0.227)
$r_{t-1}^{ext} * H_{t-1}$				0.61
				(0.869)
Constant	0.04	0.04	0.05	0.06*
	(0.032)	(0.032)	(0.031)	(0.035)
Observations	1265	1265	1265	1265
Number of groups	475	475	475	475
AR(1)	8.12e-10	0	7.49e-10	3.07e-10
AR(2)	0.738	0.909	0.782	0.918
Hansen	0.368	0.708	0.601	0.481
Diff. Hansen	0.503	0.733	0.363	0.466
No. of instruments	52	69	76	105

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text.

To validate the estimations in the second step, the Hadri-Larsson test for stationarity (Hadri and Larsson 2005) is used on the residuals (from the second step) and the null hypothesis of stationarity cannot be rejected for any of the specifications. To further validate the system GMM estimator, both the OLS and the fixed effects estimator are also used since the coefficient of the lagged TFP variable in the system GMM should lie between those of the fixed effects and the OLS (Roodman 2009a). The results from these regressions, which are not displayed here, show that the coefficient of the lagged TFP variable lies inside the credible range; e.g. for the fourth specification the OLS estimate on lagged TFP is -0.27 and the fixed effect estimate is -0.63. The GMM estimates for this variable are significant and negative in all specifications, and imply that about two fifths of the productivity lead is neutralized by the next period.

Internal R&D is significant in the first two specifications and gives a rate of return of 18-26 percent, which is in line with the literature, especially since it is a gross rate of return and shows excess returns. External R&D has a negative sign but is only significant in column (3), indicating that having only external R&D is bad for productivity growth. This negative productivity effect might be due to the lag structure. As discussed in section 3.3.2, it might be that it takes more time for external R&D to affect productivity than internal R&D. Also, as discussed by Hall et al. (2009), if applied research is contracted out, it could be that firms need to use resources to adjust to or implement the external R&D, which could result in a negative effect on productivity in the short run.

In both columns (3) and (4) it is clear that if a firm has both internal and external R&D, there are positive productivity effects, which supports the hypothesis of internal R&D being important for a firm's absorptive capacity, and shows the complementarity between the two sources of R&D.

The interaction terms with human capital are only significant, and on the 10 percent level, for internal R&D, which means that a firm gets higher productivity effects from internal R&D the more educated the employees are. However, the education level does not seem to help in absorbing the external R&D. The human capital variable in itself is never significant, a common result in within estimations since this variable does not change much over time (Hall et al. 2009). This characteristic might also affect the estimates of the interaction terms.

That the positive effect from internal R&D that we saw in columns (1) and (2) disappears in columns (3) and (4) is a bit discouraging, especially since the importance of internal R&D is well documented in the literature. However, it is probably the positive and significant interaction terms between internal and external R&D and between internal R&D and human capital that pick up this positive effect from internal R&D. Also, it is a general finding that the estimates of the rate of return are lower, and that it is more difficult to find significant estimates, in within estimations as compared to cross sections (Hall et al. 2009).

3.4.1 A deeper look at the results

To further investigate the results presented in the previous section two main routes have been undertaken. First the sensitivity of the results is examined in terms of the estimation of TFP and then the sensitivity of the results is examined in terms of outliers, the lag structure and the R&D sample. Table 3.6 summarizes the results from different estimations of TFP and Table 3.7 summarizes the rest of the sensitivity analysis.

3.4.1.1 Sensitivity to the estimation of TFP

Concerning the estimation of TFP, a two-step estimation procedure, like the one used in this chapter can be criticised since the presence of measurement errors or problems in the first-step estimation is carried forward to the second step. Van Biesebroeck (2007) reviews ways of getting TFP estimates and checks their robustness against factor price heterogeneity, measurement errors and differences in production technologies. He finds that the system GMM is one of the most robust estimators in the presence of both measurement error and heterogenous production technology. However, if productivity shocks are persistent, the semiparametric estimation method introduced by Olley and Pakes (1996) is more reliable. This method assumes that one part of a productivity shock in time t is observed by the firm, but not by the econometrician, and that the other part is not observed by either. At the beginning of each period, the firm observes this productivity shock and determines whether to exit the market, or to remain and make new investments in capital. With the sample of firms for this study it is not possible to get estimates for each industry j separately using this method. Hence, the first step is reestimated with all the firms simultaneously, now including industry dummies, with both this method and the system GMM. These two estimation methods produce very similar results. The results from the second step of the estimation with these two TFP estimates are shown in columns (1) and (2) in Table 3.6. Now that the first step is not estimated for each industry separately, the significance of the interaction term between internal R&D and human capital disappears, but the other variables are very similar to the ones reported in Table 3.5.

TABLE 3.6

Different estimations of TFP

Dependent variable: Growth rate in total factor productivity				
	(1)	(2)	(3)	(4)
	Olley-Pakes	System GMM	Törnqvist	System GMM
$lnTFP_{t-1}$	-0.45***	-0.44***	-0.35***	-0.28***
	(0.095)	(0.097)	(0.08)	(0.08)
r_{t-1}^{int}	-0.05	-0.02	-0.04	0.07
	(0.152)	(0.139)	(0.14)	(0.13)
r_{t-1}^{ext}	-0.54	-0.66	1.25**	1.31***
	(0.496)	(0.502)	(0.60)	(0.48)
$r_{t-1}^{int} * r_{t-1}^{ext}$	0.08*	0.08*	-0.03	-0.21
	(0.041)	(0.042)	(0.30)	(0.26)
H_{t-1}	0.08	-0.03	-0.16	-0.53
	(0.344)	(0.295)	(0.38)	(0.49)
$r_{t-1}^{int} * H_{t-1}$	0.36	0.38	0.15	0.12
	(0.561)	(0.541)	(0.30)	(0.32)
$r_{t-1}^{ext} * H_{t-1}$	0.34	0.65	-2.55*	-2.44**
	(1.045)	(1.034)	(1.30)	(1.14)
Constant	-0.01	0.03	0.04	0.07
	(0.042)	(0.040)	(0.05)	(0.05)
Observations	1274	1274	547	547
Number of groups	477	477	244	244
AR(1)	4.98e-08	1.83e-09	4.99e-06	9.50e-06
AR(2)	0.916	0.788	0.607	0.650
Hansen	0.335	0.342	0.646	0.584
Diff. Hansen	0.297	0.195	0.879	0.479
No. of instruments	105	105	89	86

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text except for column (4) where the second and third lags of lagged TFP are used as instruments instead of the first and second lags.

Another method of getting a measure for TFP, which is among the most robust ones, except if there are a lot of measurement errors, is an index number approach, like the Törnqvist index, which assumes constant returns to scale with respect to capital and labour in the production function in the first step and calculates the growth rate in TFP from the following equation:

$$\Delta \ln TFP_{ijt} = lnY_{ijt} - lnY_{ijt-1} - \frac{s_{ijt}+s_{ijt-1}}{2}\left(lnL_{ijt} - lnL_{ijt-1}\right) - \left(1 - \frac{s_{ijt}+s_{ijt-1}}{2}\right)\left(lnK_{ijt} - lnK_{ijt-1}\right), \quad (3.7)$$

where s_{ijt} is the cost share of labour in value added for firm *i* in industry *j* at time *t*.[4] The level of TFP for firm *i* at time *t* is given by:

$$lnTFP_{ijt} = lnY_{ijt} - \overline{lnY_{jt}} - \tilde{s}_{ijt}\left(lnL_{ijt} - \overline{lnL_{jt}}\right) - \left(1 - \tilde{s}_{ijt}\right)\left(lnK_{ijt} - \overline{lnK_{jt}}\right), \quad (3.8)$$

where $\tilde{s}_{ijt} = 0.5\left(s_{ijt} + \overline{s_{jt}}\right)$. It is only possible to calculate these TFP estimates up to 2002 due to data constraints. Moreover, the cost share of labour in value added is often higher than one, and excluding those observations reduces the sample by half. Estimating step two when TFP has been calculated using the Törnqvist index does not change the results compared to using system GMM in the first step, and then estimating the second step on this smaller sample, as shown in columns (3) and (4) in Table 3.6. However, the results are somewhat different in this smaller sample compared to the results presented in Table 3.5. Here external R&D is significantly positive by itself, and significant but negative when interacted with human capital. Moreover, the interaction between internal and external R&D is negative, but not significant. This sample of firms is characterized by lower R&D intensities than the full sample, something that will be further addressed in the next part of the sensitivity analysis.

In sum, the results are not sensitive to the estimation of TFP in the first step, but there seems to be some sensitivity to the chosen sample.

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[4] Using the properties of the superlative index, the cost shares of labour in value added have been smoothed following Harrigan (1997).

3.4.1.2 Sensitivity to the investigated sample

Concerning outliers in the sample, there are no indications of outliers in the estimates of total factor productivity or in the human capital variable. However, for the R&D intensity variables there exist observations with R&D intensities above 100 percent. Removing the two observations that really look like outliers, with an internal R&D intensity over 800 percent and an external R&D intensity over 600 percent, makes no difference to the results, but when the 38 observations with R&D intensities between 100 and 500 percent are excluded, only lagged TFP is significant. Nonetheless, these observations mainly exist in those industries with the highest R&D intensities, and there is nothing particular about these observations indicating that there is reason to include them. The results from the estimation excluding R&D intensities over 100 percent are shown in column (1) of Table 3.7.

It is a common result that the rates of return to R&D differ between sectors (Hall et al. 2009). Hence, the next step is to divide the sample into industries with high and low R&D intensities following the mean internal intensities displayed in Table 3.2 so that the high R&D intensity industries are Machinery and equipment, Computers and electrical machinery, Radio, television and communication equipment, Medical, precision and optical instruments and Motor vehicles and other transport equipment. The results are displayed in columns (2) and (3) in Table 3.7. The first thing to note is that there is faster convergence for firms in high R&D industries. In general, the results for the high R&D intensity industries are very similar to the ones reported in Table 3.5. However, there are some differences in which variables are significant. External R&D is now significantly negative and the interaction between internal R&D and human capital is no longer significant. The negative estimate on external R&D could again be explained by the fact that it takes time to adjust the external R&D appropriately, and thereby we see this negative effect in the short run. Another similarity to the earlier results, which is not shown in the table, is that internal R&D is significant and of the same magnitude in specifications (1) and (2) as those presented in Table 3.5. The results for the low R&D intensity industries are very different, but similar to those obtained in the sample used when calculating the Törnqvist index. Here external R&D is positive and significant and the interaction between internal and external R&D is significantly negative. The implication of these results could be that firms that do not perform much R&D should outsource it, whereas firms with much R&D should opt for strategies including both in-house and outsourced R&D.

Two routes have been undertaken to examine if the results are sensitive to the lag structure. First the effect on the growth in TFP at time *t* of lagged TFP at time t-1, and lagged R&D variables at time t-3 is estimated, and then the effect on the average growth in TFP over three years of lagged variables at t-3 is estimated. The results from these estimations, shown in columns (4) and (5) in Table 3.7, are fairly similar to each other, except that lagged TFP is not significant for the average growth rate, and that human capital is positively significant for productivity growth three years ahead. However, the results differ from the ones reported in Table 3.5 in the sense that external R&D is again negative and significant, the interaction between internal and external is not significant and the interaction between external R&D and human capital is positive and significant. At this time horizon, internal R&D does not seem to increase the absorptive capacity whereas the education level of the employees does. Concerning the negative estimate on external R&D, these results show that it does not seem to be the lag structure that explains it. It could of course be that three years is still a short time horizon, but it is more difficult to explain the negative effect here.

The literature provides some possible explanations for the negative effect. Antonelli (1989) surveys the literature on profitability and R&D investments where the general theory is that, due to financial markets' reluctance to sponsor uncertain R&D projects, R&D expenditures are positively correlated with high profitability and liquidity. However, empirical research has found both positive and negative relationships. Antonelli (1989) explains a negative relationship with a failure-inducement hypothesis stating that firms facing declining profits and increasing competition invest in R&D to modify their production mix and market conditions. He also finds support for this hypothesis in Italian firms. In a context of declining profits it might be easier to find financing for the outsourcing of R&D, since a firm does not necessarily take all the risk of the R&D project itself. The negative effect of external R&D could then be explained by this argument. Johansson and Lööf (2008) investigate how a firm's R&D strategy, in terms of being a persistent or an occasional R&D performer, affects productivity and profitability, and find that occasional R&D has a negative effect indicating that firms choosing occasional R&D are those that have productivity problems. The firm that persistently performs R&D undergoes a learning process in which it develops routines for performing R&D as well as acquires experience in how to commercialize R&D results, at the same time as accumulating a stock of knowledge. Outsourcing of R&D is a much more occasional strategy than the performance of in-house R&D and it could be that it is not only the absorptive capacity of internal R&D that is needed to absorb external R&D, but also a persistent outsourcing strategy.

As a last sensitivity check, I only examine those firms that have both internal and external R&D at the same time, since there are a lot of zeros in the sample, especially for the external R&D intensity. The results are displayed in column (6) in Table 3.7, and again external R&D is found to have a negative effect. Moreover, in this sample the absorptive capacity hypothesis is confirmed in terms of both internal R&D and the education level of the employees.

In sum, the results reported in this chapter are somewhat sensitive to the chosen sample. Decreasing the variance in R&D intensities makes it more difficult to find significant estimates, and finding a negative effect from external R&D is common in many variations of the estimation except for low R&D industries where external R&D has a positive effect. The capacity of internal R&D and human capital for absorbing external R&D is clearly sensitive to the chosen sample.

TABLE 3.7

Summary of sensitivity analysis

Dependent variable: Growth rate in total factor productivity						
	(1) Outliers removed	(2) High R&D industries	(3) Low R&D industries	(4) Longer lags[a]	(5) Average growth in TFP over 3 years[b]	(6) Both internal and external R&D
$lnTFP_{t-1}$	-0.34***	-0.41***	-0.21***	-0.47***	-0.04	-0.43***
	(0.074)	(0.125)	(0.076)	(0.074)	(0.032)	(0.121)
r_{t-1}^{int}	0.09	0.02	-0.04	-0.01	0.13	0.20
	(0.099)	(0.102)	(0.315)	(0.096)	(0.082)	(0.150)
r_{t-1}^{ext}	0.33	-0.84**	1.98**	-0.78***	-0.43**	-1.39***
	(0.454)	(0.409)	(0.884)	(0.194)	(0.177)	(0.454)
$r_{t-1}^{int} * r_{t-1}^{ext}$	0.09	0.09**	-0.74*	0.18	0.04	0.12***
	(0.368)	(0.037)	(0.413)	(0.294)	(0.046)	(0.032)
H_{t-1}	-0.21	-0.08	-0.38	0.04*	-0.28	-0.14
	(0.292)	(0.443)	(0.282)	(0.024)	(0.212)	(0.307)
$r_{t-1}^{int} * H_{t-1}$	0.51	0.25	1.16	0.07	-0.08	-0.17
	(0.492)	(0.233)	(0.976)	(0.201)	(0.147)	(0.318)
$r_{t-1}^{ext} * H_{t-1}$	-0.78	1.09	-3.37	1.93*	1.11**	2.30***
	(0.827)	(0.780)	(3.352)	(1.160)	(0.490)	(0.819)
Constant	0.04	0.11***	0.02	0.17***	0.05**	0.01
	(0.032)	(0.041)	(0.035)	(0.048)	(0.024)	(0.075)
Observations	1227	713	548	946	522	459
Number of groups	464	258	218	392	226	189
AR(1)	0	3.81e-07	1.21e-05	2.91e-07	1.10e-06	1.96e-06
AR(2)	0.828	0.904	0.744	0.297	0.021	0.591
Hansen	0.478	0.489	0.760	0.768	0.456	0.422
Diff. Hansen	0.550	0.373	0.512	0.662	0.383	0.428
No. of instruments	98	103	96	91	73	105

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text except for column (5) where, due to the autocorrelation tests, only instruments lagged two periods are used in the difference equation. [a] Except for lagged TFP, t-1 actually denotes t-3. [b] t-1 actually denotes t-3.

3.5 Discussion and conclusions

This chapter has examined the impact of internal and external R&D expenditures on firm productivity. Using Swedish data on manufacturing firms for the period 1991 to 2004, the results reveal a rate of return to internal R&D of 18-26 percent when no interaction variables are included. This finding is in line with the general literature on R&D and productivity. The positive effect of internal R&D becomes smaller and insignificant when including the interaction variables with external R&D and human capital, due possibly to this effect being picked up by one or both of the interaction terms.

The effect of external R&D on productivity is not completely clear, but most of the findings indicate that it is negative. This result has several possible explanations. First, it may be that it takes more time to see the positive effect because the outsourced R&D is directed towards product development, which implies a negative effect in the short run due to adjustment costs. Second, it may be due to the failure inducement hypothesis, according to which firms invest in R&D to counteract declining profits. Third, it may be that firms only outsource R&D occasionally, in which case the firm does not have the routines to do this in an efficient way or that it is a sign of productivity problems. However, the negative effect disappears when removing the observations with high R&D intensities. Then the estimate on external R&D is positive. Hence, for firms that do not perform much own R&D it may be a good strategy to outsource it in order to exploit the R&D capabilities of other firms, in line with transaction cost theory.

There is some support for internal R&D as being important for a firm's absorptive capacity and thereby enhancing the effect of external R&D. However, in line with previous findings, support for complementarity seems to be sensitive to which industries are investigated. The support for complementarity in high R&D intensity sectors is in line with the Cohen and Levinthal (1989, 1990) notion of absorptive capacity where they argue that a firm's internal R&D is more important in industries where there is faster technological change.

The findings also suggest that the employees' level of education is important for the firm's capabilities to absorb external R&D, especially in a longer time perspective and for firms with both in-house R&D and outsourced R&D. The results concerning complementarity between internal R&D and the employees' level of education are less clear.

The sensitivity of the results to the chosen sample highlights the need for more studies in this area. With more data and longer time spans it might be easier to disentangle contexts in which we find different results and when it is optimal for firms to outsource R&D. Specifically, the results of high versus low R&D intensity industries emphasize the differences of the effects between sectors. These differences do not necessarily exist only in this division of sectors, which points at the need for more studies on specific industries. It could be that the same industries in different countries are more similar than different industries in the same country, and examining the productivity effects of internal and external R&D in certain industries in several countries could be a possible route for future studies.

Acknowledgments

The author is grateful for helpful comments and suggestions from Pontus Hansson, Martin Andersson, Johan Blomquist, participants at 'The 2010 Ratio Colloquium for Young Social Scientists: Understanding Firm Growth' in Stockholm, August 2010, participants at the National Conference in Economics in Lund, October 2010, seminar participants at the Research Institute of Industrial Economics in Stockholm, November 2010, and seminar participants at the Department of Economics in Lund.

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Appendix

TABLE 3.8

First step: Production function estimation. Dependent variable: log of value added

SNI 92		Employment		Capital		Obs.	No. of groups	AR(2)	AR(3)	Hans.	Diff. Hans.	No. of instr.
15-16	Food, bev. and tobacco	0.78***	(0.074)	0.16***	(0.057)	648	85	0.70	0.21	0.97	0.43	40[a]
17-19	Textiles, clothing and leather	0.90**	(0.377)	0.03	(0.131)	246	29	0.31	0.33	0.32	0.32	18[a]
20-22	Wood, paper and publishing	1.01***	(0.089)	0.00	(0.054)	1040	122	0.43	0.41	0.46	0.84	40[a]
23-24	Refined petrol.; Chemicals	0.73***	(0.145)	0.18*	(0.090)	737	105	0.00	0.91	0.35	0.52	38[a,b]
25-26	Non-metallic mineral products	0.91***	(0.151)	0.16	(0.105)	903	117	0.75	0.82	0.48	0.32	40[a]
27-28	Basic metals and metal products	1.05***	(0.077)	0.05	(0.065)	1027	125	0.61	0.39	0.91	0.68	58[b]
29	Machinery and equipment	0.91***	(0.049)	0.06*	(0.035)	1675	224	0.02	0.54	0.24	0.31	138[b]
30-31	Computers and electrical mach.	0.78***	(0.104)	0.13	(0.112)	433	79	0.08	0.27	0.66	0.64	26[a,b]

Continued overleaf

TABLE 3.8 continued

First step: Production function estimation. Dependent variable: log of value added

SNI 92		Employment		Capital		Obs.	No. of groups	AR(2)	AR(3)	Hans.	Diff. Hans.	No. of instr.
32	Radio, television, communic. eq.	1.01***	(0.241)	0.05	(0.175)	195	33	0.02	0.78	0.45	0.79	22 [a,b]
33	Medical, precision, and optical instr.	0.62***	(0.183)	0.19**	(0.094)	660	103	0.53	0.18	0.90	0.35	40 [a]
34-35	Motor vehicles and other transport eq.	0.85***	(0.108)	0.11*	(0.066)	600	83	0.90	0.42	0.47	0.32	38 [a,b]
36-37	Other manuf; Recycling	1.00***	(0.188)	0.08	(0.110)	494	53	0.19	0.42	0.67	0.33	20 [a,b]

Robust standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(2) and AR(3) are tests for autocorrelation of second and third order in residuals, respectively. Hans. is the Hansen test of overidentifying restriction. Diff. Hans. is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. [a] Instruments are collapsed. [b] The first lag used as instrument in the difference equation is the third lag. Time dummies included in all models. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used.

Chapter 4

Productivity Effects of Privately and Publicly Funded R&D

4.1 Introduction

The importance of research and development (R&D) for innovation, and subsequently for economic growth, has been stressed since the beginning of the 1990s following the development of endogenous growth theory (Romer 1987, 1990, Grossman and Helpman 1991, Aghion and Howitt 1992). Since the beginning of the 1980s the business enterprise sector in the OECD countries has continuously increased its expenditures on R&D and in 2008 it spent 671 billion USD in total, which is equivalent to 1.6 percent of GDP. Of these expenditures, 6.5 percent was financed by the government, a decrease from 21 percent at the beginning of the 1980s (OECD 2010c).

The objective of this chapter is to examine whether there are different productivity effects from privately and publicly funded R&D performed in the business sector. Earlier studies on productivity effects from privately and publicly funded R&D have mainly used U.S. data (see e.g. Levy and Terleckyj 1983, Griliches and Lichtenberg 1984, Lichtenberg and Siegel 1991, Griliches 1995, Archibald and Pereira 2003, Bönte 2003). The study in this chapter extends the previous literature by using a panel of industries from several OECD countries. It is important to note that the notion of publicly funded R&D in this chapter always means publicly funded R&D performed in the business sector as opposed to publicly funded R&D performed in the public sector.

The theoretical reason for government support to R&D dates back to Arrow (1962), who argues that a free enterprise economy is expected to underinvest in R&D due to the nature of the innovation process. Because the outcome of R&D is uncertain, most R&D takes place in large firms that can spread the risks over several projects. However, the economy potentially misses out on fruitful R&D projects in small firms that are unable to diversify risks. In addition, the non-rival nature of new knowledge implies that the marginal cost of spreading the new knowledge is zero, which makes it difficult for inventive firms to fully appropriate the returns from the R&D investment, thus leading them to invest less in R&D. These features of the innovation process, which result in less investment in R&D than is socially optimal, are the rationale for public support of R&D.

Jaffe (1998) discusses how the public funder of R&D should take into account both the private and the social returns to R&D when choosing projects to finance. Even if the objective of the public funder is to maximize social returns, it may not be the best option to fund the projects with the highest perceived social returns if these projects are also the ones with the highest perceived private returns since these projects would be undertaken anyway. Instead, the public funder should focus on the projects where there are large differences between the private and the social rate of return. However, David et al. (2000) point out that it might be the projects with the highest private returns that are funded in order to ensure the success of public funding of R&D.

If projects with lower private returns receive funding, the risk of a crowding-out effect on private R&D is smaller than for projects with higher private returns. However, it could be that a private firm that gets funding for projects with high private returns may have the opportunity to undertake more risky projects that would not have been performed otherwise.

Investment in R&D is believed to affect not only the firm's own productivity, but also other firms' productivity through spillover effects. By trading with, or just being located close to, an R&D performing firm, another firm can gain access to new technology and thus experience effects on its own productivity. If private and public funding of R&D is directed towards different kinds of projects, there could also be differences in their spillover effects. For example, if public funding of R&D is more directed towards basic research than private funding, there may be larger spillover effects from the former. Therefore, I also examine whether there are different spillover effects of publicly and privately funded R&D performed in other industries within the country.

The growth in total factor productivity (TFP) for industry i in country j is modelled not only to depend on privately and publicly funded R&D, but also on the growth in TFP in the frontier country and a lagged TFP variable. To estimate this model I use the system GMM estimator where it is possible to control for country-industry fixed effects and endogeneity of both TFP and R&D variables. The findings confirm the importance of privately funded R&D for industry productivity. However, the results also indicate that the public funder of R&D does not seem to find projects with either high private returns or high spillover effects.

The rest of the chapter is organized as follows. Section 4.2 reviews related literature and the empirical evidence, section 4.3 describes the theoretical and econometric frameworks and the data, section 4.4 contains the results and section 4.5 concludes the chapter.

4.2 Related literature

Related to the arguments for the need of government support to R&D, Link and Siegel (2007) discuss the importance of technology infrastructure for long-term technological advancement and economic growth. By technology infrastructure they mean an organizational form that supports knowledge creation and knowledge flows between developers and users of technology. Besides, the efficiency of these institutions in providing technology and related infrastructure services is essential to an efficiently functioning national innovation system. In line with Arrow (1962), they also suggest that there are several technological and market factors that cause private firms to appropriate lower returns from investments in technology infrastructure and to face greater risks than society does. The authors point out that there are high technical risks associated with this kind of underlying R&D, that it takes a long time to complete the R&D and commercialize the resulting technology and that the underlying R&D easily spills over to multiple markets and is not appropriable. Private firms' difficulties in appropriating the social returns can therefore make the risk unacceptably large for a private firm considering an investment. This reasoning can be interpreted as supporting the idea of Jaffe (1998) that public R&D policy should aim at projects where there are large spillover gaps and the private rate of return is low compared to the social rate of return.

The arguments of Arrow (1962) and Link and Siegel (2007) usually apply to basic research, which is associated with higher risks and longer time to completion than applied R&D. However, a higher rate of return is generally reported on basic R&D as opposed to applied or development R&D (Hall et al. 2009). Hall et al. (2009) suggest that this finding could reflect successful basic R&D projects where the higher risk factor results in higher returns. It is also the case that most studies find a higher rate of return for process as compared to product R&D. However, Hall et al. (2009) argue that it is difficult to disentangle the effects of the two, that they are complementary to a certain extent, and that these results could also depend on the difficulty of measuring the effects of product R&D because of the poor reflection of quality improvements in the price indices. In addition, new products imply adjustment costs that could lower productivity in the short run. Thus, if public support to R&D targets basic or process oriented research we might expect to see higher rates of return from this R&D than from privately funded R&D if the latter is more directed towards applied and product oriented research.

In evaluating the effects of government support to R&D, there has been a focus on the question of complementarity or substitutability between privately and publicly funded R&D. Does increased public funding of R&D increase or decrease private expenditures on R&D? Policy makers have been interested in the outcome of studies on this issue because they want to make sure that the funding they provide does not just replace investments that would have taken place anyway. However, the results from these studies are mixed. David et al. (2000) review 33 studies on this matter, performed on different levels (line of business, firm level, industry level and aggregate level), and all their results show is that it seems to be more common to find evidence of complementarity on the macro level than on the firm level. The same conclusion is drawn by García-Quevedo (2004) who, in a meta-analysis of the econometric evidence on the complementarity or substitutability between publicly and privately funded R&D, cannot say anything about how the design of the study affects the results except that firm-level studies more often find substitution effects.

Instead of looking at only the question of complementarity or substitutability, there is a strand of literature trying to evaluate the *productivity effects* of privately and publicly funded R&D. In general, these studies have indicated a much larger rate of return for privately funded R&D than for publicly funded R&D (Hall et al. 2009). For example, in a study of the aggregate U.S. industry sector, Levy and Terleckyj (1983) find the elasticity of privately funded R&D to be 28 percent, whereas the elasticity of federally financed R&D is only 6.5 percent. Lichtenberg and Siegel (1991) and Wolff and Nadiri (1993) find that federally funded R&D has an insignificant effect on productivity, whereas privately funded R&D has a significant rate of return of 30-60 percent. In line with these results, Griliches and Lichtenberg (1984) and Griliches (1995) find a significant positive premium for company financed R&D relative to federally financed R&D. There are even findings of a negative rate of return to publicly funded R&D, e.g. Poole and Bernard (1992) find a negative effect of publicly funded defence production on total factor productivity.

How can this lack of support for positive effects of publicly funded R&D be explained? Lichtenberg and Siegel (1991) argue that one way to interpret these results is that private companies are better than the federal funder at finding R&D projects with higher returns, and Hall et al. (2009) maintain that it is likely that private firms are less efficient in their research when using the public purse. Alternatively, it could be that it is difficult to measure the benefits from government funded R&D projects in the sense that output in industries with high levels of publicly financed R&D, e.g. defence related industries, is difficult to measure (Lichtenberg and Siegel 1991). And, as Griliches (1986) points out, much of the direct output of federally funded research is sold back to the government and is thus not likely to be reflected in the firm's productivity. Moreover, Leonard (1971) reports evidence from the U.S. where the federal funds are concentrated in a few industries, such as aircraft, missiles and electrical equipment, resulting in overinvestment in R&D and lower returns.

Lichtenberg and Siegel (1991) are of the opinion that a small or insignificant effect on productivity from publicly funded R&D could be reasonable if publicly funded R&D instead has an indirect positive impact on productivity in the sense that it improves economic welfare by stimulating additional privately financed R&D, or by generating positive spillover effects of R&D that is performed outside a given firm or industry. If the public funder of R&D aims at projects with lower private returns, but high social returns, as proposed by Jaffe (1998), the results of a lower rate of return on publicly financed R&D could hence indicate a successful R&D policy (Bönte 2003). In line with this reasoning, Bönte (2003), who finds no significant differences in the effect on U.S. industry productivity of privately and publicly funded R&D, notes that, because his data is on the industry level, it may be that his estimates pick up the spillover effect between firms, which is not visible in firm-level studies. Moreover, Archibald and Pereira (2003), using a vector autoregressive model to examine the 'total' effect of publicly funded R&D on private sector performance in the U.S. 1956-1988, argue that publicly funded R&D not only has a direct effect on output, but also positively affects private investment in physical capital and private R&D spending. They find the total effect on private output to be much larger for publicly funded R&D than for privately funded R&D.

On the topic of spillover effects, there are also studies trying to directly investigate whether there are differences in the size of the spillover effects from privately and publicly funded R&D. However, the empirical evidence gives mixed results. Mamuneas and Nadiri (1996) and Mamuneas (1999) find positive spillover effects from publicly financed R&D when investigating the effect of publicly funded R&D on the cost behaviour of U.S. manufacturing industries. However, when examining the effects on total factor productivity, Wolff and Nadiri (1993) and Bönte (2004) reveal a significant spillover effect only from privately funded R&D, whereas publicly funded R&D has an insignificant effect. Bönte (2004), however, provides some support for positive spillovers, from both privately and publicly funded R&D in low technology sectors. He further suggests that the lack of support for spillovers from publicly funded R&D might be a result of the public funder primarily aiming at improving health care or national security and not at increasing the efficiency of private production. Moreover, the literature on behavioural additionalities of public funding of R&D points at the importance of intangible social returns such as competence building and networking (Georghiou 2004).

In sum, the empirical evidence in some sense supports Jaffe's (1998) idea of public policy supporting projects with lower private returns, but the lack of results of positive productivity effects of spillovers from publicly funded R&D does not support this idea. However, it may be that the spillover effects are not visible in the short time perspective that is often the case in these kinds of studies. The arguments for public support of R&D, as stated by Arrow (1962) and Link and

Siegel (2007), generally support the idea that the public funder should fund basic research where the time horizon is longer and risks are greater. But then we would see higher rates of returns for publicly funded R&D, which we do not. Hence, public support of R&D seems to be aimed either at social welfare goals other than increasing productivity, or at product innovations where there is an adjustment cost for firms, resulting in a lower productivity in the short run. In practice, many countries seem to have a mix of R&D funding policies where some aim at more basic research whereas others aim at more applied research (see e.g. OECD 2006, Link and Siegel 2007, Bloch and Krogh Graversen 2008, Bergman et al. 2010).

4.3 The empirical analysis

This section first describes the theoretical framework that underlies the model to be used in the empirical analysis. It then extends the baseline model and transforms it into an econometric specification. Finally, it describes the data and discusses issues pertaining to the measurement of the variables.

4.3.1 Theoretical framework

Following the standard methodology, an industry i in country j produces output, value added (Y), at time t using physical capital (K) and labour (L) according to a standard neoclassical production technology,

$$Y_{ijt} = A_{ijt} F_i(K_{ijt}, L_{ijt}), \qquad (4.1)$$

where A_{ijt} is a measure of TFP and F_i is an industry-specific production function which assumes constant returns to scale and diminishing marginal returns to each input factor. TFP is in turn a function of the stock of knowledge in the industry, generated by R&D performed in the industry itself and in other industries within the country.

To relate to the convergence literature, there also exist spillover effects in a general sense so that the growth in TFP, in any industry, is stimulated by the diffusion of new and existing technologies from the frontier country for a given industry (see e.g. Scarpetta and Tressel 2002, Griffith et al. 2004, Cameron et al. 2005). TFP for a given industry *i* in country *j* at time *t* can therefore be modelled as an autoregressive distributed lag ADL(1,1) process where the level of TFP is assumed to be cointegrated with the level of TFP of the technological frontier country, defined as the country with the highest TFP in any given industry and indexed by *F*:

$$lnTFP_{ijt} = \alpha_1 lnTFP_{ijt-1} + \alpha_2 lnTFP_{iFt} + \alpha_3 lnTFP_{iFt-1} + u_{ijt}. \quad (4.2)$$

Under the assumption of long-run homogeneity ($1 - \alpha_1 = \alpha_2 + \alpha_3$), equation (4.2) has the following equilibrium correction model representation.

$$\Delta lnTFP_{ijt} = \alpha_2 \Delta lnTFP_{iFt} + (1 - \alpha_1) TGAP_{ijt-1} + u_{ijt}, \quad (4.3)$$

where $TGAP_{ijt-1} = lnTFP_{iFt-1} - lnTFP_{ijt-1}$ is the technological gap between the frontier country *F* and country *j* in a given industry. The further industry *i* in country *j* lies behind the technological frontier, the larger the gap term and the greater the potential for productivity growth through technological transfer.

The residual in equation (4.3), u_{ijt}, includes the main variables of interest, privately and publicly funded R&D expenditures in the industry ($R^{P,G}$) and spillovers from privately and publicly funded R&D expenditures in other industries within the country ($S^{P,G}$):

$$u_{ijt} = \gamma_1 \left(\frac{R^P}{Y}\right)_{ijt-1} + \gamma_2 \left(\frac{R^G}{Y}\right)_{ijt-1} + \gamma_3 \left(\frac{S^P}{Y}\right)_{ijt-1} + \gamma_4 \left(\frac{S^G}{Y}\right)_{ijt-1} + \rho' X_{ijt-1} + \eta_{ijt}, \quad (4.4)$$

where the superscripts *P* and *G* denote privately and publicly funded R&D, respectively. The variable *X* is a vector of control variables and η is a stochastic error. Equations (4.3) and (4.4) together give the basis for the econometric specification:

$$\Delta lnTFP_{ijt} = \alpha_2 \Delta lnTFP_{iFt} + (1-\alpha_1)TGAP_{ijt-1} + \gamma_1 \left(\frac{R^P}{Y}\right)_{ijt-1} + \gamma_2 \left(\frac{R^G}{Y}\right)_{ijt-1} + \gamma_3 \left(\frac{S^P}{Y}\right)_{ijt-1} + \gamma_4 \left(\frac{S^G}{Y}\right)_{ijt-1} + \rho' X_{ijt-1} + \eta_{ijt}. \quad (4.5)$$

We will see support for the reasoning of Jaffe (1998), that the public funder of R&D supports the projects with lower private returns but higher spillover effects, if $\gamma_2 < \gamma_1$ and $\gamma_4 > \gamma_3$, whereas the reasoning of David et al. (2000) will be supported if $\gamma_2 > \gamma_1$ or if they are equal. Even if $\gamma_4 < \gamma_3$ or there is no difference between them, Jaffe could be right since it may be that we do not see the effect of spillovers just one time period later. Moreover, if the public funder mainly funds basic research and privately funded R&D is more directed towards applied research then we would expect $\gamma_2 > \gamma_1$, based on the existing empirical evidence. We would also expect spillovers from this kind of research to be larger, i.e. $\gamma_4 > \gamma_3$.

4.3.2 Empirical framework

This section describes how total factor productivity is measured and gives a more detailed description of the econometric specification to be estimated.

4.3.2.1 Calculating total factor productivity

To calculate total factor productivity the superlative index approach of Caves et al. (1982) is used. Assuming a translog production function, the growth rate in TFP can be measured as follows:

$$\Delta lnTFP_{ijt} = ln\left(\frac{Y_{ijt}}{Y_{ijt-1}}\right) - \frac{1}{2}\left(s_{ijt} + s_{ijt-1}\right) ln\left(\frac{L_{ijt}}{L_{ijt-1}}\right) - \left(1 - \frac{1}{2}\left(s_{ijt} + s_{ijt-1}\right)\right) ln\left(\frac{K_{ijt}}{K_{ijt-1}}\right), \quad (4.6)$$

where s_{ijt} is the share of labour costs in value added. This share is in reality quite volatile over time, which indicates the presence of measurement errors. I therefore use the properties of the translog production function and smooths the observed labour shares using an estimation procedure from Harrigan (1997). This smoothing procedure is based on regressing s_{ijt} on a country-industry constant and on the capital-labour ratio, using a fixed effects estimator where the coefficient of the capital-labour ratio is allowed to vary across industries. The fitted values from this regression are then used in the calculation of the growth rate of TFP in equation (4.6).[1]

To be able to calculate the variable for the distance to the frontier, *TGAP*, we also need a measure for the *level* of TFP in industry i in country *j*. To have a measure of TFP that makes it possible to compare the TFP levels between countries at the same time as allowing for industry-specific technology, a common reference point is chosen for each industry – the geometric mean of value added, labour and capital in that industry over all countries (Van Biesebroeck 2007):

$$lnTFP_{ijt} = ln\left(\frac{Y_{ijt}}{\overline{Y_{it}}}\right) - \tilde{s}_{ijt}ln\left(\frac{L_{ijt}}{\overline{L_{it}}}\right) - \left(1 - \tilde{s}_{ijt}\right)ln\left(\frac{K_{ijt}}{\overline{K_{it}}}\right), \quad (4.7)$$

where a bar above a variable denotes the geometric mean of that variable in industry i at time *t*. The variable $\tilde{s}_{ijt} = \frac{1}{2}\left(s_{ijt} + \overline{s_{it}}\right)$ is the average of the labour share in industry i in country *j* and the geometric mean of the labour shares in industry i, and again the smoothed labour shares are used. The assumptions of perfect competition in output and input markets, optimizing behaviour by firms, and absence of measurement errors need to hold to calculate this measure of TFP (Van Biesebroeck 2007). Here, constant returns to scale are also assumed, but it is not a necessary assumption for this measure of TFP. However, without information on the level of scale economies, it is difficult to control for them and I follow the general practice of assuming constant returns to scale.

4.3.2.2 The econometric specification

Equation (4.5) is modified in a few ways in order to end up with the econometric specification to estimate. First, following Lokshin et al. (2008) equation (4.5) is

[1] When using a translog production function and standard market-clearing conditions are assumed to hold, the share of labour costs in value added is given by $s_{ijt} = \theta_{ij} + \phi_i \ln{(K_{ijt}/L_{ijt})}$. If actual labour shares deviate from this equation by an i.i.d. measurement error term, its parameters can be estimated using a fixed effects estimator (Harrigan 1997). This procedure is also used e.g. in Griffith et al. (2004).

extended to include quadratic terms of the R&D variables. There is empirical evidence of decreasing returns to R&D even though the quadratic terms have often been excluded in empirical studies due to the problem of estimating the linear and quadratic term simultaneously. This problem might still be prevalent in this study, but as Lokshin et al. (2008) point out, the availability of panel data reduces it.

Second, the vector of control variables is specified to include a variable for the level of human capital (H) in country j, measured as the share of the population of those more than 15 years old and with completed tertiary education.[2] To capture the business cycle effect, the variable ΔU_{jt}, measured as the difference in one minus the unemployment rate, is included following Guellec and van Pottelsberghe de la Potterie (2004).

Third, the measure of domestic inter-industry spillovers from R&D is calculated following Wolff and Nadiri (1993), where spillovers are assumed to occur through trade in the sense that spillovers from R&D in industry k in country j is proportional to the trade intensity of industry i in country j. Denoting this trade intensity M_{kij}/Q_{ij} where M_{kij} is the total amount of intermediate goods sold by industry k to industry i and Q_{ij} is total output in industry i, the domestic spillovers, $S^{P,G}$, can be written as:

$$S_{ijt}^{P,G} = \sum_{k \neq i} \left(\frac{M_{kij}}{Q_{ij}} \right) R_{kjt}^{P,G}.$$

Fourth, the error term, η, is divided to include a country-industry specific effect, μ_{ij}, a time effect, λ_t, and an idiosyncratic error, ε_{ijt}. The econometric specification to estimate then becomes:

[2] The results are not sensitive to other common human capital variables like the average years of schooling or the share of the population that has completed secondary education.

$$\Delta lnTFP_{ijt} = \beta_1 \Delta lnTFP_{iFt} + \beta_2 TGAP_{ijt-1} + \beta_3 \frac{R^P_{ijt-1}}{Y_{ijt-1}} + \beta_4 \left(\frac{R^P_{ijt-1}}{Y_{ijt-1}}\right)^2 + \beta_5 \frac{R^G_{ijt-1}}{Y_{ijt-1}} + \beta_6 \left(\frac{R^G_{ijt-1}}{Y_{ijt-1}}\right)^2 + \beta_7 \frac{S^P_{ijt-1}}{Y_{ijt-1}} + \beta_8 \frac{S^G_{ijt-1}}{Y_{ijt-1}} + \beta_9 H_{jt-1} + \beta_{10} \Delta U_{jt} + \mu_{ij} + \lambda_t + \varepsilon_{ijt}. \quad (4.8)$$

Equation (4.8) is hence equation (4.5) with the extensions outlined above. The estimates on β_4 and β_6 will show if investments in R&D are characterized by decreasing returns to scale, as often stated in the theoretical literature. A positive estimate on β_1 will show that there is technological transfer in the sense that when the frontier country is advancing, some of this new technology will spread to the other countries. And the estimate on β_2 will show if there is convergence in the sense that the countries that are further behind the frontier can enjoy more spillover effects of technology transfer from the frontier country.

4.3.3 Data

The study in this chapter uses data for 18 manufacturing industries from 13 OECD countries in the period 1987 to 2007. The countries are Austria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Norway, Spain, Sweden and the U.S. The countries are chosen based on data availability, and most industries are on the two digit level, but some are grouped together due to data limitations.

Data on value added, capital formation, labour, trade intensities and deflators comes from the OECD STAN data base (OECD 2010d, OECD 2010e), data on R&D expenditures and their source of funds comes from the OECD Science, Technology and R&D Statistics (OECD 2010a), data on education levels comes from the Barro and Lee (2010) dataset and data on unemployment rates is from the OECD Labour Force Statistics (OECD 2010b). Value added and R&D expenditures are deflated using country-industry specific value added deflators and capital is deflated using country-industry specific capital deflators (base year

2005).[3,4] All variables are converted to USD using economy-wide PPPs. The literature on productivity effects highlights the importance of industry-specific PPP exchange rates, but empirical findings using industry-specific PPPs compared to those using aggregate PPPs generally do not differ much (see e.g. Scarpetta and Tressel 2002, Griffith et al. 2004, Unel 2008).

4.3.3.1 Measurement of variables

Labour is measured as the number of employees in a given industry *i* times the average annual hours worked in country *j*. Capital stocks (*K*) are calculated using the perpetual inventory method as follows:

$$K_{ijt} = (1-\delta)K_{ijt-1} + I_{ijt},$$

where *I* are real investments in physical capital in time *t*, δ is the depreciation rate of capital and, following the literature, assumed to be 8 percent (see e.g. Machin and van Reenen 1998, Brandt 2007, Madsen 2008, Unel 2008). To calculate initial capital stocks a presample growth rate of 5 percent is assumed. It should be noted that the results are not sensitive to different assumptions about the depreciation rate or the presample growth rate. Neither labour nor capital is corrected for double counting of R&D expenditures in the sense that some of the employees and some of the physical capital are used in R&D. In this way, the estimated rate of returns to R&D will be excess returns.

R&D statistics are not always collected on an annual basis. For almost half of the countries the data is biennial, for two countries the data is sometimes annual and sometimes biennial and for one country the data is at first only available every fourth year, and then the data is biennial. Missing values in the R&D variables have been linearly interpolated when data exists both the year before and the year

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[3] Most deflators are on the two digit level but for some countries and some industries a more aggregated deflator is used due to data constraints.

[4] It is not clear which is the most appropriate deflator for R&D. However, the results presented in this chapter are not sensitive to a deflator that is an average of the industry-specific value added deflator and the more aggregated manufacturing value added deflator in the country.

after.[5] In total almost 20 percent of the observations on R&D expenditures has been interpolated. Another problem concerning the R&D variables is distinguishing between privately and publicly funded R&D projects. In reality, it is often the case that a specific R&D project is financed by both the private firm and the public sector, but that distinction is not possible to make with this data.

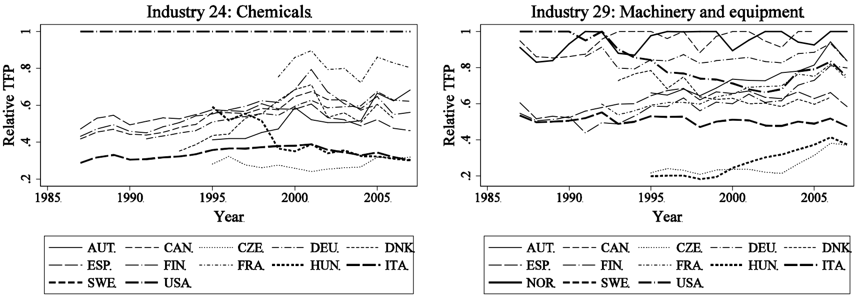
The trade intensity, M_{kij}/Q_{ij}, is derived from Input-Output tables and these are only available for three periods, the mid-1990s, the early 2000s and, the mid-2000s. Therefore, the first trade intensity is used for the period up to 1997, the second is used for the period from 1998 to 2002, and the third for the period from 2003 to 2007. The trade intensity variable is then multiplied with R&D expenditures in industry k at time t to give the variable for possible spillovers in industry i of country j, $S_{ijt}^{P,G}$.

4.3.3.2 Descriptive statistics

From the calculation of total factor productivity, it can be seen that the U.S. is the frontier country in 38 percent of the industry years. In some industries it is the same frontier country over the whole period, whereas the frontier country changes a lot in other industries. Figure 4.1 shows TFP relative to the frontier (TFP_{ijt}/TFP_{iFt}) for two industries, Chemicals and Machinery and equipment. In Chemicals, the U.S. is the frontier country over the whole period, whereas in Machinery and equipment, the frontier shifts between the U.S., Norway and Canada.

[5] Linear interpolation is not unproblematic. However, in this study the interpolation does not seem to affect the results in terms of the size of the estimates or the significance level.

Figure 4.1. Relative TFP (TFP_{ijt}/TFP_{iFt})



The final sample of industries includes 205 industries and a total of 2176 observations. Table 4.1 displays some descriptive statistics and shows that the overall means of the two R&D intensity variables differ quite a lot.

TABLE 4.1

Descriptive statistics

Variable	Obs.	Mean	Sd.	Min	Max
ΔlnTFP	2176	0.02	0.15	-2.19	1.79
ΔlnTFP_F	2176	0.01	0.10	-1.37	0.41
TGAP	2176	0.57	0.52	0.00	4.03
R^P/Y	2176	0.05	0.08	0.00	0.79
R^G/Y	2176	0.01	0.03	0.00	0.37
S^P/Y	2176	0.02	0.12	0.00	2.94
S^G/Y	2176	0.00	0.01	0.00	0.30
H	2176	0.09	0.04	0.03	0.26
ΔU	2176	0.00	0.01	-0.05	0.03

To show that R&D intensities also differ a lot between industries and between countries, Table 4.2 contains mean R&D intensities by industry for the sample as a whole and for two sample countries, France and the Czech Republic. France is one of the countries with higher R&D intensities and the Czech Republic is one of the lower R&D intensity countries. In general, industries with high privately funded R&D intensities also have a lot of publicly funded R&D, but there are exceptions. The chemicals industry, which includes pharmaceuticals, has a lot of privately funded R&D but not so much R&D funded by the public sector. The sector for 'other transport equipment', which includes the building and repairing of ships and boats, and aircraft and spacecraft manufacturing, has very high publicly funded R&D intensities because there are a lot of defence outlays in this sector.

TABLE 4.2

Mean R&D intensities (in percent) for all countries, France and the Czech Republic

	Total		France		Czech Rep.	
Industry (ISIC Rev 3)	R^P/Y	R^G/Y	R^P/Y	R^G/Y	R^P/Y	R^G/Y
15-16: Food, beverages and tobacco	0.94	0.04	1.11	0.05	0.11	0.01
17-19: Textiles, clothing and leather	0.97	0.06	0.96	0.05	0.49	0.04
20: Wood	0.41	0.05	0.32	0.04	0.02	0.00
21-22: Paper and publishing	0.64	0.03	0.35	0.01	0.06	0.02
23: Coke, refined petroleum products	2.82	0.05	4.51	0.17	0.34	0.00
24: Chemicals	10.07	0.25	17.44	0.77	3.80	0.21
25: Rubber and plastics products	2.27	0.10	6.03	0.04	1.55	0.02
26: Non-metallic mineral products	1.24	0.06	1.96	0.04	0.73	0.05
27: Basic metals	2.30	0.13	3.41	0.06	1.00	0.13
28: Metal products	1.02	0.10	0.79	0.03	0.51	0.08
29: Machinery and equipment	4.13	0.70	3.84	1.34	2.22	0.37
30: Office, accounting and computing machinery	14.69	1.43	22.77	1.89	0.44	0.00
31: Electrical machinery	4.56	0.23	8.61	0.23	1.33	0.09
32: Radio, television and communication eq.	24.57	2.08	33.41	5.68	4.06	0.61
33: Medical, precision and optical instruments	10.42	1.93	9.63	4.44	2.12	0.33
34: Motor vehicles, trailers	8.87	0.52	19.75	0.08	9.94	0.02
35: Other transport eq.	7.33	5.16	13.69	11.18	12.44	1.38
36-37: Other manufacturing; Recycling	1.03	0.04	2.37	0.05	0.58	0.03

4.3.4 Estimation strategy

There are several possible problems to consider in the estimation of equation (4.8). There are country-industry fixed effects which may be correlated with the explanatory variables. Hence, a fixed effects estimator is needed. However, equation (4.8) also includes an implicit lagged dependent variable in the *TGAP* term, and using a fixed effects estimator in this situation will bias the estimate on *TGAP* if the time dimension, *T*, is small (Nickell 1981). In this sample the average time span is only about ten years, which may induce quite a large bias. Moreover, there could be some problems of endogeneity. There may be common shocks, not captured by the other variables, to an industry across countries, and hence the $\Delta lnTFP_{iFt}$ variable would be endogenous. R&D expenditures are usually assumed to be weakly exogenous in the sense that current shocks can influence future levels of R&D, but not past levels, i.e. $E((R/Y)_{ijt-1},\varepsilon_{ijt}) = 0$. With a short time dimension, this variable will be biased in a within groups setting. However, for publicly funded R&D expenditures, the story might differ. Because the process of getting funding can be quite lengthy and the budget for this part of the R&D expenditures is not decided upon by the industry, it could be argued that this variable is strictly exogenous.

To deal with these issues, I will use the system Generalized Method of Moments (GMM) estimator, proposed by Arellano and Bover (1995) and further developed by Blundell and Bond (1998). The system GMM uses a system of equations where lagged levels of the explanatory variables are used as instruments for an equation in first differences, and lagged first differences are used as instruments for an equation in levels. In the estimations for this chapter, the variables for TFP growth in the frontier country, the technological gap and privately funded R&D are instrumented. In the first difference equation, the first lags of TFP growth in the frontier and of R&D intensities are used as instruments, whereas the first, second and third lags are used for the technological gap term. The first lag of the first differences of the variables is used for all endogenous variables in the levels equation. In all specifications, a collapsed instrument set is used to keep the instrument count down.[6] When using the system GMM, it is also possible to test the validity of the instruments and the assumed exogenous variables with the Hansen test of overidentifying restrictions. Here, a separate test is used for each instrument subset, and the results indicate that the used instruments are all valid and that publicly funded R&D can be treated as an exogenous variable. Due

[6] See Roodman (2009) for a discussion on the importance of limiting the instrument count.

to the use of lagged variables as instruments, the sample of observations is reduced to 1971 observations on 205 industries.

4.4 Results

Table 4.3 shows the estimation results for five different specifications, where the first four are simpler versions of equation (4.8) with different R&D variables excluded in each of them. The fifth specification includes all the variables in equation (4.8), and is the most preferred specification.

Starting with the main variables of interest, neither privately nor publicly funded R&D is significant in the first two specifications, but when the squared R&D terms are included, the variables become significant. Privately funded R&D expenditures show clear signs of positive but decreasing returns, whereas publicly funded R&D expenditures seem to be characterized by increasing returns to scale. However, the linear term is negative for publicly funded R&D, indicating that low levels reduce productivity growth.

The growth rate of TFP as a function of the R&D variables, following the fifth specification, is displayed in Figure 4.2. For privately funded R&D the effect on productivity increases up to an R&D intensity of 0.39, and then it declines and becomes negative at an R&D intensity of 0.78. About 99 percent of the industries have privately financed R&D intensities that are lower than 0.39, and could hence increase their productivity by increasing their R&D expenditures. For those levels of privately funded R&D, the rate of return ranges from 82 percent for those with no R&D to 0 percent for those with R&D intensities of 0.39. For the median industry, in terms of privately funded R&D, the results imply a rate of return of 78 percent.

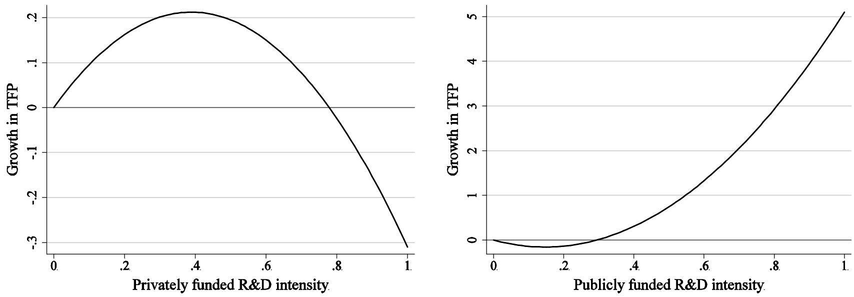
TABLE 4.3

Estimation results

Dependent variable: Growth rate in total factor productivity					
	(1)	(2)	(3)	(4)	(5)
$\Delta lnTFP_{iFt}$	0.10	0.09	0.10	0.12	0.12
	(0.074)	(0.084)	(0.074)	(0.073)	(0.084)
$TGAP_{ijt-1}$	0.14**	0.13*	0.13*	0.15**	0.15*
	(0.066)	(0.077)	(0.067)	(0.066)	(0.078)
$(R^P/Y)_{ijt-1}$	0.54	0.42		1.09***	0.82**
	(0.497)	(0.636)		(0.386)	(0.380)
$(R^P/Y)^2_{ijt-1}$				-1.40***	-1.13***
				(0.458)	(0.430)
$(R^G/Y)_{ijt-1}$	-0.36	-0.24		-2.12**	-1.50*
	(0.575)	(0.660)		(0.901)	(0.854)
$(R^G/Y)^2_{ijt-1}$				7.22**	5.18*
				(3.133)	(3.068)
$(S^P/Y)_{ijt-1}$		0.38	0.43*		0.31
		(0.250)	(0.226)		(0.213)
$(S^G/Y)_{ijt-1}$		-2.12	-1.67		-1.66
		(1.477)	(1.679)		(1.591)
H_{jt-1}	0.36	0.33	0.39*	0.36	0.36
	(0.251)	(0.266)	(0.222)	(0.221)	(0.250)
ΔU_{jt}	0.58**	0.51	0.53*	0.62*	0.56*
	(0.284)	(0.327)	(0.305)	(0.316)	(0.327)
Observations	1971	1971	1971	1971	1971
Number of industries	205	205	205	205	205
AR(1)	0.012	0.012	0.012	0.016	0.014
AR(2)	0.262	0.275	0.296	0.284	0.287
Hansen	0.630	0.681	0.656	0.657	0.840
Diff. Hansen	0.661	0.689	0.664	0.656	0.896
No. of instruments	31	33	30	34	36

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text.

Figure 4.2. Growth in TFP as a function of privately and publicly funded R&D



For publicly funded R&D the total effect on productivity growth is negative until the R&D intensity is above 0.29, something that is only true for about 0.1 percent of the industries in the sample. Hence, for most industries in the sample there is a negative effect on productivity from publicly funded R&D. These results are in line with the reasoning of earlier findings regarding a low or insignificant effect even though publicly funded R&D has a negative effect here. It could be that Hall et al. (2009) and Lichtenberg and Siegel (1991) are right in their interpretation that private firms are more efficient in choosing projects, but it could also be that publicly funded R&D is directed mainly towards product development, which induces a negative effect in the short run. Poole and Bernard (1992) argue that their finding of a negative rate of return (from publicly funded defence production) depends on the Canadian defence production being more closely linked to the way the market is politically managed than to the intrinsic characteristics of defence production. This reasoning is in line with that of Bönte (2004) or Georghiou (2004) in that there could be welfare goals for public R&D other than increasing firm productivity. The negative effect may also depend on the difficulties of measuring the benefits from publicly funded R&D, as pointed out by Lichtenberg and Siegel (1991).

For the spillover variables, only the estimate for spillovers from privately funded R&D is significant, and only when the other R&D variables are excluded. Yet, it is a positive estimate of around 0.3-0.4 in all specifications. The variable for spillovers from publicly funded R&D is insignificant in all specifications. Hence, it is not possible to explain the negative effect from publicly funded R&D with the arguments of Jaffe (1998) about a higher spillover effect. However, it may be argued that it takes much more than one period to get an effect on productivity growth from the spillover variables. For example, Bönte (2004) and Unel (2008) both use spillover variables lagged three periods. But allowing longer lags in the estimation does not change either the sign or the significance level of these variables. It may also be that the trade intensities from three points in time, taken from the input-output tables, are too static to be a good approximation of the true trade intensities.

TFP growth in the frontier country is not significant in any of the specifications. However, this variable suffers from a discontinuity problem because every time the frontier country changes, the growth rate is set to zero.[7] Nevertheless, the rest of the results are robust both to dropping this variable and to excluding the frontier country. The technological gap variable is positive and significant in all specifications with a value of 0.13-0.15 indicating that within each industry the countries that are further behind the frontier experience higher productivity growth. This convergence rate is perhaps somewhat higher than is found in most similar empirical studies, but not disturbingly high. In a study investigating Polish manufacturing industries, Kolasa (2008) finds a convergence rate of 0.10-0.20, whereas others (see e.g. Scarpetta and Tressel 2002, Griffith et al. 2004, Cameron et al. 2005, Economidou and Murshid Antu 2008) have found everything between 0.02 and 0.11. The estimate on the technological gap variable is also a test for the system GMM estimator, because the estimate of this implicit lagged dependent variable should lie between those of the OLS and fixed effects estimators, which it does.[8]

[7] This procedure is also used by Griffith et al. (2004).
[8] OLS gives estimates of TGAP of 0.07-0.08, and the fixed effects estimator gives estimates of TGAP of 0.20-0.22.

Both the human capital variable and the business cycle variable have the expected positive signs, but the human capital variable is only significant in one of the specifications, and only on the 10 percent level, whereas the business cycle variable is significant at least on the 10 percent level in all but one of the specifications.

4.4.1 Effects in different subgroups of the sample

To see if the results differ among subgroups of the sample, the sample is divided based on (i) the distance to the frontier and (ii) the intensity of privately funded R&D. The first division is based on the argument that there is greater potential for R&D to increase TFP growth the further behind the technological frontier an industry is situated (Griffith et al. 2004). The second division is based on the findings that the returns to R&D differ between sectors (see e.g. Bönte 2004, Hall et al. 2009). In the first case, an industry is classified in the group that is further away from (closer to) the frontier, 'large gap' ('small gap'), if the mean value of TGAP in this industry is above (below) the median over all industries. A similar procedure is used to divide the sample into high and low private R&D intensities. Table 4.4 shows the results from the estimations on these subgroups for the specification including all variables of interest.

The first two columns show the results from the subgroups based on the distance to the frontier. Concerning the R&D variables, the linear and squared terms of privately funded R&D are significant in both columns, but with a higher rate of return for those industries that are further from the frontier, a result that corroborates the findings of Griffith et al. (2004). The estimate on the linear term for publicly funded R&D is again negative but only significant for those industries that are closer to the frontier, and the quadratic term is insignificant. The major differences between the two columns concern the growth in the frontier and the technological gap variable. These two variables are only significant for those industries that are closer to the frontier suggesting that an industry needs to be relatively close to the frontier to enjoy spillovers from the frontier industry and to experience convergence. Moreover, the estimate on the technological gap variable for the industries closer to the frontier is much higher than those in Table 4.3 when all industries are included, indicating that within this group there is faster convergence towards the frontier. This finding means that even though there is larger potential for technology transfer for industries far behind the frontier, it seems that an industry needs to be quite close to the frontier to enjoy spillovers and convergence. This reasoning is in keeping with that of absorptive capacity, as described by Cohen and Levinthal (1989, 1990); i.e. that firms or industries need to have certain capabilities to enjoy spillovers. Griffith et al. (2004) test and confirm the role of R&D for technology transfer in a similar setting to this study. However, a direct test of this hypothesis lies outside the scope of this study. Another interesting finding in this division of the sample is that the education variable is only significant for the industries closer to the frontier.

The two last columns in Table 4.4 show the results from the subgroups based on the intensity of privately funded R&D. For the high R&D intensity group, the linear terms for both privately and publicly funded R&D are significant with the same signs as before, as well as the quadratic term for publicly funded R&D. The quadratic term for privately funded R&D is only significant in the low R&D intensity group, and it is the only one of the industry's own R&D variables that is significant. Spillovers from privately funded R&D now seem to have a positive effect in both subgroups, and spillovers from publicly funded R&D also have a positive effect in the low R&D intensity group. This latter result corroborates the findings of Bönte (2004). Industries that do not perform much R&D themselves gain more from other industries' R&D than those industries with much R&D of their own. Another interesting result in this division of the sample is that the technological gap term is not significant for any of these subgroups. Hence, it does not appear that the R&D intensity affects the possibilities for technology transfer, which is in contrast to the findings of Griffith et al. (2004). However, as pointed out before, their hypothesis is not directly tested in this study.

TABLE 4.4

Large vs. small technological gaps and high vs. low R&D intensities

Dependent variable: Growth rate in total factor productivity				
	(1)	(2)	(3)	(4)
	Large gap	Small gap	High R&D	Low R&D
$\Delta lnTFP_{iFt}$	0.02	0.28***	0.01	-0.07
	(0.118)	(0.085)	(0.073)	(0.398)
$TGAP_{ijt-1}$	0.13	0.22***	0.05	0.01
	(0.113)	(0.067)	(0.074)	(0.104)
$(R^P/Y)_{ijt-1}$	1.25***	0.44*	1.19**	0.61
	(0.464)	(0.245)	(0.581)	(0.566)
$(R^P/Y)^2_{ijt-1}$	-1.43**	-1.78***	0.22	-2.63***
	(0.611)	(0.442)	(1.677)	(0.906)
$(R^G/Y)_{ijt-1}$	-3.04	-0.69*	-2.44*	6.71
	(2.535)	(0.382)	(1.273)	(7.338)
$(R^G/Y)^2_{ijt-1}$	10.73	2.32	8.55*	128.39
	(20.436)	(1.401)	(4.682)	(555.686)
$(S^P/Y)_{ijt-1}$	0.34	0.53	0.31**	2.77*
	(0.220)	(0.357)	(0.148)	(1.556)
$(S^G/Y)_{ijt-1}$	-1.80	6.63	-1.11	55.83**
	(1.971)	(5.431)	(1.063)	(26.024)
H_{jt-1}	-0.25	0.14**	0.02	-0.17
	(0.323)	(0.069)	(0.217)	(0.427)
ΔU_{jt}	0.74	0.69**	0.34	0.32
	(0.817)	(0.323)	(0.384)	(0.341)
Observations	988	983	978	993
Number of industries	105	100	107	98
AR(1)	0.043	0.009	0.012	0.111
AR(2)	0.269	0.810	0.315	0.464
Hansen	0.764	0.770	0.927	0.445
Diff. Hansen	0.724	0.535	0.762	0.397
No. of instruments	36	36	36	36

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text.

4.4.2 Robustness of results

To check the validity of the results several procedures have been undertaken. First, to see if certain industries or countries drive the results I separately drop one industry and one country at a time. Second, a few outliers in the dependent variable have been excluded. Third, to increase the within variation in the data, the industries with only a few observations are dropped, and fourth, I use average productivity growth as the dependent variable. These procedures are further discussed in the following paragraphs, and the results are summarized in Table 4.5. The general conclusion is that the significance of the technological gap term and that of the quadratic terms of R&D intensities are not very robust, whereas the rest of the results are quite robust.

Dropping one industry at a time from the sample shows that the significance of the variables for publicly funded R&D is not quite as robust as for privately funded R&D, but the size of the estimates is very similar throughout. Dropping one country at a time instead, gives similar conclusions to dropping one industry at a time. Significance for publicly funded R&D disappears in some estimations, but is always close to the 10 percent level. Significance for the technological gap variable also disappears in some cases. This variable is originally only significant on the 5 or 10 percent level and this exercise, together with the results shown in Table 4.4, suggests that this variable is somewhat sensitive to the chosen sample.

Concerning outliers, there are a few possible outliers in the dependent variable. Excluding these observations again makes the technological gap variable insignificant, as can be seen in columns (1)-(3) in Table 4.5. The variable for spillovers from privately funded R&D is now significant with a similar estimate to those presented earlier. The rest of the variables are in general unaffected by this procedure, except that both privately and publicly funded R&D are significant in the first specification.

TABLE 4.5

Results from robustness checks

Dependent variable: Growth rate in total factor productivity									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Outliers removed			At least eight observations			Averages		
$\Delta lnTFP_{iFt}$	0.10	0.03	0.04	0.13*	0.10	0.12*	0.19**	0.15*	0.18*
	(0.066)	(0.081)	(0.069)	(0.065)	(0.072)	(0.064)	(0.082)	(0.080)	(0.095)
$TGAP_{ijt-1}$	0.09	-0.01	-0.00	0.12*	0.10	0.10	0.03	0.00	0.02
	(0.068)	(0.114)	(0.075)	(0.074)	(0.080)	(0.074)	(0.027)	(0.031)	(0.027)
$(R^P/Y)_{ijt-1}$	1.20***	0.59	1.10***	0.86*	0.92**	0.97**	0.55***	0.52***	0.37
	(0.370)	(0.633)	(0.418)	(0.492)	(0.427)	(0.485)	(0.143)	(0.157)	(0.274)
$(R^P/Y)^2_{ijt-1}$			-1.05**			-0.22			-0.11
			(0.488)			(1.484)			(0.641)
$(R^G/Y)_{ijt-1}$	-0.94*	-0.33	-1.93**	-0.88	-0.98	-3.99**	-2.10**	-2.25**	-4.01*
	(0.495)	(0.593)	(0.977)	(1.117)	(1.021)	(1.600)	(0.894)	(0.946)	(2.198)
$(R^G/Y)^2_{ijt-1}$			6.39*			18.89**			35.10
			(3.438)			(7.466)			(25.134)
$(S^P/Y)_{ijt-1}$		0.56	0.51**		0.20	0.24		0.19	0.37***
		(0.438)	(0.225)		(0.506)	(0.466)		(0.130)	(0.133)
$(S^G/Y)_{ijt-1}$		-1.33	-0.95		-0.84	-1.01		-0.52	-2.53**
		(1.654)	(1.294)		(3.877)	(3.580)		(1.241)	(1.077)
H_{jt-1}	0.07	-0.12	-0.13	0.43	0.34	0.35	-0.01	-0.13	-0.08
	(0.249)	(0.302)	(0.228)	(0.311)	(0.333)	(0.320)	(0.120)	(0.141)	(0.090)
ΔU_{jt}	0.49*	0.05	0.07	0.44	0.37	0.40			
	(0.275)	(0.511)	(0.307)	(0.353)	(0.353)	(0.361)			
Observations	1960	1960	1960	1563	1563	1563	238	238	238
No. of industr.	205	205	205	129	129	129	79	79	79
AR(1)	0.000	0.000	0.005	0.026	0.029	0.031	0.097	0.087	0.083
AR(2)	0.263	0.294	0.295	0.307	0.315	0.328	0.493	0.470	0.291
Hansen	0.503	0.295	0.490	0.613	0.624	0.704	0.536	0.445	0.254
Diff. Hansen	0.796	0.319	0.560	0.964	0.977	0.980	0.894	0.736	0.430
No. of instr.	33	33	36	31	33	36	36	38	45

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text except for column (1), which also uses the second lag of privately funded R&D in the first difference equation, and for columns (7)-(9) where the instrument set is not collapsed due to the short time span.

In the analysis the average time span of data on an industry is about ten years, but the shortest time span is only three years, which makes it difficult to capture the within variation over time. Gradually excluding the industries with the shortest time spans does not affect the results much. The quadratic R&D terms lose their significance after a while, but the estimates are similar and the linear terms are significant with the same signs as previously displayed; privately funded R&D is now also significant in the first two specifications. Again, the estimate on the technological gap variable becomes insignificant after a while. Moreover, the estimate for TFP growth in the frontier turns up significant in some of the estimations. Columns (4)-(6) in Table 4.5 show the estimates when there are at least eight observations for each industry.

Instead of using R&D variables lagged more than one period, another way to approach the question of the time it takes for R&D to affect productivity is to use R&D against average productivity growth over several years. Therefore, the dependent variable and contemporaneous TFP growth in the frontier are averaged over one 5-year period and four 4-year periods, and for the other variables the values for the first year in the period are used. This procedure heavily reduces the sample to only 79 industries and 238 observations. Columns (7)-(9) in Table 4.5 display the results from this estimation. The R&D variables have the same signs as before, and again both privately and publicly funded R&D are significant in the first two specifications. In column (9), however, only the linear term for publicly funded R&D is significant. But both estimates for the spillover variables are now significant with a positive sign for privately funded R&D and a negative sign for publicly funded R&D. The technological gap term is again insignificant whereas the estimate on TFP growth in the frontier is significant on the 10 percent level with a value of 0.15-0.19. The results concerning both the spillover variables and TFP growth in the frontier indicate that it takes some time for both R&D and technology from the frontier to spill over to the other industries.

In sum, the first results, presented in Table 4.3, are in general robust in several aspects. However, both the technological gap term and the squared R&D terms are sensitive to the chosen sample. In addition, this analysis has given some support for the existence of positive spillovers from privately funded R&D.

4.5 Conclusions

This chapter has examined the productivity effects from privately and publicly funded R&D in a panel of manufacturing industries in 13 OECD countries, at the same time as controlling for endogeneity of the variables. The importance of privately funded R&D for industry performance is confirmed. For most of the industries in this sample, privately funded R&D is found to have a private rate of return between 0 and 82 percent whereas publicly funded R&D has a negative private rate of return, but the significance of this variable is somewhat sensitive to which countries or industries are included. The results concerning publicly funded R&D are also in line with previous research, which in general has found a low, insignificant or negative effect.

Looking at the spillover effects of R&D from these two sources of funds, there is some evidence that there is a positive, and quite large, effect from privately funded R&D whereas the estimate on the spillover variable from publicly funded R&D is almost always insignificant, or even negative. Thus, it does not seem that the public funder of R&D manages to find the projects with the highest private rates of returns, disproving the David et al. (2000) contention that it might do in order to ensure the success of the public funding program. Neither does it seem to find the projects with the largest spillover gap, in contrast to the claim by Jaffe (1998). However, it may still be that Jaffe is right, but that we do not see the positive spillover effects on this time horizon.

As previously discussed, it may be that the government primarily has goals other than increasing productivity when funding business R&D. This reasoning would explain a lower or an insignificant effect, but not a negative one. The negative effect of publicly funded R&D may hence be a result of private firms being less efficient in spending the public funds or mainly using them for product development.

As mentioned in the introduction, the OECD countries have diminished their share of publicly funded R&D by quite a lot during the time period of this study. A reason for this reduction might be the lack of results of positive effects and the fear of substituting private R&D expenditures.

This study only deals with publicly funded R&D that is performed in the business sector. The effects of publicly funded R&D that is also performed in the public sector is another question where other results might emerge.

Acknowledgments

The author is grateful for helpful comments and suggestions from Pontus Hansson, Klas Fregert, Martin Andersson, Johan Blomquist and seminar participants at the Department of Economics in Lund.

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