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The R&D of Norwegian Firms: an Empirical Analysis

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Abstract: This work aims at investigating the determinants and the effects of R&D investments in a panel data of Norwegian medium and large firms from year 1995 to 2005. There is evidence of cash constraints in the R&D expenditures, but they were less strong for beginning R&D. There is an almost proportional relationship between R&D and sales, suggesting that the externality reduction and the economies of scale for big firms are likely as strong as the alleged diminishing returns to scale and the burocratic inefficiencies of large organizations. Firms of low-intensive sectors rely much more on sales and liquidity than the high-intensive sectors. Being foreign does not have a significant impact on R&D if the firm invests, but it has a negative impact on the probability of investing, suggesting the existence of sunk costs in beginning R&D.

It can be shown that R&D Granger-causes physical investment, while the opposite does not hold. This confirms the story of Lach-Schankerman and Lach-Rob, who see R&D as a random innovation process that creates innovations randomly. These, in order to be profitable, must be embodied in physical capital.

R&D has some effects in increasing sales volume, while it does not show significant effects on profitability. In the high-intensive sectors, anyway, these relations seem stronger.
This analysis can convey policy implications, especially for the sunk costs argument and the foreign ownership.

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Outline

Introduction: Research questions

The purpose of this work is to investigate the relationship between R&D and its determinants and its impact on firm's success. I will use a detailed dataset of economy-wide firms active in Norway since 1995 to 2005. The focus on the determinants will stress the most discussed arguments in the literature, like the relationship between size, profits, liquidity and R&D, or between firm's sector and R&D. There will also be an analysis of the R&D pattern in time as well as an analysis of the foreign ownership on R&D.

The relationship between size and R&D was found to be different from work to work. In particular, the two leading alternatives are the proportional (Cohen-Klepper, 1996, Klepper, 1996, Klette-Griliches 2000, Klette-Kortum (2001)) and the diminishing relationship (Jaruzelski, 2005), where size is measured with sales revenues. Profits and liquidity could also impact R&D expenditures, especially if its expected returns are uncertain (past good results can adjust them upwards) or if there are liquidity constraints, which are more likely to occur for small firms. R&D can have different roles in the different sectors and it may have had a particular trend in time. Foreign ownership also can impact the total invested amount, provided that firms invest, as well as the probability of investing. Fors and Svensson (2000) find that Swedish multinational firms prefer to invest just in Sweden, while Prasad (2004) finds that multinational firms are increasing their R&D expenditures in foreign countries. Foreign ownership can have an effect on R&D if there are sunk costs in beginning R&D (Santos, 2008) or for the cheaper Norwegian high-skilled labor. These findings may have interesting policy implications.

I will discuss whether it will be possible to build up one single model both for the investing firms as well as for the not investing ones. The natural candidates are the Tobit model (Tobit, 1958) or the Heckman two-step procedure (Heckman, 1979). The alternative is to analyze R&D investments through a two-part model (Manning, Duan and Rogers, 1987). I will analyze the advantages and the drawbacks of both.

After having analyzed the determinants of R&D investments but before analyzing its effects on the success indicators of a firm, like profitability, increase in sales etc, I will analyze the relations between the tangible and the untangible investments, i.e. physical capital and R&D. Some literature point out the causality from R&D to physical investments (Lach-Schankerman, 1989, Lach-Rob, 1996), the other way round (Tovainen-Stoneman, 1998) or a two-way relationship (Chiao, 2001). I will try to answer also to this question for the case of Norway. The causality from R&D to investments has its roots in Lach and Schankerman's theory of R&D as a random innovation process. This process randomly generates potentially profitable innovations that, in order to be actually profitable, must be embodied in physical capital. This implies that the variance of physical investments is higher than the variance of the R&D. R&D, indeed, is performed just on the expected value of its returns, while capital investments are triggered by a useful innovation. On the other hand, even if technological opportunities can stimulate physical investments, R&D may not be the best indicator for it, due to spillovers. Indeed, Tovainen and Stoneman (1998) found the opposite relationship. I will try to shed some light on this issue too.

Finally, I investigate the effects of R&D on firm's success. A common place is that R&D will give competitive advantage and improve firm's performance, but a large empirical literature (Von Braun, 1996, Kandybin-Kihn, 2004, Jaruzelski, 2005) seems to contradict it. Some relationship was found just for the increase in sales volume (Jaruzelski, 2005), but not for profits nor other indicators. Unfortunately the dataset I analyze does not have any measure for innovation (patents). So I will have to analyze the relationship between R&D and sales growth or profits, without an intermediate measure for innovation. I will analyze whether there is a different relationship in Norway and to which extent the existing literature finds support or contradictions.

1 Innovation and R&D

Innovation and technological changes were always thought to be the motors of economic growth. Innovation can be defined as “the ability to define and develop new products and services and deliver them to the market” (Bordia et al., 2005) and a “highly cross-functional activity” (ibidem). This definition conveys the meaning of R&D from the point of view of the firm, but it does not take into account its basic importance in growth. For the firms this is just one of the many management's instruments to improve firm's performances, but from a global point of view this is the most basic tool to allow long-term economic progress. Sena (2004), on the contrary, defines innovation as “the engine that drives the growth machine of modern capitalist economies”. Linking these two definitions, that consider the two opposite features of innovation, we can understand both the incentives to develop it (in Bordia) and its consequences on the whole economy (in Sena).

Innovation entered all the modern dynamic macroeconomic models, since the influencial considerations of Schumpeter (1950), passing through the initial formalizations of Solow's model (1956), and finally arriving to the endogenous growth theory and the knowledge economy models (Romer, 1990, Grossmann-Helpman, 1991, Aghion-Howitt, 1992, Jones, 1995). Schumpeter's view of innovation is dynamic too, even if not mathematically formalised, as he focused on the “creative destruction”, the process that leads to innovation and the evolution of industries (Malerba, 2005). In spite of that, Schumpeterian view was afterwards intended in a static way, giving more importance to market structure and firm size (ibidem). Much of the analysis, indeed, carried out in order to test the “Schumpeterian predictions” had not much in common with the spirit of his work. The good thing is that now we have a huge literature about the relationships between R&D, innovation and firm size.

One of the most popular statements related to him is that the most important innovations have been performed by very large firms, many times monopolists. This is quite at odds with classical microeconomic theory. While competitive firms have the largest incentives to innovate, monopolists have larger funds and so can finance more easily their own efforts.

Especially if credit markets are imperfect, these two issues has an opposite impact, so many papers were devoted to disentangle these two effects and to see which one was stronger.
The other path of innovation literature deals with endogenous growth models. One main assumption is that technology is a public good, or at least non-rival and partially excludable (Romer, 1990, Jones, 1995, Arnold, 2005), but the conclusions of these theories were in some sense similar to Solow's most important prediction: savings and physical investment are not able to explain sustained economic growth. The only variable that can do that is technology.
This is the reason why innovation and R&D have allured such a wide interest from economists, politics and public opinion. In the so-called Lisbon agenda there was even a commitment to develop policies and provide basis for an economy in which knowledge would be the driving force of economic growth (Segarra, 2007). One of the main reasons to develop a public policy for R&D is the main economic argument of the externalities. R&D is mainly information and so it has the characteristics of a public good (Arrow, 1962, Sena, 2004), so there are spillovers (Aghion-Howitt, 1992, Sena, 2004) that can affect R&D spending. In industrial organization theory, as they are positive, they will lead to a suboptimal outcome.

But R&D is not just information. as Cohen and Levinthal point out (1989), R&D is information but also it "enhances firm's ability to assimilate and exploit existing information". From a theoretical point of view is not clear *a priori* whether R&D expenditures are larger or smaller than the optimum. Even admitting that they are smaller, designing a good policy is not straightforward at all. Villard (1958) suggests the government to give subsidies for R&D, but thirty years later Acs and Audretsch (1988) found, consistently with Griliches (1986), that government-financed R&D is much less productive than private R&D. They found that, in USA, the correlation between private R&D and innovation (the sum between product and process innovation) was 0.746, but it was just 0.481 between total R&D and it. Government-financed R&D, then, conveys the risk of being an unproductive expense and they may also change the relative expenditure between basic and applied R&D. A subsidy to R&D has, as all subsidies, a substitution and an income effect. If the income effect is strong enough, all firms may be willing to play more defensively. They may want to focus more on small and certain innovations rather than uncertain but potentially large ones (Rosen, 1991). This may lead to a pattern with less revolutionary innovations.

Furthermore, and maybe more troublesome, the characteristics of R&D makes it difficult to design a competition policy for the innovative markets. Markets in which technological change is important are never perfectly competitive (Stiglitz et al., 1987). Technology, indeed, is basically knowedge, so it suffers from imperfect information (Stoneman-Diederen, 1994). This is the reason why R&D and its implications are very difficult to treat with the basic neoclassical tools, in particular when it comes to design R&D policy. Competition effects, as well as social gain, are not clearcut at all. These intriguing characteristic of R&D and innovation reflect the many ways they have been treated.

Firstly, the empirical literature focused on input-oriented innovation indicators in analysing the impact of innovation on firm's productivity (Segarra, 2007). In this setting, the production function approach predominated. R&D was proposed to be entered in the knowledge production function and was treated like a normal input (Griliches, 1979). The aim was also at calculating the output elasticity of R&D (Mansfield, 1965, Griliches, 1973). Secondly, the number of patents was used as a measure of innovative output, or in absolute value (Scherer, 1965, Griliches, 1990, Klette, 2001) or divided by R&D investments (Cohen-Klepper, 1992). Finally, other studies attempted to embody the quality of innovations rather than their quantity, using the number of citations collected by a patent (Jaffe-Trajtenberg, 2005). Yet, despite all these efforts, no measure of innovation receives the favors of all the economic world.

As well as for R&D policy design, also R&D output rises many questions.
Many other economists, indeed, do not belong to the preceding categories. Rogers (2006), for example, uses the ratio added value/R&D in assessing R&D productivity, while many others (Jaruzelski et al., 2005, Von Braun, 1997, Kandybin-Kihn, 2004) simply treat R&D as an input in the production. They analyse its relationship with the most common success indicators of a firm, like profits, increase in sales and increase in profits. Klette and Kortum (2001), as a final *caveat*, suggest not to believe in the possible positive relationships between R&D and productivity (in their paper it is the number of patents), as it is just weakly correlated with the more important correlation between R&D and innovations.

We can easily see that this jungle of definitions and suggests (in how to assess R&D productivity) is well far from being cut down. But this is just the “magic” of the creative process.

R&D is a risky process that does not guarantee results. Firms, nevertheless, have good reasons to try. An innovation can permit to enter a new market, to lower production costs, to expand its own market share, even to follow some anticompetitive strategies, like creating barriers to entry (Mueller-Tilton, 1969, Robinson-Chiang, 1996) or making the firm enjoy some monopoly power. This can be achieved both through a large product innovation or through practices on the border on legality, like patenting each minimal change with respect to its own product. Xerox did like that in the 60's and 70's (Cabral, 2002). In this way, the potential entrants would have to spend more R&D than the necessary in order to acquire information about the technology and to invent around existing patents (Mueller-Tilton, 1969).

1.1. Determinants of R&D

Large part of the literature is devoted to analyse which kind of firms should be the most interested in R&D. Starting from Schumpeter, many analyses were carried out both from a theoretical and a practical point of view. “Second Schumpeter”’s favour for large firms is well known and many others followed his theory (or, better, the static version of his theory). Hamberg (1964) underlines that R&D should come from the biggest firms, as they have more financial strength and so they can support many projects simultaneously. This can let them spread the risk and appropriate more easily the uncertain outcomes of R&D, as they have more products. Having a higher output volume, they can also spread the cost on a higher sales basis and reap more private advantages (Cohen-Klepper, 1996). Furthermore, a strong market position (a concentrated oligopoly) can make the firm enjoy the possible cost reduction on a larger sales volume, making it more convenient for a large firm to invest in R&D (ibid.). Klepper (1996) also focuses on the appropriability of returns from innovation. His reasoning is that the bigger the firm, the more it can appropriate its own R&D efforts. So we should expect not only a positive relationship between R&D and size, but, if this were the only effect, an increasing relationship between the ratio R&D/sales and size too. In particular, we would see an increase in process R&D. This finding is also confirmed in the paper of Cohen and Klepper quoted above. Here they construct a model that, under reasonable hypotheses, yields that process innovations have proportional returns with size, while product innovations have less than proportional returns. The reason is that a process innovation, like a unity cost reduction, is very difficult to sell to another firm. A process innovation is intrinsically embodied in the heart of the firm and it will have a value as high as the unity saving multiplied by the quantity sold. A product innovation, on the other hand, can create a new market or induce a competition similar to Chamberlin's monopolistic competition (1933) and it is also much easier to sell. In all of these circumstances this is relatively more attractive for a small firm than for a large one.

These findings are consistent with other papers: Mansfield(1981) reports that large firms have a higher ratio basic/risky R&D than small firms and that, in large firms, the increase in basic R&D is more than proportional with size, while risky R&D grows less than proportionally. Rosen (1991), in a theoretical article (like Cohen and Klepper's one), shows that large firms have more incentives to invest in safer R&D than small competitors. This can be linked to "replacement effect" theory (Tirole, 1988, Reinganum, 1985), for which an incumbent would invest less than its potential competitors as, in case of a drastic innovation, it would simply replace itself. A good compromise is that incumbents invest relatively less in product innovation, i.e. the type of R&D that can cause drastic innovations, than process innovation with respect to small firms. This is what happens in reality. Also incumbents, that normally are much bigger than potential competitors, have more incentives in investing in basic R&D: this is where most of the spillovers occur (Scherer, 1965). So, the bigger the market share, the bigger the efforts in basic R&D.

From a social point of view, a monopolist will not necessarily hurt welfare in a technological intensive market. The monopolist will produce less quantity, which makes R&D less than in a perfectly competitive market, but there are not spillovers, so it will invest much faster. This can lead even to more innovations and a faster growth in economy (Jovanovic-Lach, 1989). Imagining then that total R&D is a good proxy for innovation, and assuming that innovation is a desirable thing, many other researchers tried to understand which market structure was more adapt to enhance R&D and which public policies could improve these outcomes. Dasgupta and Stiglitz (1980) in a theoretical paper affirm that, at low levels of concentration, an increase of it would benefit total R&D expenditures. At high levels, on the contrary, an increase would dampen it. The shape of R&D with respect to concentration will be then like an inverse "U". So the best market structure for R&D is the "competitive oligopoly" (ibid., Worley, 1961, Adams, 1979, Villard, 1959). Adams supports this conclusion in his empirical paper, stating that R&D intensity (i.e. the ratio R&D/sales) in medium firms is higher than both in small and large ones. The reasons can be listed as: 1) Spillovers, 2) Small firms prefer to have informal R&D, 3) Big firms have more inefficiencies.

1.2. Policy issues

These three issues pose important challenges for the government. How should an optimal policy be designed? Some authors analysed the impact of the typical subsidies, some others the possible relaxations of antitrust policies to allow for R&D cooperative agreements. Spencer and Brander (1983) assess the importance of subsidies to R&D also for considerations of industrial strategy. They found an important correlation between foreign sales and R&D expenditures. If we set up a game where the players are the government, whose objective is maximizing domestic welfare, and the foreign firms, the government will have the incentive to subsidize R&D, as this will have a similiar effect to subsidize exports. This is interesting especially if subsidizing exports is prohibited by international agreements. A study of OECD (1985), quoted in Le (1987), confirms that an increase in R&D, with respect to the total value added, has a significant effect in the share of high-technology products in export. Tomiura (2004) found support for these findings also in a dataset of Japanese firms. He founds that internal R&D is strongly correlated with exports in the science-based sector. Brod and Shivakumar (1997) showed, anyway, that R&D subsidies create problems of moral hazard. They suggest then to rely more on cooperation agreements: in this way government avoids spillovers as well as cost duplication (firms can create synergies and even spread the risk). This comes at a price, which is the risk of collusion, but if spillovers are sufficiently big, benefits outweight this drawback. Otherwise, if spillovers are negligible, R&D cooperation can reduce total R&D, as firms will try to soften the product market competition intensity (ibid.). Also Katsoulacos and Ulph (1998) underline this problem, in particular for R&D Joint Ventures. Barlevy (2006), finally, claims the existence of a dynamic externality which make the firms short-sighted, making R&D expenditures more procyclical than the optimal. The opportunity cost of growth is lower during recessions, so policies aimed at encouraging R&D should be more active during the troughs of the economy.

In order to design an optimal policy, nevertheless, it is necessary to have an idea of the quantitative effect of the issues mentioned above. How much does a small firm prefer to carry out informal R&D? How much big firms are affected by inefficiences?
These will be two of the questions addressed in this work.

1.3. Foreign ownership

Another question of interest, which received very little attention in the literature, is the possible effect of foreign ownership on R&D. From existing literature we know the trends and the reasons why a firm invests in a foreign country. Trend in foreign R&D expenditures showed a positive and large pattern in US: R&D spending by U.S. affiliates of foreign companies more than doubled from $6.5 billion in 1987 to $17.2 billion in 1996. It grew at an average annual rate of 11.6% per year since 1987. In fact, R&D expenditures by foreign companies in the United States have grown much faster than total R&D expenditures by U.S.-owned firms within the United States. (Serapio-Dalton, 1999).

The reasons why a firm invests in R&D in a foreign country can be, following Narula and Zanfei (2003), to respond to different demand and market conditions across locations. So the firms need to adapt their existing product and process technologies through foreign-located R&D. However, supply factors and the need to gain access to local competencies have become an increasingly important motivation to engage in asset-augmenting R&D abroad. This is due, *inter alia*, to the "growing tendency for multi-technology products, and to the fact that patterns of technological specialisation are distinct across countries, despite the economic and technological convergence associated with economic globalisation" (ibid.).
As a result, there is a growing mismatch between what home locations can provide and what firms require. In general, innovation systems and technological specialisation of countries change only very gradually, and – especially in newer, rapidly evolving sectors - much more slowly than the technological needs of firms. So, firms must seek either to import and acquire the technology they need from abroad, or venture abroad and seek to internalise aspects of other

countries' innovation systems. Thus, in addition to proximity to markets and production units, firms also venture abroad to seek new sources of knowledge, which are associated with the innovation system of the host region. Kuemmerle (2005) had similar ideas. In his opinion, firms create foreign R&D centres "to acquire new knowledge and augment the firm's home base, or in order to apply existing knowledge to local markets and manufacturing facilities and thus to exploit the firm's knowledge base". But this was just the results of a questionnaire survey and an interview with senior executives in the company, and performed just in the pharmaceutical and electronic sector. Arvanitis and Hollenstein (2006), analyzing Swiss firms' foreign R&D, found that the reasons why a firm invests in foreign R&D are almost the ones that determine the total amount invested. They do not report, nevertheless, whether foreign firms invest, *ceteris paribus*, as much as a national firm. Le (1987), in a survey of Canadian high-technology firms, reports that foreign firms invest much less than national ones on average, while Rogers (2006) affirms that foreign firms do not have a premium in R&D rate of return. One reason why foreign firms could be willing to invest in R&D in Norway is that highly skilled labour is relatively cheap, compared to other countries, due to the compression of the wages.

I will analyze on my dataset the impact of the foreign dummy on the expected R&D investment, both on the decision whether investing and on the invested amount. In doing so, we can also find clues to answer to Sutton (1991) and Santos' (2008) argument of very high sunk costs for beginning R&D. Sutton, in his book "Sunk Costs and Market Structure", addresses the problem of sunk costs in various industries, among them in R&D-intensive ones. Santos analyzes a sample of Portuguese firms in the moulds industry and, by assuming optimizing behaviour, he concludes that fixed R&D costs are nearly 1.7 times the average yearly firm sales. If foreign *investing* firms invested the same quantity as a national firm, but the ratio of foreign investing firms on the total of foreign firms were lower than the ratio of national investing firms on the national ones (i.e. if E[R&D| foreign, R&D>0]=E[R&D| national, R&D>0 but P(R&D>0| foreign]<P(R&D>0| national]), then we would have a strong argument to support the sunk costs argument. On the contrary, if the probability that a foreign firm invests is the same as the probability that a national one does, the strength of the sunk costs argumentation would be reduced. Indeed, foreign multinational probably already invest in their own country. They may not want to duplicate the start-up costs.

1.4 Effects of R&D

The discussion about the determinants of R&D will be coupled with the analysis of its effects. Parisi et al. (2005), in a survey on Italian manufacturing firms tracked from 1995 to 1998, find that R&D is closely related with the probability of introducing a product innovation, while fixed capital spending is related to introducing a process innovation. These results seem quite logical, but a more important point was found in other researchs. The productivity of larger firms, i.e. innovations per R&D dollar, is lower than small firms (Cohen-Klepper, 1992). But the reason, for the authors, is not an inefficiency of big firms, but the fact that, as they can appropriate more their own efforts, they invest more, and so R&D marginal productivity decreases. This can be the reason why small firms *seem* more productive. In the view of the authors, their R&D productivity is higher just because they stop before. We can imagine it with a Cobb-Douglas production function: both labor and capital have a marginal productivity negatively related with, respectively, labor and capital. The same could be for R&D.

On the other side, nevertheless, also other views hold. Yeaple (1992) reports that, in twentyfive interviews with R&D managers in both large and small companies, they agreed that a large company typically spends from three to ten times as much as a small one to develop a particolar product. Theorically Cohen and Klepper's theory and Yeaple's findings could hold together, but it seems difficult that the *increase* in private gains due to size are so high as to compensate this productivity loss. Cohen (1995) states that innovation is more productive in large firms as a result of complementarities between R&D and other functional activities, such as marketing and manufacturing. Link (1981), in a dataset of US manufacturing firms, found a positive relationship between returns on R&D and firm size.

Other authors have an opposite view. Scherer and Ross (1990) think that R&D productivity is undermined in large firms because of loss of marginal control, or through excessive bureaucracy. Griliches (1980) found no significant evidence of increasing returns in R&D to firm size, just with the exception of chemical and petroleum industries. Graves and Langowiz (1993), together with Acs and Audretsch (1988), found evidence for decreasing returns to scale in R&D. Cohen and Klepper (1996, b) had the same results, while they found that R&D expenditures were proportional to sales, like Klette and Griliches (2000). The research of many decades ago gave similar result too. Scherer, in 1965, found that the five hundred largest corporations, in year 1955, exhibited a decreasing relationship between patents and size too.

In all these studies the measure for innovation was the number of patents, or patents to R&D ratios (with the exception of Griliches). So, even using the same measure for innovation, there are still two opposite views. Furthermore, patents are just an intermediate stage in the process of transforming research inputs into benefits (Pakes-Griliches, 1984), not the final outcome. This is a very important point: in practice, many patents can be registered for just one innovation (the Xerox case), or, on the contrary, a product or process improvement may be not patented. Further to these serious problems, "the use of patent counts as a measure of innovation output does not provide direct evidence to show the innovative impact on a firm's competitive advantage" (Tsai-Wang, 2005). Scherer (1965), in his research, goes further: interpreting the profitability of any patent as a random variable with some probability distribution, he found that it is highly skewed toward the low private value, with a very long tail into the high value side. It can be well approximated by a Pareto distribution with a coefficient k of less than 0.5. Its expected value is $E[X]=kx_{(1)}/(k-1)$, where $x_{(1)}$ is the smallest observation in the sample, and exists just for $k>1$. So neither the mean nor the variance exist. In addition to the problem that there is not a 1:1 relationship between innovations and patents (we can call it "input-throughput problem"), analysing productivity or profitability through the number of patents shows another problem too (we can name it as "throughput-output problem"). A way to deal with that could be to cut, in some point, the profits distribution of patents, eliminating the cause of the infinite mean. But this would be like limiting the number of coin tosses in a St.Petersburg game, taking away the most valuable tail of the distribution. These can be the inventions that open up new markets and technologies. Also Sanders (1962) contests the measurement of inventive activity through the number of patents.

So some other ways were used in assessing R&D utility. Griliches (1980) and Tsai and Wang (2005) use the R&D output elasticity in the following way: $f_{it}=a_{it}+\gamma r_{it}+\varepsilon_{it}$, where f is the growth rates of TFP and r is the R&D capital. γ, in Tsai-Wang's paper, allows for a quadratic function of size S, measured in value added, $\gamma=\beta_0+\beta_1 S+\beta_2 S^2$. They find a better productivity for small and large firms with respect to medium size ones (the β_2 was positive and significant).

This capital-based approach “ignores many of the distorsions associated with research that are formalized by the new growth theory, including monopoly pricing, intertemporal knowledge spillovers, congestion externalities and creative destruction” (Jones-Williams, 1997).
For all these problems, then, some authors focused on some more concrete variables, like sales, profits and their relationship with R&D spending. There is plenty of literature in this empirical field too. Von Braun (1997), analyzing a dataset with the largest world's electronic companies, found almost no correlation between increased R&D spending and improvement in profitability. Kandybin and Kihn (2004), in a dataset with the thousand firms that, all around the world, spent most on R&D in 2004 (the Booz Allen Hamilton Global Innovator 1000), discovered no correlation between R&D investments and market shares, increase in sales or in profits. On the contrary, they found that the best performing firms, in terms of ratio of profits from new products divided by R&D, were the firms that invested less on R&D. The authors then analyzed the returns on incremental innovation investments, finding also here diminishing returns. They called the marginal returns on R&D the “innovation effectiveness curve”, that is decreasing with R&D and surprisingly stable within a company. This suggests that, even if projects within a portfolio change, R&D productivity is like a “fixed effect” of the firm, borrowing the expression from econometrics. This finding is confirmed also in Wakelin (2001) , who assesses the importance of the innovation history of the firm and the sector in influencing the rate of return to R&D. Jaruzelski (2005), analyzing the same dataset, found no relationship too between R&D spending and the primary measures of economic or corporate success, like growth, profits or shareholder return. He found a negative relationship between size and R&D spending (while other authors, many of them quoted above, found a proportional relationship) and, in contrast with Kandybin and Kihn, that the low-investing firms had worse results than the others. He pointed out also that R&D spendings are very concentrated in the biggest firms: the top 2000 investing firms spent, in 2004, $410 billion, just $26 billion (6.8%) more than the top 1000 considered in his dataset. Klette and Kortum (2001), finally, state that the ratio R&D/sales (R&D intensity) is independent from size, in contrast with Jaruzelski, and that its distribution is highly skewed, with many firms reporting zero R&D even in high-tech sectors. These issues will be investigated in this work too.

1.5 Relationship R&D-physical investments

In analyzing the success indicators of the firms, R&D as explanatory variable will be coupled with physical investments, because of the deep links between them. They are like the two mirror images of the same concept: renouncing to profits today for the expectation of higher profits tomorrow. R&D is the intangible part of this, while physical investment is its tangible part. There is a literature about the complementarity of R&D with physical investment, which can be summed up in Bernstein and Nadiri (1984) and Chiao (2001). Bernstein and Nadiri found that R&D tends to be complementary with physical investment, while substitute for labour. Chiao, who also analyzed the relationship R&D-investment with a dynamic simultaneous approach, found the same relationship of complementarity.

While assessing the impact of R&D on the success of a firm, I will follow this approach, considering in our analysis both R&D and investments. Taking as granted that R&D and investment are complements, still literature tried to investigate whether there is a causality between them and, if there is, its nature. There is a large literature about this topic, which includes two main issues of interest: first, wheter R&D Granger-causes physical investment or the other way round and, second, the relationship between the variance of R&D and the variance of investments. Granger causality (Granger, 1969) is a concept used in time-series analysis, for which a time series X is said to Granger-cause Y if it can be shown, or through a series of F-tests on lagged values of X (and with lagged values of Y also known) or through a simple t-test, that those X values provide statistically significant information about future values of Y. The first author that addressed the relationship R&D-investment was Schumpeter (1939), who generated a theory of business cycles based partly on a causal link between exogenous successful inventions and subsequent capital investment. Schmookler (1966) developed the same basic idea in a framework where inventive activity stimulates physical investment, with the difference that here the innovative activity is endogenous. Later, Lach and Schankerman (1989) and Lach and Rob (1996) tested these hypotheses in an empirical analysis of science-based industries. They found that there is a one-way relationship between R&D and investment, where the first Granger-causes the second. The explanation they provide is in the model of industry evolution they built up, where "the dynamics are driven by a process of endogenous innovation followed by subsequent embodiments in physical capital" (Lach-Rob, 1996). They imagine R&D as a random innovation process that, if successful, needs some physical capital investment to make it profitable. Because investments are caused by random innovations, the variance of investments is expected to be higher than the variance of R&D. R&D is performed depending on future expectations, which make it less volatile and more independent with respect to past realizations. One of the main consequences is that R&D can cause physical investment. Lach and Rob(1996), in the same article, and Klette (2001) found that Var(Inv)>Var(R&D). This is what I are interested to test in our work.

On the other hand, these results in the literature are not clear. Tovainen and Stoneman (1998), in a research on 185 UK firms from 1984 to 1992, found that the variance of the log levels of R&D is twice as large as that of investment and, totally at odds with the previous literature, that physical investment Granger-causes R&D. They hypothesize that it is reasonable to expect that technological opportunities will stimulate investment, but that firm's own R&D is not a good indicator of such opportunities. Because of spillovers, technological opportunities may arise also from the R&D of other firms in the same industry, other industries, universities etc. Furthermore, "new offerings from the capital goods industries, learning, design and other such activities may all generate new technological opportunities that are not adequately proxied by the firms own R&D" (ibid.). These findings, in the view of the authors, indicate that some of the stylized facts as stated by Lach and Schankerman are not as stylized as might have originally been thought and that more empirical work in the area of the dynamic relationship between R&D and investment is still required.

Chiao (2001), after three years, sheds some other intriguing shadows on these issues. He starts, too, by analyzing the hypotheses of Lach-Schankerman and Lach-Rob. He found that, first, increasing the number of time periods and/or the number of firms with respect to their studies, their results do not hold anymore, and second that, employing a dynamic simultaneous approach, previous R&D affects current physical investment but previous investment affects current R&D too. In the literature, then, we can find all the types of relationships: R&D causes investments (Lach-Schankerman, 1989, Lach-Rob, 1996), investment causes R&D (Tovainen-Stoneman, 1998) and a two-way positive relationship (Chiao, 2001). In this work I will address this issue, in order to shed more light on it and to decribe the behaviour of Norwegian medium and big firms.

To sum up, my research questions can be summarized as:

- What are the main determinants of R&D investments in Norway? I will use both the regressors most widely used in the literature (sales, profits and liquidity) as well as qualitative variables (sectorial dummies, time dummies, foreign dummy).
- How is size related to R&D investments? The answer will let us know whether the appropriability argument is stronger, weaker or compensates the diminishing returns one.
- How does being foreign affect R&D expenditures in Norway?
- How R&D investments are related to the success indicators of a firm?

2. The Dataset

The dataset I have analysed derives from various preceding administrative datasets, received from Statistics Norway with the permission from the Data Inspectorate in Norway and kept in BI – Norwegian School of Management and Frischsenter. They include financial and accounting firm-level information, such as profits, sales, work force, industrial classification and survey data on R&D expenditures. They include also the NACE code, the Norwegian code to identify the firm sector. This code embodies the same information as the American SIC (Standard Industrial Classification). The initial datasets were the "Regnskap" (= "accounting", in Norwegian) datasets, one for each year from 1995 to 2005. They include all the data of the balance sheet and economic statement, so profits, sales revenues, labor costs, work force and so on. The Regnskap datasets were merged together, in order to have a complete dataset for all the years from 1995 to 2005, and then merged with "Tidsseriebasefrisch" (="Time series"). This is a dataset generated by Frischsenter on the basis of the information from Statistics Norway. It included more information about the firms, like the industrial classification and the R&D expenditures. Both Regnskap and Tidsseriebasefrisch are based on accounting data. I have merged these datasets and kept only the firms that were present in both of them. Fortunately the number of matched firms is very high, so the information loss was not a concern here. Just one firm had a different value for sales revenues in Regnskap and Tidsserie for some reporting error, so that observation was excluded.

Then I merged the resulting dataset with the various "Eierskap" (= "Ownership") datasets, one for each year since 2000 to 2005, which have information about the ownership of the firms active in Norway in this period. We can know from them wheter a firm is actually owned by Norwegians, by foreigners or whether there is a participation of both in its ownership. The useful point of unifying Eierskap datasets with our dataset is that we can analyse how foreign ownership affects R&D investment in Norway; the drawback is that we lose the data from years 1995 to 1999.

Fortunately, this is actually not a serious concern, as since 1995 to 2001 the data on R&D were sampled just once every two years: that means that in Regnskap-Tidsseriebasefrisch we have R&D data just for 1995, 1997, 1999, 2001,2002,2003,2004 and 2005. The data before 2001

would be missing if we use any lagged value of R&D, so it would be lost anyway in the analysis of the relation between R&D and physical investments and in assessing the impact of R&D.
So every time that foreign ownership will be analysed, or everytime that a lagged value for R&D is included in a regression, we will have a sample of firms just from year 2000 to 2005.
This will make us lose some observations, but there are some cases where introducing a lagged variable will be necessary. So analysing foreign ownership at the cost of losing the observations of years 1995, 1997 and 1999 is probably a good trade-off.
Both the Regnskap-Tidsserie and the Eierskap datasets include firms of every size. As there are the biggest firms, there are also firm with just 1 employee. The problem is in the sampling procedure, as for R&D just firms with more than 100 employees were asked, by Statistics Norway (the Norwegian institute of statistics), for their R&D expenditures. Firms from 50 to 100 were asked just in some years (without a clear rule), while firms with less than 50 were asked very few times, but especially if they reported a positive amount in the preceding year. That means that firms with less than 100 employees are a source of a potential selection bias – especially the smallest ones. Including them in the regression would lead to think that many small firms perform R&D, while this is due to the sampling procedure. Furthermore, it is well known that small firms normally perform much more informal R&D than big firms (Cohen, 1987, Schmookler, 1959) . It is common that they do not have a specific R&D department, laboratory or specialised personnel. Nevertheless, they research too. An error in reporting R&D, also, because of their small size, can be relatively worse than a reporting error for a big firm, as the relative amount of R&D/sales will change much more. For these problems I decided to analyse just firms with more than 100 employees.

Also for them, anyway, we do not have complete information. Statistics Norway asked them to provide data on their R&D expenditures and the information is said to be mandatory, but no sanction is imposed if they do not answer. The "true" mandatory obbligations are the balance sheet and the income statement and R&D is not a part of them. Many firms then simply do not answer. The ones that answer are included in the "R&D statistikken" (= "R&D statistics") and are actually the firms we can analyse. The initial number of observations, after merging the accounting data with the dataset about R&D expenditures, is 9685, due to 1937 firms.
Because of different intersectorial sampling procedures, also some sectors were taken away.

The firms of the construction, the wholesale trade and the land transport sectors were asked for their R&D only if they had more than 250 employees. This could create another type of selection bias, because we would see only very big firms in these sectors, while for every other sector we have firms with more than just 100 employees. In order to avoid this, I decided to take them away. They were 596 observations.

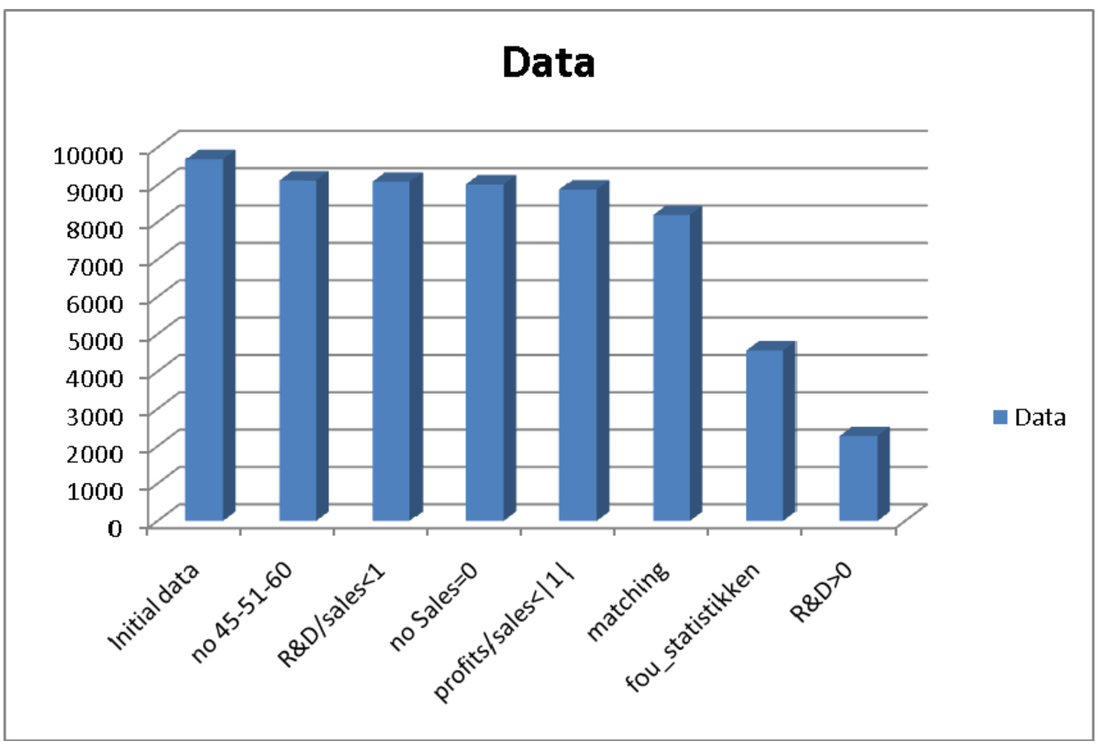
The resulting dataset has afterwards been "cleaned". Hall and Mairese (1995) clean their data by removing outliers in both growth rates and levels (any level outside median +/- 3*interquartile range and growth of value added <-90% and >300%). They also remove any firms with less than three years of observations in the data. Also Los and Verspagen (2000) omit any firm with an "excessive" sales growth (+80%). I partly followed these approaches, but with a "rule of reason" depending on my dataset. I did not take away the firms with few years of observations, as many firms are present only few times. Removing them would greatly reduce the available information. Nevertheless I followed an approach similar to Hall-Mairese and Los-Verspagen.
I took away the firms that had, even in just one year, a ratio R&D/sales greater than 1, as it is not a sustainable strategy in the long run. The reasons for having such a high ratio cannot be that these firms are in the start-up period, as in the dataset there are just firms with more than 100 employees, and looking at their start date, we see that no firm (among the ones with R&D/sales>1) is new-born. The reasons can be simply measurement error (misreporting in the official accounting or errors in creating the initial dataset) or the firm may have large revenues in foreign countries (declared in the foreign accounting, but not to the Norwegian one), while performing R&D in Norway. In any case, these observations would create problems to our analysis, so I took them away. They were 32 observations.

Then I disregarded the firms that had no sales in the current year. These firms may be just a dependance of another firm with a particolar goal, for example a research center: in this case, considering them as a firm 'tout court' would seriously bias our results. They could also be firms that have just exited from the market but, for accounting reasons, are still present in our dataset (for example for the dismissal of the assets, etc). In both cases they would give problems to our work, so they have been taken away. They were 75 observations.

I also did not consider firms that had, in any year, a ratio profits/sales less than -1 or greater than 1. The reasons for having a ratio outside the interval [-1, +1] can be an imminent bankruptcy (<-1), or a dismissal of assets before exiting the market (>1). In both cases, these are exceptional moments that cannot be considered as normality. As these firms could bias any inference, I took them away too. They were 139 observations.

The non-matching data between the accounting and the R&D data were already taken away in the datasets merging phase, but some firm were present more than once a year. The reason can be that it recognised some errors in the data reporting, so it sent another declaration in order to correct them. In this case I kept just the last observation. Furthermore, some observations did not have the match in the 'eierskap' (ownership) dataset. This cleaning took away 678 observations.

Finally, but most importantly, we can actually analyze the R&D investment only of the firms that answered to the survey which, for that, were registered in the 'fou_statistikken' (R&D statistics) database. This ruled out 3626 observations (the 44% of the total).
The dataset that we can actually analyse, then, includes 4567 observations (1464 firms) out of the precedent 9679 (1934 firms). The observations with positive R&D are 2271, due to 797 firms.



I created other variables to make the analysis more complete.
First, I created a sectorial dummy for each NACE sector, using the first two digits (in order to avoid both creating too specific and too general sectors), following an approach already used by Rogers (2006). The omitted dummy is the primary sector (agriculture, fishing and mining).
Also I created time dummies, one for each year except 2005. So the coefficients of the sectorial dummies can be seen as deviations from the primary sector, while the coefficients of the time dummies as deviations from year 2005. The idea of time dummies is widespread as in microeconometrics as also in scientific papers dealing with R&D. Two authors that use this approach are Segarra-Blasco (2007) and again Rogers (2006). Wooldridge (2002) confirms that using time dummies is a good idea when dealing with datasets with a large number of individuals and few years.

Using time and sectorial dummies implicitly assumes that the coefficients of the regressions will not change across sectors and years. While this can be a reasonable assumption for the years (excluding exceptional events, there is no reason why the determinants of R&D expenditures should change from one year to another), the issue is not so straightforward for the sectors. In one sector past profits can have a certain impact on R&D expenditures and a different one in another one. Pooling firms of different sectors together, we assume that this does not happen. Actually a formal F-test of this hypothesis (that manufacturing and non-manufacturing firms could be pooled) was performed in Rogers (2006) and was rejected. Nevertheless, two reasons make me decide to pool the firms anyway. First, running separate regressions for each sector would make burdensome the analysis of the results, would make the reader sink in many uninteresting details and would reduce the precision of the estimates. I am interested in the economy-wide effect of the variables, even if there are econometric drawbacks (Marcellino, 2006, and Wooldridge, 2002). This is the price we have to pay to obtain semplicity. But this is a good deal, as our interest does not lie in the effect of the independent variables in each single sector. Second, the dummy approach will let us notice the difference from one sector to another at first sight. If we are interested in discovering which sectors normally devote most of their revenues to R&D, the answer will be clear in one regression. This would not be possible by running two or more separate regressions, one for each sector, as all the coefficients would change.
After creating time and sectorial dummies, I created many types of lagged variables and many growth variables. All of them will turn out to be useful in the following analysis.

All the price values in the dataset have been normalised to the price level in 1998. All the financial variables are then in real values, so we avoid to give more importance to the firms present in the dataset just in the last years.

This dataset, as almost every dataset, has some limitations. It is not a balanced dataset, as many firms are observed just few times, while others are present since 1995 until 2005. Anyway, having removed the structural sources of potential bias (like the three differently sampled sectors and the small firms), the missing observations do not make the dataset affected by selection bias. The only loss is in the total available information. On the contrary, the elimination of small firms could be considered in itself a limitation. But the problems arising from including them would likely be greater than the problems from excluding them, not only because of informal R&D and the linked problems in measuring its true value, but because the small firms in the original datasets are affected by selection bias. The probability of being sampled in one year depended on having reported positive R&D in the previous year. These two facts would be a much greater problem than simple missing information.

Another limitation is that financial data here are taken by accounting data. Accounting data can be different from economic data, they follow different rules and each national taxation system can give different incentives in misreporting the true economic values. Nevertheless, this is a hardly tackleable problem (Rogers, 2006). As we have only firms that operate in Norway, having just one taxation system will not make this problem worse. Having firms operating, say, both in Norway and Sweden would make the problem more serious. R&D data, anyway, are audited, so they are highly reliable.

Unfortunately, on the contrary, data on R&D are pooled altogether, without separating between basic and applied R&D. This would have been a very interesting topic, as much literature discusses the different incentives that large and small firms have in developing these two kinds of R&D (Scherer, 1965, Rosen, 1991, Jovanovic-Lach, 1999).
Finally, as we just have accounting data, we do not know the number of released patents. Normally, in the literature, patents are seen as a measure of productivity (Scherer, Klette), even if some authors follow other ways (Rogers: value added/R&D; Cohen-Klette: Innovation/R&D). We can think to patents as a “throughput” between the R&D-input and the sales (or profits, or

sales growth, etc)-output. As we do not have this, our analysis will have to "jump" from the input to the output directly. This will hide the underlying dynamics of R&D process, but it is an approach widely used also in the most recent literature (Kandybin, 2004, Von Braun, 1996, Mansfield, 1981, Jaruzelski, 2005).

So, even if the dataset has some limitations, after the above mentioned corrections it does not have any known selection bias and it is very rich. Many datasets in other researches have much less observations and are much less broad in sectors, variables and time, so it is nevertheless a quite good dataset to work on.

2.1 Econometric models

In this work I will analyse the data using various microeconometric techniques, in order to deal with panel data. This is the reason why I will not use simple OLS regressions.
I will use the following techniques.

GLS: Generalized Least Squares is a generalisation of OLS that allows us to deal with panel data, by relaxing some of the assumptions of OLS. In particular, it relaxes the assumptions of homoscedasticity and uncorrelation between error terms. The advantage of GLS compared to OLS is that we can allow for a positive correlation between error terms within the same firm over time. The reason is that if a firm has a dependent variable (say R&D investment) which is in 2000 higher than its expected value, conditional on the explanatory variables (like sales, past profits, sectorial dummies etc), we expect that in 2001 the dependent variable will be higher too. Probably we have unobserved heterogeneity that is not explained by the independent variables: it can be due to the ability of the managers, the know-how and so on. The practical change in the estimators is in the variance-covariance matrix. While in OLS it was diagonal and with all the elements equal to each other, here we allow for a positive intra-firm correlation (keeping the correlation between errors of different firms equal to 0) and for heteroscedasticity. These features will let us deal with panel datasets that include both very large and small firms (heteroscedasticity) and to the within-firm residual correlation, the time-series dimension (Fox, 2002). Both features will show up to be important. The estimators are $\hat{\beta}_{GLS}=(X'\Sigma^{-1}X)^{-1}(X'\Sigma^{-1}y)$ and their variance is $Var(\hat{\beta}_{GLS})=(X'\Sigma^{-1}X)^{-1}$. Following the approach of Holt and Scott (1981), we can define $Cov(u)=\sigma^2 B$, where u is the error term and B is a block diagonal matrix with submatrices B_j of order m_j*m_j for each cluster (firm). J is the number of the clusters (firms). Each B_j has, as elements, 1 in the diagonal and ρ in the other positions, where ρ is the correlation of the residuals within the same firm over time. $\hat{\beta}_{GLS}$ is consistent and unbiased, like OLS, but is more efficient. More importantly, the inference and hypothesis testing is now valid, while with OLS it is not. Unfortunately we do not know "a priori" Σ, but we can estimate it. This leads to the so-called "Feasible Generalised Least Squares" (FGLS), that gives biased estimators (in finite samples). The reason is that to build the estimator Σ^ we must use the observations on Y and X, so Σ^ and the error terms are correlated by definition. Anyway FGLS gives consistent estimators.

Because there is not indipendence between within-firm residuals, OLS estimators' standard errors will be downward biased, so the inference for t or F tests will be invalid (Kish, Frankel, 1974). The true probability intervals are wider. We would find the estimators more significant than what they really are and hypothesis testing would be misleading. Considering the size of the dataset and that FGLS keeps into account the intra-firm correlation of the residuals, I find FGLS better than simple OLS.

Probit: this model aims at describing situations where the dependent variable is binary, i.e. $y=\{0,1\}$. It avoids the problems that arise with a simple OLS estimation. When y^* is binary, OLS could estimate a value for y greater than 1 or less than 0, which is not coeherent, as the $E[y|x]=P(y=1|x)*1+P(y=0|x)*0$, that is $E[y|x]=P(y=1|x)$. As the expected value of y is a probability, it must be constrained between 0 and 1, but the predicted value can be outside this interval. Furthermore OLS implies constant partial effects. A second problem is heteroscedasticity. Let us assume that $y=x\beta+\varepsilon$; as $y=\{0,1\}$, $\varepsilon=1-x\beta$ with probability $P=x\beta$, and $\varepsilon=-x\beta$ with probability $1-P=1-x\beta$.

$E[\varepsilon^2]=(1-x\beta)^2P+(-x\beta)^2(1-P)=(1-x\beta)x\beta=P(1-P)=E[y](1-E[y])$.

That means that Linear Probability Models has also a problem of heteroscedasticity. We could use a GLS estimator in order to keep into account it, but still the predicted probability could be outside the interval [0,1]. So it is better to use another specification, the Probit.

Probit specification assumes that there is an underlying continuous unobserved variable, $y^*=x\beta+u$, and that $y=1$ if $y^*>0$ or $y=0$ if $y^*<0$.

So $P(y=1)=P(u>-xB)=1-P(u<-xB)=1-G(-xB)=G(xB)$. Probit assumes that G is the Normal Cumulative Distribution. Logit, a close relative of Probit, assumes the logistic distribution of the error term. I will perform Probit model when dealing with the probability of investing in R&D.

Tobit (type I): this model (Tobin, 1958) deals with censored observations. It allows to have consistent estimates when a censoring limit would make OLS inconsistent. It is a mixture of probit and truncated regression (Tobin,1958; Smith and Brame, 2003) for partly continuous variables but with positive probability mass at one or more points (Wooldridge, 2002).

We assume an underlying model $y^*=x\beta+u$. The observed variable is y. $y=y^*$ if $y^*>0$, $y=0$ otherwise. As it is a maximum likelihood estimation, it requires the normality of the error terms and homoscedasticity (Smith and Brame, 2003; Reynolds and Shonkwiler, 1991).

So $E[y|y>0]=x\beta+E[u|u>-x\beta]=x\beta+\sigma[\varphi(x\beta/\sigma)/\Phi(x\beta/\sigma)]$ and $E[y]=\Phi(x\beta/\sigma)x\beta+\sigma\varphi(x\beta/\sigma)$.
It also needs that the partial effects of each variable on the probability of observing $y>0$ is the same as the impact on the amount of y (Wooldridge, 2002; Lin and Schmidt, 1984; Heckman, 1979; Smith and Brame, 2003). The need for normality and homoscedasticity is stricter than in OLS-GLS, as in Tobit model not only the efficiency but also the consistency is affected. Also the need for constant relative partial effect is something undesirable. These are limitations on which I will come back later.

Heckman two-stage estimation: Heckman's estimation (Heckman, 1979) is a two-steps procedure: The first step is the selection equation: $z^*=\gamma w+u$, with $u\sim N(0,1)$ and z^* unobserved, where $z=1$ if $z^*>0$ and $z=0$ if $z^*<0$. So it is a probit regression. If $z=1$, then we observe the value of y. In this case we have the second step: $y=\beta x+e$, with $e\sim N(0,\sigma^2)$. From the first step we can estimate the vector of inverse Mills ratio (estimated expected errors), then we perform OLS on the second step by regressing y on the explanatory variables and the vector of inverse Mills ratio (i.e. performing a truncated regression). This will remove the part of the error term correlated with the explanatory variables and will avoid the sample selection bias. The set of the explanatory variables of the second equation should be a subset of the explanatory variables of the selection equation. They could also be the same, but this would bring problems of multicollinearity (Wooldridge, 2002), as the inverse Mills ratio could be well estimated with a linear function of the vector of independent variables. This procedure will let us estimate the coefficients of the truncated regression E[y]. OLS and GLS, on the other hand, will let us see $E[y|y>0]$, regressing just the positive y on the explanatory variables. If we think that in the "true" model y can have both positive and negative values, Heckman procedure is the right one. If we are just interested in the effect on y *given that it is positive*, we can simply run OLS-GLS on the positive values. I will come to that later.

Fixed and Random effects: these two methods are designed especifically for panel data.
Both have a structure like $y_{it}=x_{it}B+a_i+u_{it}$, where a_i is specifical for each firm. In FE method a_i's are like dummy variables and are fixed parameters. In RE the estimation is done via generalized least squares (GLS) and a_i's are treated like random variables. They are assumed to have a normal distribution and to be uncorrelated with the explanatory variables in order to have consistent estimates. Even if there is heteroscedasticity, its estimates are consistent (Wooldridge, 2002).

In FE we use each firm as a control for itself and it is equivalent to performing OLS on the deviations from the mean for each firm (Allison, 2005). FE allows to see the effects only of the variables that change over time. This is a high cost: all the impact of the sectorial and nationality dummies is canceled out (unless there is a change in nationality or sector in time). Furthermore, FE makes the problem of measurement errors worse, as it consists in OLS on the deviations from the mean. This implies that we include the measurement error two times in the regression, which this will make the attenuation bias larger (Rogers, 2006, Mairese-Siu, 1982). Measurement errors are an important problem in self-reported accounting data. For these two reasons I will not use it widely while studying the determinants of R&D. I will rather use RE and FGLS, which considers both the information within firm as well as between firms, permitting to estimate also the variables that do not change over time (like the "foreign" and the sectorial dummies). I will use FE while studying the effects of R&D on the success indicators and the relationship R&D-physical investment. In this case FE are more suited than RE for they take away all the fixed characteristics that affect the success of a firm, leaving just the variables that we include.
FE use only the "within" information. So they discard the between-person variation, yielding considerably higher standard errors than those produced by methods that use both kinds of information. This has, anyway, a good consequence: the between-person variation is likely to be contaminated by unmeasured personal characteristics that are correlated with the explanatory variables. By focusing on just the within-person variation we increase the sampling variability, but we likely get less biased estimates.

Breusch-Pagan test: this is a test for heteroscedasticity. It is necessary to test the null hypothesis of homoscedasticity because heteroscedasticity, in some models (like Tobit), will not affect just the efficiency but also the consistency of the estimators. It is a "constructive" test, in the sense that it specifies the form of the alternative hypothesis of heteroscedasticity as a multiplicative function of the residuals with the explanatory variables (Breusch and Pagan, 1979). Zaman (1995) showed that it is valid just for linear functions of residuals with the explanatory variables. It consists, in the version of White (Marcellino, 2006), in running an auxiliary regression of u_i^2 on the same variables as in the original regression and then obtaining an F statistic (or t-statistic, if there is just one independent variable). Another way is to obtain the LM statistic, $LM=nR^2$, which for large n under the null hypothesis is distributed as $\chi^2(n)$. If the χ^2 value (or the F-test) exceeds the critical value at the chosen level of significance, we reject the null hypothesis of homoscedasticity.

Shapiro-Wilk test: this is a test for normality. This test is defined as $W=(\sum^{n}_{i=1}w_iX'_i)^2/\sum^{n}_{i=1}(Xi-X_{mean})^2$, where $w'=MV^{-1}(M'V^{-1})(V^{-1}M)^{-1/2}$. M denotes the expected values of standard normal order statistics for a sample of size n and V is the corresponding covariance matrix. Null hypothesis of normality is rejected for low values of W.

3 Determinants of R&D

The analysis of the determinants of R&D expenditures will be lead through with a focus both on total R&D and on the ratio R&D/sales. Half of the present literature, basically, follows the first approach, half the second (Jaruzelski, 2005, Scherer 1965, Klepper, 1996). There are advantages in both. The first gives us a straightforward idea of "who is investing how much", while the second, recognizing that R&D is deeply connected with the size, offers some econometric advantages, like a reduction of heteroscedasticity and a more normal distribution of the residuals. This would let us run, in principle, consistent Probit or Tobit models and avoid the dimension bias. It also enables comparisons about the relative importance of innovation in different sectors without worrying about the average size of their firms (Jaruzelski et al., 2005).

In this chapter we have many types of regressions, in order to analyse the probability of investing in R&D, the total amount and the ratio R&D/sales invested. We also have some descriptive statistics to look more closely at the real data. The variables that I will included in these regressions will be explained singularly.

Profits: more past profits could make the firm less risk-averse with respect to a "random innovation process" like R&D (Lach, 1996, Klette, 2001), making them more willing to invest more. In this case its coefficient would be positive. On the other hand, if a firm does not change its risk-aversion after a successful innovation, or if it believes that it is investing optimally, its coefficient should be around zero. We expect these results both for the probability of investing as for the absolute and relative amount invested.

Liquidity: a higher present liquidity could make it easier to face new investments in the future, if capital markets are imperfect. This makes it likely that a firm with a high liquidity will invest a higher amount in R&D. At the same time it may increase the probability that a firm invests.
In these cases we expect the coefficient to be positive. In the R&D regression we will include the total liquidity amount.

Sales: there is a huge literature about the relationship of this variable with R&D. A large part of the literature uses the workforce to assess firm size, while another large part uses sales. I will use sales for many advantages that it has with respect to employment. Following Scherer (1965), sales are responsive to short run shocks and they are the principal scale variable considered in company R&D budget decisions. In the R&D regression we simply expect a positive and significant relationship, but the interesting part will be in the R&D/sales regression. A coefficient around zero would imply an almost linear relationship between R&D and sales, while a negative coefficient would imply that R&D grows less than proportionally with sales. Understanding this relationship can have important implications in assessing, indirectly, the productivity of R&D. We can think to the "effectiveness curve" of Kandybin-Kihn (2004), for example.
Sales value is also expected to have a positive effect on the probability of investing: descriptive statistics, in the literature as well as in our dataset, shows an increasing percentage in the ratio investing firms/total firms as size grows up.

All these variables will be used in their lagged version, which permits to avoid the simultaneity problem (Rogers, 2006). Using their current value would not permit to distinguish between the effect that R&D has on them and the opposite way round. Using lagged values, in order to avoid this problem, is an approach also used by Lach and Rob (1996), while assessing the causality between R&D and investments. A significant relationship does not necessarily mean causality, but at least we can remove this first concern. In addition, profits and liquidity show another problem, if entered in the regression with their current values. An increase in current R&D would, by definition, lower both liquidity and profits, because it absorbs money without giving immediate results. The estimates of profits and liquidity coefficients would then be biased.

Foreign: this dummy is 1 if the firm is foreign, 0 if it is Norwegian. If foreign firms are structured as the Norwegian ones, we would expect this dummy to have a not significant effect both on the probability of investing and on the invested amount. But if foreign firms are, at least in part, just "selling dependances" of the mother firm, or if there are significant sunk costs in beginning R&D, we expect a negative coefficient both on the total amount as on the probability of investing. Empirically some multinational firms centralize R&D in their home country, while others invest in R&D even abroad (Narula-Zanfei, 2003). The analysis of this coefficient can suggest which type of these firms is the majority in Norway.

Sectorial dummies: these dummies show the effect of each industrial sector on the expected invested amount in R&D, R&D/sales and the probability of investing. We can be pretty sure that not all the sectors have similar optimal R&D expenditures. These dummies will show which sectors are more research-intensive. An analysis with dummy variables implies that we force the coefficients of the other explanatory variables to remain constant across different sectors. This can be a simplistic assumption, but the easiness and the linearity of interpreting just one regression instead of fourtynine (as the number of sectors are) make the advantages of this approach overwhelm its drawbacks. Furthermore many sectors have too few observations (firms*time) to allow for a meaningful analysis. A good compromise is to compare the results of the regression with all the sectors together with other two regressions, one for the high-investing sector and one for the rest. The high-investing sector will be defined later, after knowing the sectorial coefficients. These dummies represent the sectorial effect with respect to the primary sector, defined as agricolture, fishing and mining. In the R&D regressions the coefficient of these dummies will not be very meaningful, as it will depend on the average size of the firms in that sector. In this regression, the only interesting thing is to see which sectors have a significant impact. The coefficients will become meaningful in the R&D/sales regression, as in this case they will be the average difference in this ratio compared to the primary sector.

Time dummies: these dummies capture the eventual changes in time of the dependent variable. They assume, in the same way as the sectorial dummies, that the coefficients of the other variables remain the same across different years. In this case this is not a problem, as all the monetary values, like profits, sales and R&D, have been deflated with the Norwegian CPI, taken from Statistics Norway (the Norwegian institute of statistics). The year of reference for the deflation was arbitrarily taken as 1998. I preferred to deflate them using CPI rather than the production price index because the most important financial values, like profits and sales, are logically more related to the final prices rather than to input prices. An overall price index, rather to a production price index, to deflate these variables was used also in Mairesse and Siu (1982). These dummies show the expected difference of the dependent variable with respect to year 2005.

3.1 Descriptive Statistics

Here the average values and other descriptive statistics for R&D expenses, during each year, will be computed. In this part I limited my analysis to the firms which invest in R&D.

The two components explaining the variations in total R&D are the average investment for each firm and the total number of firms investing in R&D. The average investment will be the 'mean', while the number of firms involved in R&D is 'N'. The amounts are expressed in 1000 NOK.

The investments have already been deflated, using the CPI, in order to allow for a comparison of the real investments in the different years.

	N	233
1995:	**Mean**	28751.647 (5152.87)
	Total	6699133.76

	N	284
2002:	**Mean**	25006.2043 (4267.03)
	Total	7101762.03

	N	293
1997:	**Mean**	29466.6939 (4294.48)
	Total	8633741.31

	N	324
2003:	**Mean**	17851.871 (3918.44)
	Total	5784006.21

	N	267
1999:	**Mean**	27788.2119 (4789.83)
	Total	7419452.59

	N	261
2004:	**Mean**	22307.883 (3571.93)
	Total	5822357.46

	N	294
2001:	**Mean**	25281.6808 (1726)
	Total	7432814.17

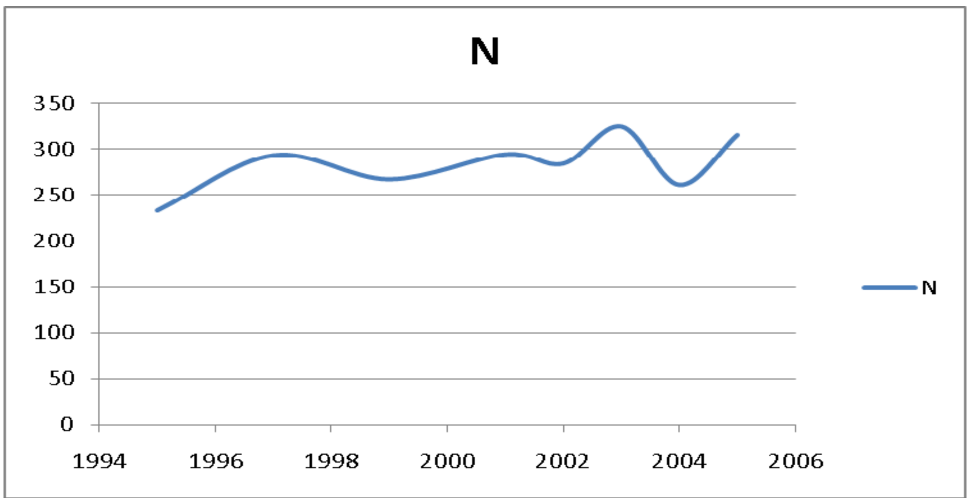
	N	315
2004:	**Mean**	18510.50 (3450.04)
	Total	5830807.99

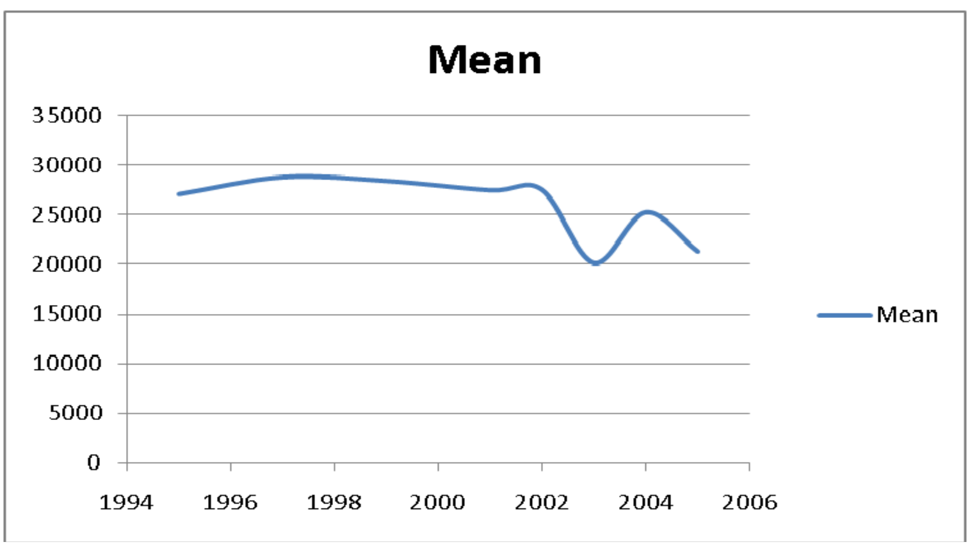
	N	2271 (average 283 per year)
Total:	**Mean**	24096.9069 (3989.36)
	Total	54724075.5 (6840509 per year)

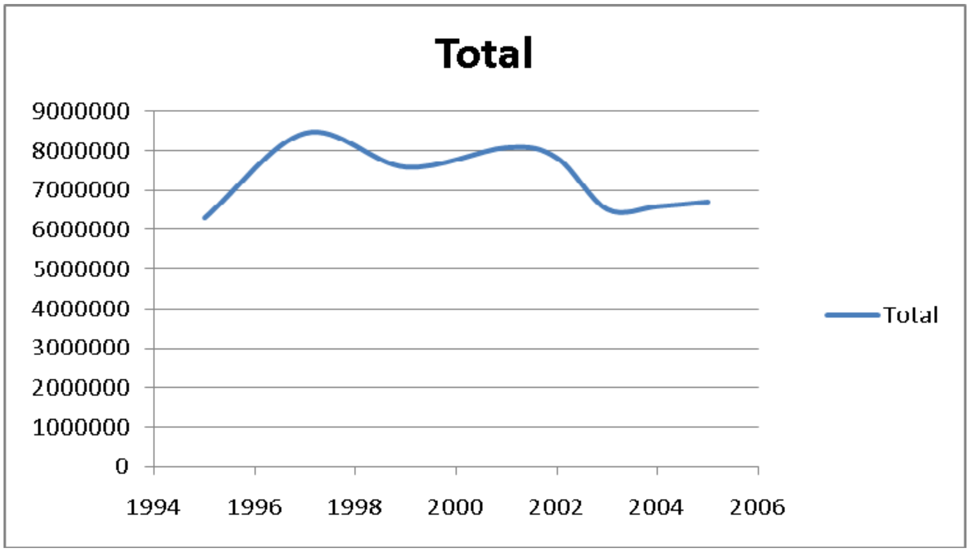
In year 1995 the firms with more than 100 employees which declared some positive investment in R&D were 233, with an average expense of 28,751,647 NOK during the year. The total investments in R&D from these firms was then 6,699,133,000 NOK

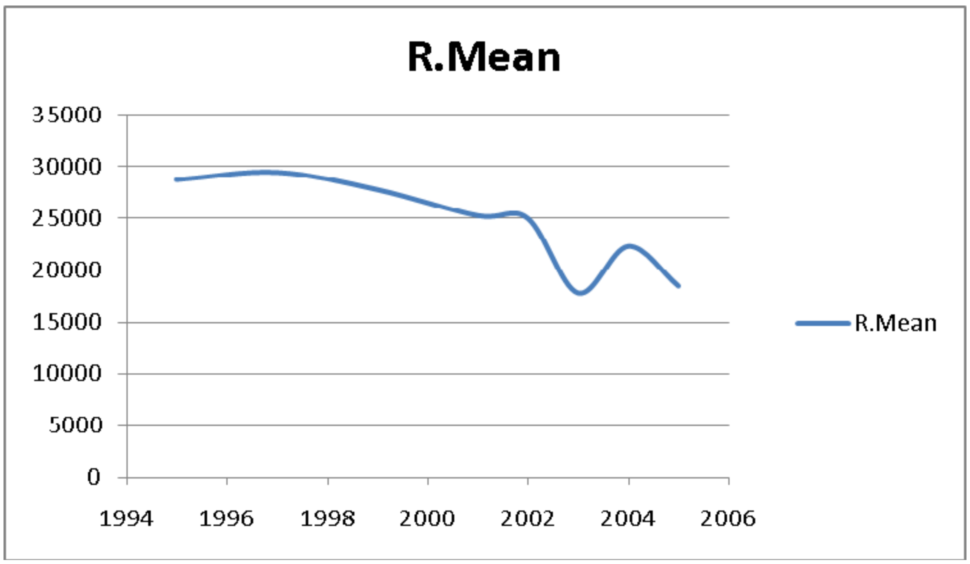
With respect to 1995, in 1997 there is a much larger number of big firms (>100 employees) which invest in R&D (233 in 1995, 293 in 1997) when also the average value of the investments had a slight increase. The total investments are then 8,633,741,310 NOK, an increase of 28.87% with respect to 1995, when they were 6,699,133,760 NOK. In year 1999 we had a slight reduction in the number of investing firms, 267 from 293, and still a very similar amount in the declared R&D. In year 2001 we have a similar total amount invested in R&D, but due to contrasting effects: on one hand we have a larger number of investing firms (294 instead of 267), on the other hand we see a smaller average expenditure (25.281.680 rather than 27.788.212 NOK). We can see similar results also for year 2002, while in year 2003 we have a growth in the number of investing firms, but a diminish in the average amount. The changes from year 2003 to year 2004 have an opposite pattern with respect to the changes from 2002 to 2003. Here again we see less investing firms, but a higher average amount. In 2005 again we have the opposite shift: more firms but less expenditure.

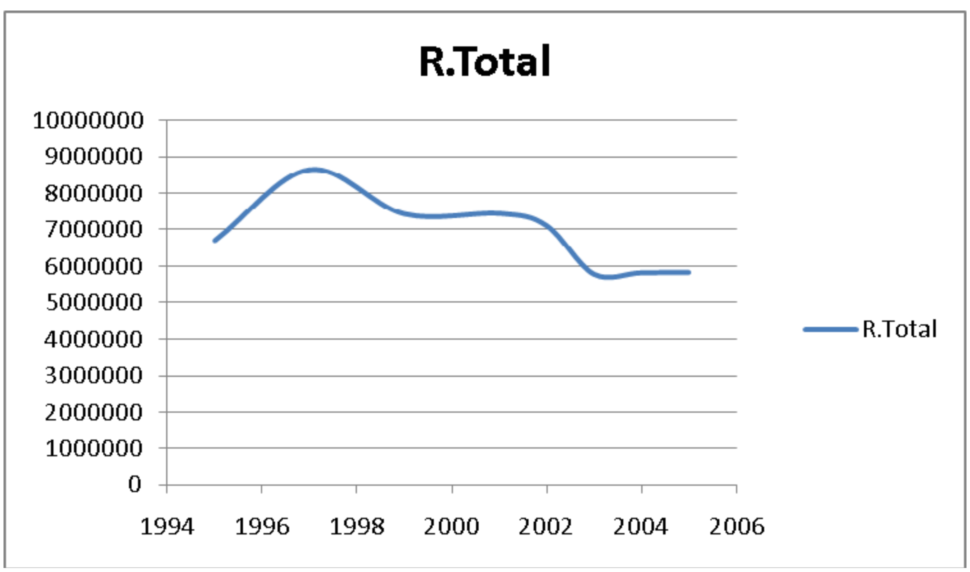
It seems then that there is some kind of negative correlation between the number of investing firms and the invested amount. In the following graphs the missing years were fitted as means between the preceding and the following year.





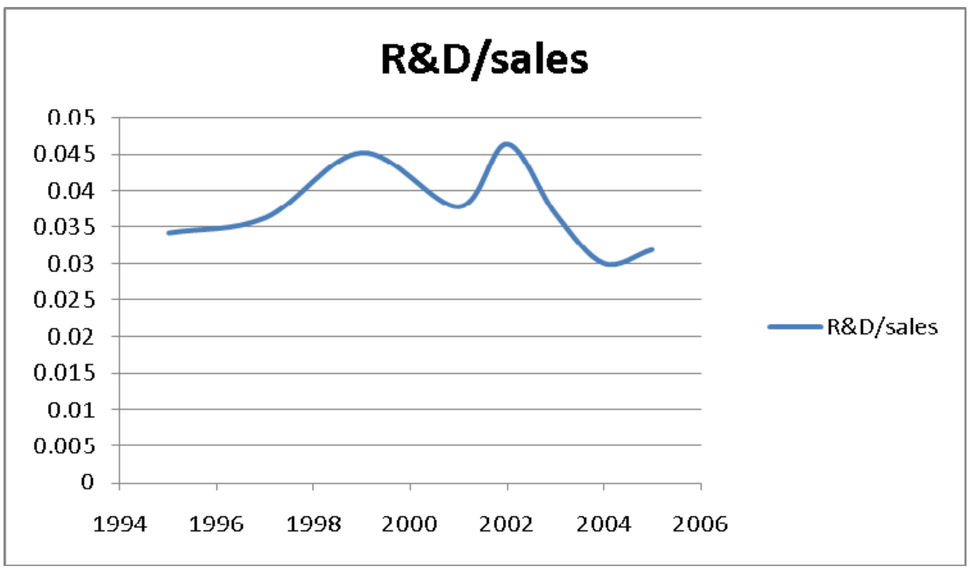

Total
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1994
1996
1998
2000
2002
2004
2006
Total

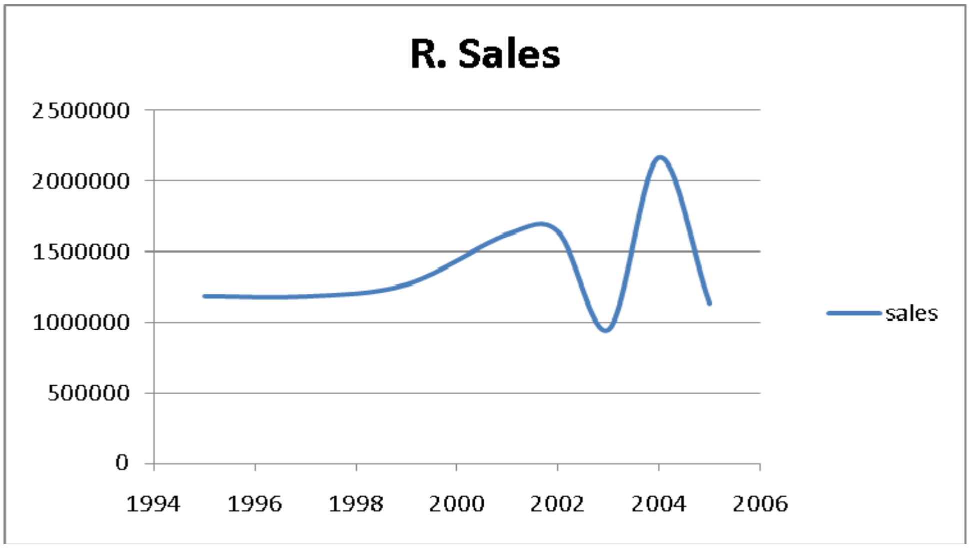

R.Mean
35000
30000
25000
20000
15000
10000
5000
0
1994
1996
1998
2000
2002
2004
2006
R.Mean


R.Total
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1994
1996
1998
2000
2002
2004
2006
R.Total

All these values are in 1000 NOK. For the nominal total value we see no particular trend, while we see a negative correlation between N and the real mean investment in R&D. An analytical computation gives a value of Corr(N,MeanR&D)=-0.67. The weird pattern of real R&D in time is basically due to the presence/absence of Statoil, the Norwegian state company monopolist of oil, that is not present in years 2003 and 2005. These are indeed the years when R&D drop.

The real mean R&D seems clearly decreasing, while also the total real R&D shows a similar pattern, even if less strong. It will be interesting to see, then, whether this drop in real R&D is due just to the absence of Statoil in 2003 and 2005 or to some time-specific change. In that case, in a regression with R&D as the dependent variable, we expect the coefficients of the last dummies to be smaller than the coefficients of the first ones. If the drop is due to other factors, like the absence of Statoil or a drop in sales, the coefficients of the time dummies should not differ by much. In order to understand it, it is necessary to see the pattern of R&D/sales and sales in time too.





The pattern of real sales is, as before, due to the presence/absence of Statoil. Fortunately this does not have any impact on R&D/sales value, as this ratio is almost the same both with and without Statoil in the dataset. This is a good thing, as results will not be 'biased' by the presence or absence of this firm. I decided to keep the present observations of Statoil anyway, as in two years it is the biggest investor in R&D and its ratio R&D/sales is similar to the rest of the firms.

Real sales revenues do not show any particular trend and, furthermore, if we take away Statoil from all the dataset we see a positive trend.

The ratio R&D/sales shows a dramatic drop in 2003, which lasted also for years 2004 and 2005, with respect to the previous years. An identical pattern is found if we take away Statoil too.

All these observations suggest us that the change in total real investment is due to other factors than a reduction in sales (that actually did not happen). That means that we can expect the coefficients of the last time dummies to be smaller than the first dummies' ones.

Also the ratio of investing firms on the total number of firms (with more than 100 employees, as usual) can be of some interest. This will enter the analysis on the probability of investing.

Ratio of investing/total firms (>100 employees) in 1995: 233/638=37.3%

Ratio of investing/total firms (>100 employees) in 1997: 293/565=52.2%

Ratio of investing/total firms (>100 employees) in 1999: 267/610=44.75%

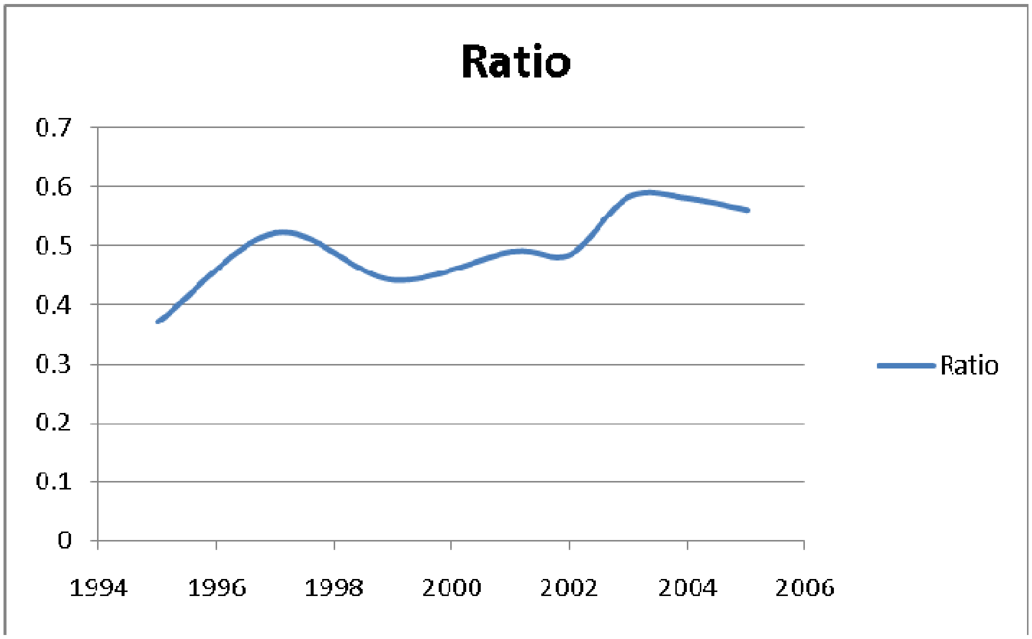
Ratio of investing/total firms (>100 employees) in 2001: 294/606=49.5%

Ratio of investing/total firms (>100 employees) in 2002: 298/599=49.74

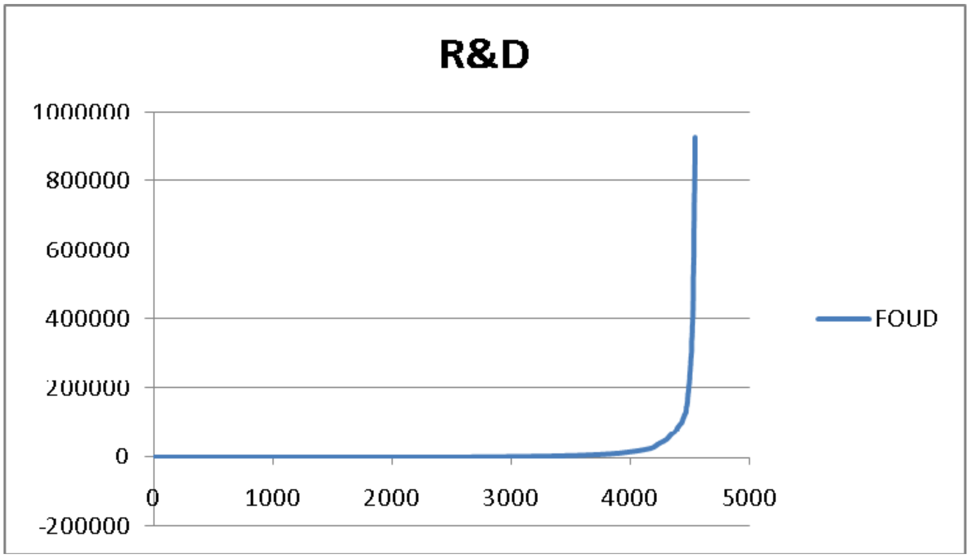
Ratio of investing/total firms (>100 employees) in 2003: 328/560=58.57%

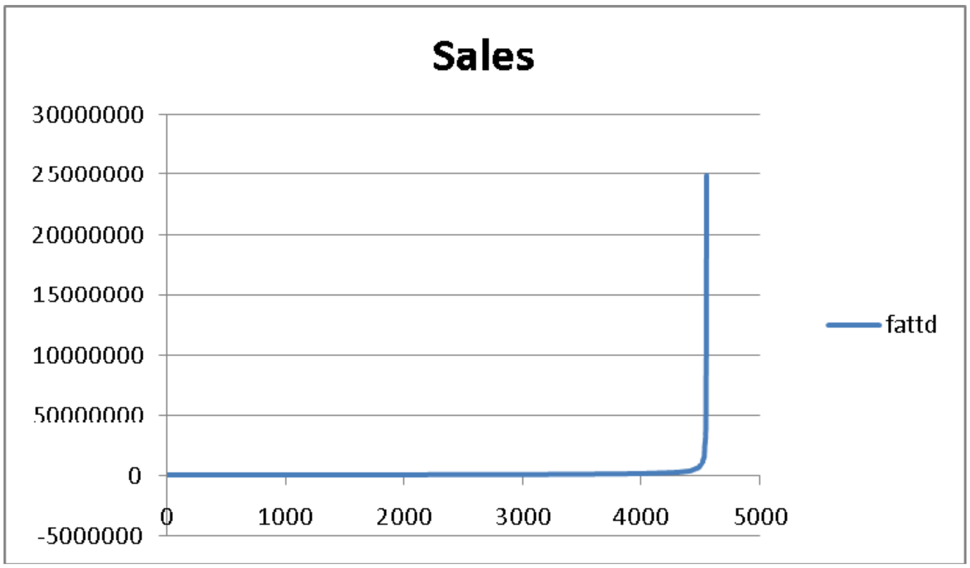
Ratio of investing/total firms (>100 employees) in 2004: 268/457=58.64%

Ratio of investing/total firms (>100 employees) in 2005: 328/581=56.45%



The trend of this ratio is quite similar to the trend of investing firms, which is upward sloping too. Real sales do not show this pattern, so we expect, in a regression with the probability of investing as dependent variable, that the coefficients of the time dummies of the last years are higher than the first ones. This is opposite to what we expect for the regression of R&D. Another issue worth of investigating is the origin of R&D. Total real sales value (at prices of 1998) are 55,068,435,200 NOK. The highest percentile of firms*time in sales invested 7,237,993,000 NOK in R&D, which is 13% of the total amount. The highest 5 percentiles invested 14,443,173,900 NOK (26%) and the highest 10 percentiles invested 24,080,357,000 NOK, the 44%. It is, then, evident that the biggest firms are the core leaders of R&D investments. In the following graph we have in the x-axis each firm*time, from the less investing in R&D (provided that R&D>0) in the left until the most investing in the right. This figure shows how much R&D is concentrated among few firms, that are the biggest ones in sales value. In the second graph we see that sales value are even more concentrated, with few very large firms. We can analyze, then, wheter the investment in R&D, relative to sales, is constant, increasing or decreasing with sales. These issues will be analyzed in the paragraph 3.1.


R&D
1000000
800000
600000
400000
200000
0
-200000
0
1000
2000
3000
4000
5000
FOUD


Sales
30000000
25000000
20000000
15000000
10000000
50000000
0
-5000000
0
1000
2000
3000
4000
5000
fattd

3.2 R&D regressions

In this section we will introduce the regressions for the determinants of R&D. R&D will be the left-hand side variable and the right-hand side variables are the ones thought, in the literature, to have an explanatory power on R&D investments.

So the general model is $y_{i,t}= c+\alpha*\pi_{i,t-1}+\beta*S_{i,t-1}+\gamma*L_{i,t-1}+\varphi*f_{i,t}+\sigma_k*m_{k,i,t}+\tau_t*T_t+\varepsilon_{i,t}$, where $y_{i,t}$ is the R&D expenditures of firm i in year t, $\pi_{i,t-1}$ is the profit of firm i in year t-1, $S_{i,t-1}$ is the sales revenues of firm i in year t-1, $L_{i,t-1}$ is the liquidity level of firm i in year t-1, $f_{i,t}$ is the foreign dummy, with value 1 if the firm i is owned by foreign agents in year t, $m_{k,i,t}$ are the sectorial dummy variables, with value 1 if the firm i is in sector j=k in year t, T_t are the time dummies, with value 1 if the observation is in year t and $\varepsilon_{i,t}$ the error term.

I used the notation $f_{i,t}$ and $m_{k,i,t}$ because there are some firms that changed ownership and sector in the period 1995-2005. I used the lagged values of profits and sales in order to avoid the simultaneity problem. Here I just considered the positive values of R&D. A discussion on whether it is possible to have a model including both the positive and the zero values will be done after the probit regression.

Here we will use a GLS procedure (a ‘clustered’ regression) in order to deal with the panel dimension of the dataset. That means that we adjust the standard error of the coefficients keeping into account that the observations within each firm are not independent, allowing for autocorrelation in the error term $\varepsilon_{i,t}$.

Linear regression (GLS)   Number of obs =   1507 (525 firms)

R-squared   = 0.3208   Root MSE   =   58643

R&D	Coeff.	Std. Error	t	P>|t|
profitdlag1	.0141732	.025007	0.57	0.571
salesdlag1	.0056388	.001826	3.09	0.002
moneydlag1	.0115173	.0056465	2.04	0.042
foreign1	6632.756	10089.22	0.66	0.511
chemical	43881.65	24631.37	1.78	0.075
tobaccoind	-42453.82	11832	-3.59	0.000
machineind	29379.96	16840.27	1.74	0.082
office_com~r	27466.04	7978.09	3.44	0.001
electric_a~s	16404.42	4239.681	3.87	0.000
radio_comm	114789.9	50322.61	2.28	0.023
medical_prd	30300.67	5878.631	5.15	0.000
motor_veh	9845.326	3590.477	2.74	0.006
detail_sale	-15029.85	3871.983	-3.88	0.000
transport_~s	-6627.208	2919.191	-2.27	0.024
post_telecom	24300.19	20862.11	1.16	0.245
data_proce~g	47058.99	13755.58	3.42	0.001
d1997	6830.605	6371.104	1.07	0.284
d1999	5452.533	6313.734	0.86	0.388
d2001	355.8582	4525.15	0.08	0.937
d2002	-2681.381	3363.537	-0.80	0.426
d2003	-987.8173	3423.503	-0.29	0.773
d2004	-1484.974	2906.019	-0.51	0.610
_cons	-777.5508	4540.285	-0.17	0.864

Before commenting the results, it is worth noting that many non-significant sectorial variables have been dropped from this summary (but were kept while computing the coefficients). Few non-significant ones have been kept if their coefficient was large.

In order to test, first of all, whether these variables can give problems of multicollinearity, following Allison's (1999) suggestions, we test the Variance Inflation Factors (VIF), a method of detecting the severity of multicollinearity. The VIF is an index that measures how much the variance of a coefficient is increased because of collinearity with the other explanatory variables. Considering the following regression equation with k independent variables $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon$, VIF can be calculated in three steps. First, we can calculate k different VIFs, one for each X_i, by first running an ordinary least square regression with each X_i as dependent variable on the other X_j, j=1,2,…, j≠i. As a second step, we can calculate the VIF factor for each β_i with the formula $VIF(\beta_i)=(1/(1-R^2)$, where R^2 is the R^2 of the regression of the first step. The square root of the variance inflation factor tells us how much larger the standard error is, compared with what it would be if that variable were uncorrelated with the other independent variables in the equation. As a common rule of thumb, there is a serious evidence of multicollinearity if any of the VIF elements is bigger than 10 and the mean of all the VIFs is considerably greater than 1. We see that there is not a problem of multicollinearity here.

Variable	VIF
Profitdlag1	6.14
Salesdlag1	5.25
Moneydlag1	3.22
Time dummies	1.58-1.94
Sectorial dummies	1.01-1.54
Mean VIF	1.57

There is some collinearity between profits and sales, but it is not so high to create too big problems.

As multicollinearity is not such a problem here, we do not need to modify this model. From the regression results, using a GLS procedure that allows the error term of each firm to be autocorrelated in time, we see that past profits do not have a significant impact on current R&D expenditures. This may suggest that past profits do not upgrade the expected returns from R&D. This is consistent with the findings of Wakelin (2001) and Kandybin'Kihn (2004) of stable returns from R&D within each firm.

Both size and liquidity (which is current assets – short term debt), on the contrary, had a significant impact on R&D. The fact that size had a significant impact was quite clear, but also liquidity shows a significant impact, with an even larger coefficient than sales. That may suggest that firms, *if they invest* (this is a regression only on the positive values of R&D), could be cash constrained and could invest not as much as they would find it optimal.

The foreign dummy does not seem to have a significant impact on R&D, if firms invest.
Many sectorial dummies were significant, which implies that, ceteris paribus, a firm in these sectors invest in R&D a significantly different amount from the firms in the primary sector. As pointed out before, we are interested just in the significancy of the sectorial coefficients here, not on the coefficients, as they depend on the average size of the firms. The most investing sectors were the chemical, the office computers, the electric, the radio and medical ones. The ones that invested less were the tobacco industry, the detail sale and the transport sectors.

The time dummies are never significantly different from zero, but we can see a decreasing trend, which fits the decreasing trend seen in the descriptive statistics. This trend was not due to a decrease in sales, as we saw from the tables in paragraph 3.1, but, as we can see also from the results of this regression (the decreasing coefficients of the time dummies), to time-specific factors. All these results, in order to be confirmed or contradicted, will be compared to the results from a Random Effects regression.

The difference from the following regression with respect to the preceding one is that now the model becomes: $y_{i,t}= c+\alpha*\pi_{i,t-1}+\beta*S_{i,t-1}+\gamma*L_{i,t-1}+\varphi*f_{i,t}+\sigma_k*m_{k,i,t}+\tau_t*T_t +a_i+\varepsilon_{i,t}$, where a_i is the unobserved effect (from the terminology of Wooldridge, 2002). Each a_i's is treated as a random variable with a Normal distribution and is assumed to be uncorrelated with the other explanatory variables. This assumption can be not straightforward, that is the reason why I will not consider the random effects model as a perfect model. In order to infer the statistical properties of the determinants of R&D it is probably better to compare the GLS to the Random Effects regression, keeping in mind the strengths and the weaknesses of both.

Random-effects GLS regression Number of obs = 1507 (525 firms)

R-sq: within = 0.0107 between = 0.3878 overall = 0.3009

R&D	Coeff.	Std. Error	z	P>|z|
--------------------+--				
profitdlag1	.0028755	.0047051	0.61	0.541
salesdlag1	.004786	.0004956	9.66	0.000
moneydlag1	.0038225	.0014334	2.67	0.008
foreign1	5285.283	6130.128	0.86	0.389
tobaccoind	-35484.4	53284.37	-0.67	0.505
chemical	27397.14	10733.09	2.55	0.011
machineind	21810.92	9448.759	2.31	0.021
office_com~r	33332.52	29420.6	1.13	0.257
electric_a~s	18277.22	13037.95	1.40	0.161
radio_comm	78295.14	14166.36	5.53	0.000
medical_prd	29700.94	14161.82	2.10	0.036
motor_veh	574.9703	8575.64	0.07	0.947
detail_sale	-16146.08	56668.81	-0.28	0.776
transport_~s	-5578.595	19269.43	-0.29	0.772
post_telecom	48050.06	14210.66	3.38	0.001
data_proce~g	53117.24	11142.69	4.77	0.000
d1997	8319.216	3405.896	2.44	0.015
d1999	4115.163	3606.442	1.14	0.254
d2001	1949.566	3051.222	0.64	0.523
d2002	-1650.499	3092.94	-0.53	0.594
d2003	-990.4011	3040.7	-0.33	0.745
d2004	-11.95617	2937.748	-0.00	0.997
_cons	694.1247	6228.768	0.11	0.911

Reassuringly, we find very similar results, which make us think that the results found before are quite robust to the different possible econometric specifications. Sales and liquidity are significant in both regressions, which gives support to the cash constraints hypothesis.

Being owned by a foreign operator does not significantly change R&D investment, for positive R&D (afterwards I will list the descriptive statistics) and it is a coherent finding with the profit maximization axiom: if there is an optimal R&D investment policy, why a foreign operator should invest less? Following the explanation of Narula and Zanfei (2003), that means that the firms that invest in R&D abroad behave like Norwegian firms. Later we will see whether there are more R&D-centralizer or decentralizer firms.

Time dummies are not significant, but the important point is that, also here, they actually show a slight decreasing trend, as we expected while analyzing the pattern of R&D and sales in time. In particular, the dummies of 2003 and 2004 are much lower than the initial dummies (1997 and 1999). This regression confirms our analysis that there were some time-specific factors that changed the R&D amount others than a change in sales.

Many of the sectorial dummy coefficients are non-significant; the highest ones are the ones of chemical industry, the radio communication, the data processing industry, the electric apparatus and the medical industry, as it was in the GLS regression. The only sectors where R&D investments seem below the primary one are the tobacco industry, transports (even if not significantly), detail sale and restoration. These results confirm what we could expect: in sectors where the innovation is very important to survive and there is a high rate of turnover, R&D investments are needed to survive and be present in the market. The chemical, radio communication and data processing are all industries which fit in this description.
The industries where R&D is below the average (unconditional on sectorial dummies) are industries where it is not so important to find new technologies: the firms in the sector of sale retailing or the sea transport do not need very innovative findings in order to remain in the market, the technologies they use are actually quite old. These results then confirm what theory predicts.

We find very similar results also if, instead of using a dummy variable for the foreign control, we use a variable which represents the foreign share in the ownership. This variable is 1 if the firm is completely controlled by foreign agents, 0 if totally Norwegian and a fraction between 0 and 1 if Norwegian and foreign agents coexist in the ownership. This variable behaves in the same way as the 'foreign' dummy. It is not statistically different from it neither from zero. If we consider only the firms that are partially Norwegian and partially foreign, we have just 55 observations, of whom 33 have missing values, so the regression would be done just on 22 firms*time. Obviously we cannot infer statistical properties from such a small sample.

We can face the above regression also with the fixed effects method. It is the "strongest" way of dealing with panel data, as it takes away all the time-invariant variables. It will let us see only the behaviour of the firms that changed sector or ownership in time.

That's why many dummies will be dropped, but this procedure can anyway give us important insights for the foreign dummy. The model is, as in the Random Effects regression, $y_{i,t}= c+\alpha^*\pi_{i,t-1}+\beta^*S_{i,t-1}+\gamma^*L_{i,t-1}+\varphi^*f_{i,t}+\sigma_k^*m_{k,i,t}+\tau_t^*T_t +a_i+\varepsilon_{i,t}$, where the a_i's are treated as fixed effects for each firm. We can see them as dummy variables. Fixed Effects regression will consider only the 'within information', as it takes away all the firm-specific factors.

Fixed-effects (within) regression   Number of obs = 1507 (525 firms)

R-sq: within = 0.0331   between = 0.0029   overall = 0.0120

R&D	Coeff.	Std. Error	z	P>|z|
profitdlag1	.002608	.0051371	0.51	0.612
salesdlag1	-.0007114	.001383	-0.51	0.607
moneydlag1	-.0031223	.0021533	-1.45	0.147
foreign1	9445.946	16810.05	0.56	0.574
treeind	107257.5	51841.82	2.07	0.039
chemical	102724.5	54616.07	1.88	0.060
metalind	101975.8	45037.16	2.26	0.024
machineind	96802.42	40097.04	2.41	0.016
electric_a~s	51419.94	51471.81	1.00	0.318
radio_com	47701.24	32577.17	1.46	0.143
data_proc~g	51924.96	47895	1.08	0.279
d1997	8168.004	3699.186	2.21	0.027
d1999	4310.196	3804.516	1.13	0.258
d2001	2462.082	3168.164	0.78	0.437
d2002	-1071.322	3174.659	-0.34	0.736
d2003	-741.1177	3123.747	-0.24	0.813
d2004	617.1733	2975.605	0.21	0.836
_cons	-14494.81	16809.06	-0.86	0.389

F test that all u_i=0: F(524, 960) = 10.42   Prob > F = 0.0000

Many dummies were dropped, as expected. The reason why some dummies were kept is that some firms, during the period 1995-2005, changed sector. Also the foreign dummy still exist, it is of comparable magnitude as in the random effects regression and is still non-significant. Even if we should not rely too much on FE model, this helps us in giving another dimension to this issue. Being foreign does not change significantly R&D investment decisions not only for firms that remained foreign during all the years of the dataset, but also for the firms that changed nationality. This is the only reliable thing we see in this regression. As a Fixed Effects regression is as an OLS regression on the difference from the mean of each variable, it is not very surprising that we find unexpected results for sales and liquidity. For an analysis of the determinants of R&D expenditures, obviously GLS and RE are more reliable.

In all these regressions we saw that the sectors most involved in R&D are the chemical, the office computer, the electric, the medical and the data processing sectors. These sectors will be defined the "high-investing sectors". In order to relax the assumption that profits, size and liquidity have the same effect in all the sectors (an implicit assumption due to the use of sectorial dummy variables in an unique regression), we can run two separate regressions, one for the high-investing sectors (from now on called HI) and one for the low investing sectors (LI, all the sample except the high-investing ones). Here the model is the same as before, but the regression will be run only for these sectors. I will run both a GLS as well as a RE model for both.

High-investing sector:

Linear regression (GLS) Number of obs = 375 (125 firms)

F(10, 124) = 1.71 Prob > F = 0.0864 R-squared = 0.1127

R&D	Coeff.	Std. Error	t	P>|t|
---------------------+---				
profitdlag1	.0121749	.0541153	0.22	0.822
omsdlag1	.0163089	.0090013	1.81	0.072
moneydlag1	.0292478	.0154525	1.89	0.061
foreign	35833.18	36623.59	0.98	0.330
d1997	29933.79	23645.07	1.27	0.208
d1999	7253.962	20268.01	0.36	0.721
d2001	18784.06	18653.57	1.01	0.316
d2002	5202.425	14179.61	0.37	0.714
d2003	-831.9974	14396.73	-0.06	0.954
d2004	-7546.812	12803.95	-0.59	0.557
_cons |	21462.15	15254.17	1.41	0.162

Low-investing sector:

Linear regression   Number of obs =   1132 (402 firms)

F(10,   401) =   21.54   Prob > F   = 0.0000   R-squared   = 0.4906

R&D	Coeff.	Std. Error	t	P>|t|
profitdlag1	-.0088394	.0110429	-0.80	0.424
omsdlag1	.0064099	.0011451	5.60	0.000
moneydlag1	.0078385	.0046661	1.68	0.094
foreign	783.8006	4396.726	0.18	0.859
d1997	-21.3015	3287.44	-0.01	0.995
d1999	3275.725	3144.656	1.04	0.298
d2001	-3442.787	2083.796	-1.65	0.099
d2002	-1403.831	1474.829	-0.95	0.342
d2003	-54.07687	1391.742	-0.04	0.969
d2004	-447.766	958.4279	-0.47	0.641
_cons	9100.774	3150.187	2.89	0.004

Profits never had a significant impact on R&D, neither in GSL nor RE, neither in the HI nor in the LI. This finding supports even more the idea that R&D is performed for its expected returns, which do not change over time.

Size, interestingly, has a much higher impact in the HI, but is much more significant in the LI. That suggests that firms in the LI rely much more on their own size when they decide how much to invest in R&D, while firms in the HI probably rely more on other factors. That means that the firms in the high-investing sectors, even if they spend a higher share of their sales in R&D (larger coefficient), their investments in R&D have a much higher variance (not significant). This view is supported also by the R^2: in the HI it is only 11%, while in the LI is reaches the 49%. This dramatic difference is due mostly to the different impact of the size in these two sectors (there is a great difference in the variance of the sales coefficient in these two regressions). One explanation for the fact that firms in LI rely much more on accounting variables can be found in Nelson and Winter's book "An Evolutionary Theory of Economic Change" (1982). Here they present a serious critique to microeconomic theory and propose an evolutionary paradigm, where economic agents rely on routines and do not behave optimally. They found many empirical evidence for that. The results of the LI regression (high significance of sales and low coefficient) suggests the existence of routines too. The fact that routines exist in the LI more than in the HI is very logical. In the HI it is much more important to analyze carefully the quality of the project, so the R&D of each year will be less dependent on size (or other financial variables) than in the LI. In one year without good projects a firm could invest a little amount in R&D, but in the next year, if there is the possibility of a good project, R&D could rise sharply. In LI, on the contrary, the importance of R&D is more limited, so it is less costly to invest in R&D following some simple "rule of thumb". A rule of thumb could be, for example, spending in R&D a fixed amount of sales, say 4%. The high R^2 and the high significance of sales in LI regression seem to confirm this hypothesis.

The results for liquidity unfortunately are not clear: the GLS regression gives a high coefficient for it, but the RE regression gives a not significantly negative coefficient (see Appendix 1). On the other hand, in the LI the results are quite small (the coefficient is 0.0078 in the GLS or 0.005 in the RE), but always highly significant. Also this result is very consistent with the conclusions drawn for the sales coefficient. In all the regressions above the foreign dummy is not significant. The time dummies show the decreasing trend in particular in the HI, meaning that the decrease in time of real R&D was due primarily to a drop in the HI.

Another question of interest is to investigate the relation between all these independent variables and not the total level of R&D, which is what I have done until now, but just the relationship between them and the probability of being a firm which invests in R&D. In order to do that properly, we should run a probit or a logit regression, to avoid the problems that we could face by running a simple OLS. The clearest problem is that with a linear probability model (OLS) we could infer a probability bigger than 1 or smaller than 0, which obviously cannot be accepted. Also, heteroscedasticity problems will arise. In order to keep into account that we deal with a panel data, I ran a probit model allowing for autocorrelation in the error term for the same firm (clustered probit). The model here is $y_{i,t}= c+\alpha*\pi_{i,t-1}+\beta*S_{i,t-1}+\gamma*L_{i,t-1}+\varphi*f_{i,t}+\sigma_k*m_{k,i,t}+\tau_t*T_t +a_i+\varepsilon_{i,t}$, where $y_{it}=\{0,1\}$, $y_{it}=0$ if firm i does not invest in R&D in time t, $y_{it}=1$ otherwise. The probability of $y_{it}=1$, which is what we are interested in, is given by $P(y=1)=P(\varepsilon_{i,t} >-xB)=1-P(\varepsilon_{i,t} <-xB)=$ $1-G(-xB)=G(xB)$, treating all the independent variables in a vectorial form. After having run the probit model, I will also compute the marginal effects of these variables in the center of the distribution.

Probit regression Number of obs = 3094 (899 firms)

Log pseudolikelihood = -1756.5575 Pseudo R2 = 0.1791

Antall_R&D	Coeff.	Std. Error	z	P>|z|
profitdlag1	5.68e-07	3.89e-07	1.46	0.144
salesdlag1	2.98e-07	6.18e-08	4.81	0.000
moneydlag1	-1.79e-07	1.34e-07	-1.33	0.183
foreign	-.3340844	.1163516	-2.87	0.004
tobaccoind	-.7700767	.350863	-2.19	0.028
graphics	-.9918995	.1863598	-5.32	0.000
chemical	.9376558	.3042538	3.08	0.002
plastic	.4150415	.2738931	1.52	0.130
non_metal_ s	.5466775	.2402784	2.28	0.023
metalind	.3688631	.1718527	2.15	0.032
machineind	.6408444	.2093374	3.06	0.002
electric_a~s	1.299171	.2481487	5.24	0.000
radio_comm	.6808776	.2906111	2.34	0.019
medical_p~d	1.292219	.4597342	2.81	0.005
motor_vehi~s	-.0522788	.1504954	-0.35	0.728
detail_sale	-1.526592	.5797403	-2.63	0.008
sea_transp~t	-.7351366	.1794082	-4.10	0.000
air_transp~t	-1.486339	.5791247	-2.57	0.010
transport_s	-1.269162	.1926872	-6.59	0.000
post_telecom	-.4224937	.2741719	-1.54	0.123
data_proc~g	-.1008675	.19665	-0.51	0.608
d1997	-.2434647	.0951178	-2.56	0.010
d1999	-.4572086	.0978117	-4.67	0.000
d2001	-.2173162	.0831877	-2.61	0.009
d2002	-.2680879	.0802577	-3.34	0.001
d2003	.0166395	.0747737	0.22	0.824
d2004	-.0301053	.0587838	-0.51	0.609
_cons	.0802248	.1183917	0.68	0.498

Marginal effects after probit

y = Pr(antall_R&D) (predict) = 0.56550625

variable	Dy/dx	Std. Error	z	P>|z|

-------------------+--

pr~dlag1	2.24e-07	.00000	1.47	0.143
salesdlag1	1.17e-07	.00000	4.88	0.000
moneyd~1	-7.03e-08	.00000	-1.34	0.182
foreign*	-.1323953	.04599	-2.88	0.004
tobacc~d*	-.2930215	.11808	-2.48	0.013
graphics*	-.3689425	.05706	-6.47	0.000
chemical*	.306916	.0706	4.35	0.000
plastic*	.1539292	.09301	1.66	0.098
non_me~s*	.1978015	.07613	2.60	0.009
metalind*	.1389736	.06079	2.29	0.022
machin~d*	.2278895	.06283	3.63	0.000
electr~s*	.3704048	.03859	9.60	0.000
radio_~n*	.2371163	.08269	2.87	0.004
medica~d*	.3673701	.06729	5.46	0.000
motor_~s*	-.0206351	.05957	-0.35	0.729
detail~e*	-.4801267	.09356	-5.13	0.000
sea_tr~t*	-.2829438	.06244	-4.53	0.000
air_tr~t*	-.4751331	.10006	-4.75	0.000
transp~s*	-.4406496	.04688	-9.40	0.000
post_t~m*	-.16721	.10617	-1.57	0.115
data_p~g*	-.039935	.07822	-0.51	0.610
d1997*	-.0965945	.03776	-2.56	0.011
d1999*	-.1808105	.03796	-4.76	0.000
d2001*	-.0861626	.03307	-2.61	0.009
d2002*	-.1063372	.03186	-3.34	0.001
d2003*	.0065422	.02937	0.22	0.824
d2004*	-.0118686	.02322	-0.51	0.609

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Interestingly, we find that the liquidity coefficient is not significant anymore (and it is even negative). This can circumscribe the importance of the cash constraints only on the total investments *provided that there is an investment*. Liquidity indeed has a positive effect in the regression of the invested R&D, but has no positive impact on the probability of investing.
The reason could be that when a firm decides whether to invest in R&D, it does not consider the present liquidity, but the long term expected returns and costs of investing in R&D. In this case, it

is logical that current liquidity does not have a significant effect in deciding whether to invest or not.

Profits are still not significant, as before, while sales continue being significant. Differently from the R&D regression, a very big number of the coefficients of the dummy variables is significant: while they were not significant in explaining the amount of the R&D investments, they are in explaining the probability of investing in it. So the firms in these sectors do not behave differently from the firms in the primary sector, *ceteris paribus*, *if they invest*, but they are more likely to invest than primary sector firms. The only sector that had a non-significant impact on the invested amount provided that R&D>0 but has a negative impact on the probability of investing is the graphic sector (whose coefficient in the R&D regression was dropped as not significant). The sectorial dummies with the largest coefficients in the R&D regression were the chemical sector, the leather sector, the office computers, the medical apparates and electric apparates. These variables are still positive and significant here too. One reason for that could be that in our dataset we just have firms with more than 100 employees. Firms of these sectors with so many workers normally must invest in R&D to find new products and survive in the market (let us just think to the leather sector or the electric apparates).

We see that being foreign, even if it does not reduce the average amount spent, reduces the probability of investing. This reduction is around 13% and is significant. It means that foreign firms in Norway *ceteris paribus* spend the same, *if they invest*, but have a lower probability of investing.

Dividing the dataset between high-investing and low-investing sector, we note that the impact of the foreign dummy is much stronger in the high-investing sector. In it, its marginal effect is -0.274 (t-value=-3.12), in the low-investing sector it is -0.058 (t-value=-1.17) (see Appendix 2). In both sectors, on the other hand, it does not affect the expected amount, provided that the firm invests.

An interesting extension of these results would be the construction of a model that can embody both the impact that the independent variables have on the probability of investing in R&D and on the expected invested amount. One of the candidates is the Tobit model. It assumes that the independent variables have a proportional effect on both the probability that the dependent variable is positive and on its value when it is positive. Looking at the Probit regression and on (truncated) OLS on the positive R&D we see these things: profits have a not significant impact on both P(R&D>0) and on E[R&D|R&D>0], while sales have a positive and significant impact on both, around half times the impact of profitability. Liquidity can give some problems, as it is not significant for the probability of investing while it is positive and significant for the R&D amount, but the worse concerns come from the foreign dummy. It has, indeed, a different behaviour: it affects negatively and significantly the probability of investing (its marginal effect in the probit regression was -0.1324, so on average it reduced the probability of investing of 13.24%), while it has almost no effect on the amount invested.

The dummy variables have not clearly the same or opposite effects, in general, but the most important ones (chemical, electric apparates, radio and medical equipment) still have in both regressions a positive and significant coefficient. The other dummy variables do not behave in a too distant manner from the theoretical prescriptions to run a consistent Tobit, but the behaviour of the foreign dummy would make it inconsistent. Furthermore, the Shapiro-Wilk test for normality rejects this hypothesis - residuals distributions seems like a normal, but with a long right side tail – and Breusch-Pagan test for heteroscedasticity rejects the hypothesis of homoscedasticity too.

Another candidate to include in the same model both P(R&D>0) and E[R&D|R&D>0] is the Heckman two-step procedure. Nevertheless this is not the best setting to apply it. Here we do not face a variable seen only under special circumstances (like wages for working people), but an actual variable, which can be directly chosen by the firms. That's why it is better to run a two-part model (Manning, Duan and Rogers, 1987). It consists in running a probit or logit, for sample inclusion, followed by a regression on the positive values of y, like it was done here.
When the goal is to analyze an underlying regression model or to predict the value of the dependent variable that would be observed in the absence of selection the Heckman model is more appropriate. When the goal is to predict an actual response, like here, the two part model is usually a better choice. A part the theoretical debates, also a practical issue arises. In the Heckman procedure, unless the set of regressors in the E[Y|Y>0] equation (the “regression equation”) is a strict subset of the set of regressors in the P(Y>0) equation (the “selection

equation"), there are serious problems of multicollinearity. The coefficients of the regression equation, indeed, are identified only due to the nonlinearity of the inverse Mills ratio (Wooldridge, 2002). Running a regression on all the sample, on the high-investing sector and on the low-investing one with the Heckman procedure, these theoretical predictions are indeed confirmed. Coefficients are never significant, except the constant term and, in the high-investing sector, the revenues in determining the probability of investing. So both from a theoretical as well as from a practical point of view the two-part model is a better choice.

For a full picture of the relationship between foreign ownership and R&D investments, we can look at the summary statistics of national and the foreign firms.

NATIONAL firms*time, **real sales**

N	6889	Mean	712263.708
Std Deviation	5225772.47	Variance	2.73087E13

FOREIGN firms*time, **real sales**

N	1376	Mean	951806.477
Std Deviation	2565145.83	Variance	6.57997E12

NATIONAL investing firms*time, **real R&D**

N	1895	Mean	22697.6794
Std Deviation	73165.1132	Variance	5353133787

FOREIGN investing firms*time, **real R&D**

N	396	Mean	30445.2847
Std Deviation	78994.6614	Variance	6240156532

Ratio foreign investing firms*time in R&D to total foreign firms: 396/841=0.471.
Ratio national investing firms*time in R&D to total national firms: 1895/3738=0.507.

From these statistics we see that foreign *investing* firms actually invest much more than the Norwegian ones, and they do so because they are much bigger, on average. On sales value they are 33% bigger than the national ones, and their R&D investments are 34% larger. Being foreign, as we saw in the regression results, does not have effects of the amount invested, if the firm invests, but has an effect on whether a firm will invest in R&D. Even if they are on average bigger (+33%), the probability that one of these invests is lower (47.1% against 50.7%). This suggests the fact that a foreign company prefers to invest in R&D in its own country. The fact that, then, *if it invests*, it invests an amount as high as a Norwegian firm would do, makes more realistic the theory of R&D sunk costs (Sutton, 1991, Santos, 2008). If there were no fixed costs, we would not expect a drop in the probability of investing. A sunk cost in R&D can be creating a laboratory and finding expert personnel, a variable cost can be beginning a new project (hiring additional researchers, etc). The fact that foreign firms have a lower probability of investing means there exist also many multinational firms that centralize R&D in their own country.

These findings can have interesting policy implications. If the government had the intention of raising Norwegian aggregate R&D, probably it should focus more on the sunk costs rather than on the variable costs. Doing so, it may make foreign firms willing to invest. If they are, they are expected to invest as much as a Norwegian one. As they are on average bigger, they will probably also invest more, after they have decided to invest. Furthermore, this will avoid the distortion toward the basic research due to R&D subsidies, pointed out by Rosen (1991). On the other hand, Acs and Audretsch (1988) showed that government-subsidized R&D is less productive than private R&D. Even a more basic question could also arise: is it really convenient for a government to subsidize R&D? Subsidizing it means that governments thinks that R&D creates positive externalities, which is quite pacific in the literature, but whose amount is difficult to estimate. Subsidizing R&D and, especially, its fixed part may create serious problems of moral hazard. We can think to the findings on the 'foreign' dummy as a 'diagnosys': for the 'treatment', if it is really worth to implement it, welfare analysis will be needed and could be an interesting development of this work.

3.3 R&D/sales regressions

Here I will analyse the impact of the size of the firm on the ratio R&D/sales. The following analysis is a test of the externality reduction and the scale effect argumentations. The first states that the bigger the firm is, the more it can appropriate its own efforts (Klepper, 1996); the second that there may be economies of scale in performing R&D. Furthermore we expect a bigger firm to be less risk-averse.

On the other side, other literature says that the percentage R&D/sales should be negatively correlated with the size of the firm, as marginal returns on R&D are decreasing, and investing after some point is not profitable (Jaruzelski, 2005).

These following regressions are just very preliminar: I do not include any sectorial, time or foreign dummy, nor profits or liquidity. I will use them for a first impression of the relationship R&D/sales and sales.

Linear regression Number of obs = 1708 (525 firms)

R-squared = 0.0012

R&D/sales	Coeff.	Std. Error	t	P>|t|
----------------------+--				
salesdlag1	-3.87e-10	1.91e-10	-2.03	0.043
_cons	.0337573	.0030606	11.03	0.000

-----------------------+--

Random-effects GLS regression Number of obs = 1708 (525 firms)

R-sq: within = 0.0002 between = 0.0003 overall = 0.0012

R&D/sales	Coeff.	Std. Error	t	P>|t|
----------------------+--				
salesdlag1	-1.96e-10	2.96e-10	-0.66	0.508
_cons	.0318631	.0029073	10.96	0.000

-----------------------+--

Here I regressed the ratio of R&D/sales on sales. We can see that sales revenues coefficient is negative and significant in the FGLS regression, while it is not significantly negative in the Random Effects regression. A Fixed Effects regression gives the same results as the Random Effects one. In no case, then, there is a positive relationship between size and R&D/sales.

This result would reduce a lot the importance of the argumentation of the externality reduction: the amount spent on R&D, if this was the case, *keeping R&D productivity the same*, should be positively correlated with the sales. But R&D productivity, as a firm increases its own R&D efforts, normally decreases. On the contrary, this regression may support the diminishing returns argumentation, or the proportional relationship between R&D and R&D/sales. This very preliminar result seems to suggest, anyway, that the externality reduction is not stronger than the diminishing returns argument.

I have divided the sample in 4 subsamples, depending on the sales volume. The first included just the firms in the top percentile for sales value, the second the firms between 90th and 99th percentiles, the third the ones between the 10th and the 90th ones and the fourth the smallest firms. I considered also the top 1%, even we have just 23 observations, because the firms in this percentile invest the 13% of the total real amount of R&D.

With random and fixed effects I obtained even a significantly positive relationship in the subsample 10%-90% (but negative for the top percentile) and no significant effect in the other subsamples. With a simple clustered regression I always find not significant coefficients.
So we cannot reject (at 95% confidence interval) the hypotesis of proportionality between R&D and sales. This result can embody the two contrasting effects of the externality reduction and of the diminishing returns in R&D, making our results very similar to the ones found by Cohen and Klepper (1996, b).

Here it is the final model, with past profitability, sales, liquidity, and the same dummies as before. As in the R&D regression, here the model is
$y'_{i,t}=c+\alpha*\pi_{i,t-1}+\beta*S_{i,t1}+\gamma*L_{i,t1}+\varphi*f_{i,t}+\sigma_k*m_{k,i,t}+\tau_t*T_t+\varepsilon_{it}$, where y'_{it} is R&D/sales, or, in the terms of the previous models, y_{it}/S_{it}.

Linear regression Number of obs = 1507 (525 firms)
R-squared = 0.2108 Root MSE = .06593

R&D/sales	Coeff.	Std.	t	P>|t|

Error				
-------------------+--				
profitdlag1	-1.21e-08	1.64e-08	-0.74	0.463
salesdlag1	1.05e-09	9.22e-10	1.14	0.257
moneydlag1	2.60e-09	3.23e-09	0.80	0.421
foreign |	.0132236	.011226	1.18	0.239
tobaccoind |	-.0273084	.0113736	-2.40	0.017
chemical |	.0424102	.0166892	2.54	0.011
machineind	.0376916	.0165228	2.28	0.023
office_com~r	.0380129	.0076749	4.95	0.000
electric_a~s	.0397415	.0090661	4.38	0.000
radio_comm	.1269145	.0328097	3.87	0.000
medical_pr~d	.073903	.0113655	6.50	0.000
motor_vehi~s |	.0197899	.0095939	2.06	0.040
water_elec~s |	-.0092833	.0042763	-2.17	0.030
detail_sale |	-.0100444	.004877	-2.06	0.040
data_proce~g	.1095203	.0297379	3.68	0.000
d1997	-.0009059	.0065956	-0.14	0.891
d1999	-.0026242	.006791	-0.39	0.699
d2001	.003023	.0061391	0.49	0.623
d2002	.002915	.0056743	0.51	0.608
d2003	.0044148	.0059602	0.74	0.459
d2004	-.0008528	.0049269	-0.17	0.863
_cons	.0094037	.0077368	1.22	0.225

--------------------+--

Also in these regressions it comes out that sales volume does not affect negatively the ratio R&D/sales. Profits and liquidity does not impact the ratio R&D/sales significantly. The foreign dummy still has a not significant impact (in the clustered regression) on R&D/sales. In the random effects regression it seems to have even a positive relationship, but this is hardly true. We saw the descriptive statistics of foreign and national firms both in terms of sales as well as of R&D, and we found that foreign firms are 33% bigger and invest, if they invest, 34% more. It seems unlikely that the foreign dummy, then, can have a significantly positive impact on R&D/sales. Probably the reason must be found in a correlation of the unobserved effects with some explanatory variable that affects the consistency of random effects model. In this case, then, we should rely more on the clustered regression (GLS allowing for autocorrelated errors within the same firm over time).

The most important sectorial dummies here are the same as in the R&D regression, i.e. the chemical, the office computers, the electric, the medical instruments and the radio communication sectors. This confirms that firms in these sectors invest more not because of bigger average dimension, but just because of the environment where they operate. In this regression the coefficients mean the average difference in R&D/sales from the primary sector. *Ceteris paribus*, then, if a firm in the primary sector invests k% of its sales in R&D, a chemical firm will invest (k+4.24)%.

If we wanted to create, like in the R&D regression, a unique model with both P(R&D>0) and E[R&D|R&D>0], we would face the same problems as before. Tobit model would still face the non-normality of the error term, the heteroscedasticity and the different behaviour of the foreign dummy in the probability of investing and on the invested amount. Furthermore, it would have a new problem. This comes from the sales variable. It has still a positive effect on P(R&D>0), but it has now a not significant impact on E[R&D/sales|R&D>0]. Tobit model would then give not consistent estimates. Heckman procedure shows the same drawbacks it showed in the R&D regression, so here too the best is to have a two-part model.

4. Relationship R&D-Investment and Success

4.1 Relationship R&D-physical investments

In this section there will be the analysis of the relationship between R&D and physical investments, in order to test which one of the different theories illustrated in the first chapter may fit Norwegian data. Lach-Schankerman (1989) and Lach-Rob (1996) state that there is a causal relationship from R&D to physical investments. Tovainen-Stoneman (1998) assess the opposite relationship, while Chiao (2001) found a contemporaneous two-ways relationship.
Here we have the descriptive statistics of Norwegian firms' R&D and investments.

Variable	Mean	Std. Error	Obs. (firms)
R&D	24096.91	74551.89	2271 (797)
Investment	26119.90	120367.5	4266 (1148)

The mean real investment in R&D is 24,096,910 NOK, with a std. dev. of 74,551,890, and the mean real investment in physical capital is 26,119,900 NOK, with a std. dev. of 120,367,500. Here we have a similar finding to Lach-Schankerman (1989) and Lach-Rob (1996). While the mean value of R&D and investments are very close, the variance of investment is much larger than the one of R&D. This seems to confirm their explanation of technological progress. R&D is undertaken for the expectation of profitable innovations, but a successful innovation occurs randomly. When it occurs, in order to make it exploitable, physical investments become necessary. That is the reason why the variance of investment is much higher than the one of R&D. R&D, indeed, as it is performed just for the expectations of useful innovations, is very persistent:

Corr. $R\&D_t$ $R\&D_{t-1}$	$R\&D_t$	$R\&D_{t-1}$
$R\&D_t$	1	
$R\&D_{t-1}$	0.8963	1

On the other hand, investments, in Lach-Rob and Lach-Schankerman explanation, are performed partly as a consequence to successful innovations. So we should expect a lower autocorrelation in investment rather than in R&D. Indeed in our dataset we find:

Corr Inv_t Inv_{t-1}	Inv_t	Inv_{t-1}
Inv_t	1	

Inv_{t-1}	0.7834	1

This correlation shows that investment is time persistent (Chiao, 2001), but that it is less persistent than R&D. This seems to strengthen the argumentations of Lach-Schankerman and Lach-Rob.

Furthermore, both a dynamic simultaneous system as well as a reduced-form VAR model with our data, using a fixed effects procedure, show a Granger-causality from R&D to physical investment, but not the other way round. The best procedure is probably a Fixed Effects model, as we should disregard all those unobserved factors different from R&D and physical investment. This will let us focus just on the interrelations between them.

A dynamic simultaneous system is a system of two equations:

1) $R\&D_t$ on inv_t, $R\&D_{t-1}$ and inv_{t-1}, so the equation is $y_{i,t}=c+\alpha*x_{i,t}+\beta*y_{i,t-1}+\gamma*x_{i,t-1}+a_i+\varepsilon_{i,t}$, where x_{it} is the physical investment for firm i in time t, y_{it} the R&D of firm i in time t and a_i's the fixed effects.

2) Inv_t on $R\&D_t$, inv_{t-1} and $R\&D_{t-1}$., so the equation is $x_{i,t}=k+a*y_{i,t}+b*x_{i,t-1}+d*y_{i,t-1}+u_{i,t}$, where $u_{i,t}$ is the error term of this second equation.

Fixed-effects (within) regression Number of obs = 736 (298 firms)
R-sq: within = 0.0591 between = 0.6665 overall = 0.6661

R&D	Coeff.	Std. Error	t	P>|t|
invd	.0050462	.0063999	0.79	0.431
R&Ddlag1	.084723	.0361412	2.34	0.020
invdlag1	-.015275	.0041994	-3.64	0.000
_cons	20174.1	856.1953	23.56	0.000

Fixed-effects (within) regression Number of obs = 736 (298 firms)
R-sq: within = 0.1881 between = 0.0213 overall = 0.0502

Inv	Coeff.	Std. Error	t	P>|t|
R&Dd	.2828196	.3586871	0.79	0.431
invdlag1	-.1032823	.0315264	-3.28	0.001
R&Ddlag1	2.159913	.2518057	8.58	0.000
_cons	-13421.17	9649.276	-1.39	0.165

We can see that there is no significant contemporaneous relationship between R&D and investment, but past R&D is significant in explaining current investment, while the opposite seems to hold in a negative fashion. The negative coefficient, anyway, should not scare as it is very small (-0.015). The significance is due to the very low standard error.

On the other hand, past R&D seems to have a very strong impact on current investment. A coefficient of 2.16 seems extremely high. This may be due to a multicollinearity problem. Current R&D and past R&D, indeed, have a correlation ρ=0.8963.

One way to avoid this is using a reduced form VAR model. This approach is very similar to the dynamic simultaneous system, but it avoids using the other contemporaneous variable in estimating each equation. It consists, in other words, in solving the simultaneous system and letting each dependent variable be explained by just the lagged values of itself and the other one.

So we will have:

1) $R\&D_t$ on $R\&D_{t}$-1 and inv_{t-1}, so $y_{,t}=c+a*y_{i,t-1}+b*x_{i,t-1}+\varepsilon_{i,t}$.

2) Inv_t on inv_{t-1} and $R\&D_{t-1}$, so $y_{,t}=c+a*y_{i,t-1}+b*x_{i,t-1}+u_{i,t}$.

Fixed-effects (within) regression Number of obs = 763 (307 firms)
R-sq: within = 0.3604 between = 0.7898 overall = 0.8175

R&D	Coeff.	Std. Error	t	P>|t|
R&Ddlag1	.3272979	.0208918	15.67	0.000
invdlag1	-.0110822	.0042337	-2.62	0.009
_cons	14737.2	620.8094	23.74	0.000

Fixed-effects (within) regression Number of obs = 1156 (443 firms)
R-sq: within = 0.1141 between = 0.5763 overall = 0.5385

Inv	Coeff.	Std. Error	t	P>|t|
invdlag1	.3029921	.0336094	9.02	0.000
R&Ddlag1	.5319937	.1535199	3.47	0.001
_cons	12017.62	4799.954	2.50	0.013

In the reduced-form VAR, which by construction does not consider the contemporaneous relationship between the two dependent variables, we see that the lagged values of each of them are highly significant for its current value, but the core result of the dynamic system still holds: past R&D can explain a part of current investment and this is a one-way relationship.

These results are confirmed even by a fixed effects regression of R&D on only past investments (coefficient: 0.49, t-value: 4.32), while lagged investments (alone) do not show any influence on present R&D (coefficient:-0.004, t-value: -0.54).

4.2. Effects of R&D

As in this dataset I have found quite a strong evidence for Lach-Schankerman and Lach-Rob theses, I will analyze the success indicators of a firm by treating R&D and investments as complements, as they did in their own works.

Fixed effects and not random effects regression will be used, again, because our goal is to focus on the differential impact of the explanatory variables on the success indicators. So the feature of FE of taking away all firm-specific characteristics is not a limitation but a "cleaning device" for our analysis. It lets us focus just on the impact of R&D and physical investments on the success indicators of a firm.

Two of the most common indicators of the success of a firm are the sales growth and the profits. In the following regressions I will deal with both of them and with many modifications of the explanatory variables, in order to have a fuller picture of these relationships. Another success device of a firm is the innovation, but unfortunately it was not possible to have patents data. That is the reason why it was necessary to analyze the impact of R&D directly on sales growth and profits. I had to jump the middle step of the productivity of R&D, normally proxied by the number of patents, and link directly the input (R&D) to the output (profits or sales growth).

Even if they are not shown here, also GLS regressions were run. They gave basically the same results as the FE model, which is probably more suited for our goals. As I aim at analyzing the differential impact of R&D on sales growth and profits, it is better to take away the unobserved effects that affect the success indicators of a firm. This is the reason why only the FE regressions will be shown here. In this regression I estimate the impact of R&D (and physical investments) on sales growth. The model is then $\Delta S_{it}/S_{it-1}=c+\alpha*y_{it-1}+\beta*y_{it-2}+\gamma*x_{it-1}+\delta*x_{it-2}+a_i+\varepsilon_{it}$, where S_{it} are the sales of firm i in year t and, as before, y_{it} is the R&D expenditure and x_{it} the physical investment.

Fixed-effects (within) regression Number of obs = 458 (231 firms)

R-sq: within = 0.0488 between = 0.0036 overall = 0.0003

Sales growth	Coeff.	Std. Error	t	P>|t|
R&D_salesl~1	2.742449	.9094749	3.02	0.003
R&D_salesl~2	-.1148845	.6964183	-0.16	0.869
invdlag1	1.36e-08	2.32e-07	0.06	0.953
invdlag2	-2.52e-07	2.00e-07	-1.26	0.209
_cons	-.0137986	.0450029	-0.31	0.759

Fixed effects method confirms that there is some kind of a positive relationship between sales growth and R&D/sales (Kandybin-Kihn, 2004, Mansfield, 1981). To have a clearer picture, I regressed the sales growth on the *increase* in R&D/sales ratio. The model here, then, becomes $\Delta S_{it}/S_{it-1}=c+\alpha*\Delta y_{it-1}/y_{it-2}+\beta*\Delta x_{it-1}/x_{it-2}+a_i+\varepsilon_{it}$.

Fixed-effects (within) regression Number of obs = 726 (297 firms)

R-sq: within = 0.0393 between = 0.0805 overall = 0.0475

Sales growth	Coeff.	Std. Error	t	P>|t|
R&D_salesg~1	-.0302138	.0073653	-4.10	0.000
inv_salesg~1	.0013853	.0016236	0.85	0.394
_cons	.0597111	.0095533	6.25	0.000

Here we see that an acceleration in the ratio R&D/sales should lower the increase in sales of the following year. A reason for that can be that a firm may invest much in R&D in order to develop some new product or process; after that it achieves the success, it can lower by much its own R&D expenditures and use the innovation to sell more in the market. Also this finding supports the hypothesis that R&D can help in increasing sales.

The other side of the success of a firm are the profits. Here I will analyse the relationship of the ratio profit/sales on past R&D and investments (2 periods).

The model then is: $\pi_{it}/S_{it}=c+\alpha*y_{it-1}/S_{it}+\beta*y_{it-2}/S_{it}+\gamma*x_{it-1}/S_{it}+\delta*x_{it-2}/S_{it}+a_i+\varepsilon_{it}$,

Fixed-effects (within) regression Number of obs = 458 (231 firms)

R-sq: within = 0.0107 between = 0.0097 overall = 0.0013

F(4,223) = 0.60 Prob > F = 0.6620

Profit/sales	Coeff.	Std. Error	t	P>|t|
R&D_salesl~1	.1358546	.2953397	0.46	0.646
R&D_salesl~2	.2431473	.2287758	1.06	0.289
inv_salesl~1	.0404189	.1357984	0.30	0.766
inv_salesl~2	.1158832	.1559487	0.74	0.458
_cons	.02705	.0141658	1.91	0.057

Here we cannot see any significant positive relationship between past R&D and current profits. Running this regression with just one lag (i.e. current profits on past year's R&D and investments – this regression was omitted), the fraction of sales revenues devoted to R&D is *negatively* and significantly correlated with the ratio profits/sales of the following year. This seems to suggest that the best performing firms are the ones that invest less than the average in R&D. These different results can be due to the high collinearity between current and past R&D, as its autocorrelation was near to 90%. Anyway here R&D does not seem to have important impacts on the short term ratio profits/sales. The F-test, furthermore, cannot reject the non-significance of all the independent variables.

The analysis of total profits on total R&D and investments (model: $\pi_{it} = c+\alpha^*y_{it-1}+\beta^*y_{it-2}+\gamma^*x_{it-1} +\delta^*x_{it-2}+a_i+\varepsilon_{it}$) seems, on the contrary, to give different results:

Fixed-effects (within) regression Number of obs = 458 (231 groups)

R-sq: within = 0.3964 between = 0.0772 overall = 0.1224

F(4,223) = 36.61 Prob > F = 0.0000

Profits	Coeff.	Std. Error	t	P>|t|
R&Ddlag1	2.759243	.8181894	3.37	0.001
R&Ddlag2	1.23574	.5017919	2.46	0.015
invdlag1	-.4927913	.1000032	-4.93	0.000
invdlag2	.6866688	.089166	7.70	0.000
_cons	-40967.96	24293.5	-1.69	0.093

Here there seems to be a positive relationship between profits and R&D, but we should be quite prudent. The collinearity between current and past R&D, indeed, was very high and the coefficients seem really large: an increase in 1000 NOK in R&D today should yield 2759 NOK in profits tomorrow. This obviously cannot be trusted. Indeed, if we just use the lags at pace 1 this relationship disappears:

Fixed-effects (within) regression Number of obs = 1194 (458 firms)

R-sq: within = 0.1252 between = 0.4330 overall = 0.2974

Profits	Coeff.	Std. Error	t	P>|t|
R&Ddlag1	-.3229957	.1884672	-1.71	0.087
invdlag1	-.4541422	.0449577	-10.10	0.000
_cons	79988.24	6151.883	13.00	0.000

Also here it is sufficient a slight change in the model, like adding another lagged value, to change the results dramatically. The positive relationship that appeared before now is vanished.

Many other kinds of regressions, that here have been omitted, show no positive relation between profit growth and R&D/sales growth of the previous period (according with Kandybin-Kihn, 2004, and Von Braun, 1996) or between profit growth and R&D/sales of the previous period. Neither with R&D of the past period nor with R&D of the two past periods it is possible to find any relationship between profit growth and R&D/sales. This can seem a “bad” result, but on the contrary it is useful to unveil some of the common places around R&D. Jaruzelski stated that 'success cannot be bought' and our findings confirm his view and his data.

The only variable that seems positively affected by R&D is sales volume. In the high-investing sector, the relationships R&D-success is stronger than in all the sample, but still not always significant. It appears to be positive for the increase in sales, like in all the sample, but also for profitability, even if just at 90% level of significance. While regressing profits on R&D and investments in the high-investing and low-investing sector, we note that R&D, in the most intensive sectors in R&D, seems to have a quite positive effect on profits (even if not at 95% significance level). On the contrary, investments do not seem to have a positive impact. In both sectors R&D had a stronger impact (even if not significant) than investments. In the low-investing one, R&D seems to have a non-positive relationship with profits. Investments also seem not to affect it positively.

In our dataset we find that R&D seems really a weak instrument to achieve success, especially if in such a short horizon of time (two years). It would have been possible to add more lags, but our dataset does not contain the R&D expenditures for years 1996,1998 and 2000. Using three lags would have reduced the dataset only to firms of years 2004 and 2005 (and only to those without missing values). The loss of information would have been too high compared to the advantage of seeing R&D effects for one year more. Furthermore, this would have made worse the problem of multicollinearity between R&D and its lagged values.

Treating these regressions with a fixed effects approach gave similar results to the simple clustered regression, which makes us believe that we did not find any relationship not because of just an econometric bad setting of the model, but because there is really not such a kind of relation. There seems to be no solid relationship between any of the success indicators of a firm (sales, profits, both normalized to sales or not, both in differential or in absolute terms) and past R&D (in all the variants as above). These results accord to literature. The only two significant findings is that R&D/sales seem to help sales growth (like in Kandybin-Kihn, 2004) and that R&D seems to cause the physical investments.

In order to concretely verify the regression results, we can analyze the descriptive statistics of our sample, in relation with the success indicators and R&D. We can also test some of the empirical claims of the literature. An interesting result is that the firms in the bottom 10% in R&D/sales ratio have a worse performance than the others (Jaruzelski, 2005).

all the sample (R&D=0 included)

Variable: PROFIT_SALES

N	4532	Mean	0.02384052
Std Deviation	0.74681682	Variance	0.55773536

all the sample (R&D>0)

Variable: PROFIT_SALES

N	2267	Mean	0.04237385
Std Deviation	0.34727667	Variance	0.12060108

top 10% in R&D/sales

Variable: PROFIT_SALES

N	226	Mean	0.015799
Std Deviation	0.86555876	Variance	0.74919197

mid 10-90%

Variable: PROFIT_SALES

N	1814	Mean	0.04316127
Std Deviation	0.23754608	Variance	0.05642814

bottom 10% in R&D/sales

Variable: PROFIT_SALES

N	227	Mean	0.06253918
Std Deviation	0.09768586	Variance	0.00954253

In contrast with Jaruzelski, we find that the firms with the best profit/sales ratio are the ones that invest *less* in terms of R&D/sales. This result is in relative terms. The result in absolute terms shows the same: the firms with the highest profits are the ones with the less R&D/sales ratio. This is an interesting result, but of difficult interpretation. We must be very careful in drawing conclusions from this. There can be many explanations for such a relationship and the diminishing returns to scale in R&D are not needed to explain it. The lower profits for the most R&D-intensive firms can be due to many factors, among them a higher competition in their sectors, or to other reasons that are not captured in these simple descriptive statistics. This seemingly inverse pattern between R&D and the ratio profits/sales can be a clue for diminishing returns to scale, but it could be just a spurious correlation too. We cannot test each single factor leading to this result, so the conclusions about that must be left for possible future researchs.

3.4 Limitations

All the analysis above has some limitations. In assessing the success indicators I used just the last two values of R&D and investments. As Hall and Scobie (2006) point out, "all the benefits from research done today are not captured and reflected in higher productivity immediately". They claim that we should use longer lags to keep into account it. Alston, Craig and Pardey (1998), in a work on the returns to research, stress the same problem. They underline that any restriction on the lag length is arbitrary and is equal to assume a rapid obsolescence of R&D. These two issues are true, but, in an analysis like ours, adding more lags would worse by much the multicollinearity problem. R&D is very autocorrelated and increasing to three the number of lags could give results difficult to interpretate.

Furthermore, for R&D we have data for each year from 2001 to 2005, but just once every two years from 1995 to 2001. Using three lags would let us analyze just the firms of year 2004 and 2005, with a serious loss in the sample dimension, further than the problem of multicollinearity. A good compromise, given the data we have, is probably using two lags. Obviously, not finding a significant relationship in these regressions does not mean that R&D has no effect on profits or increase in sales. It just shows that in a short time period (two years) the effects are not strong. But if we used a longer lag structure, the effects probably would be even *lower* (Alston et al., 1998). Assessing productivity growth using just few lags of R&D makes the estimates of R&D larger than their true value (ibid.), as productivity growth could be referred to a limited amount of R&D (the expenditures, say, of one or two years before). On the contrary, this productivity growth could be due to projects begun many years before.

Another limitation is related to the analysis of the international trade. Fors and Svensson (2000) showed that, in Sweden, "the vast majority of R&D is undertaken at home, while most of their sales are in foreign markets". This suggests that technologies developed at home are to a large extent exploited abroad. There are some reasons to believe that something similar happens also to Norway. The principal reason is that Norwegian wages are very compressed (the 95^{th} top percentile in the wage distribution has 55000 NOK per month, the 5^{th} percentile 19000 NOK, more than a third of the 95^{th} one) and so the high-educated workers, like the researchers, are relatively cheaper in Norway rather than in other countries. This may suggest that the analysis of Fors and Svensson can be related to Norway too. This finding can introduce a bias: as our data are accounting data, we just have the R&D and sales within Norway. If R&D is performed in Norway but the multinational firms have high sales in foreign countries, we may be *underestimating* the effects of R&D on the succes of a firm. This problem goes in the opposite direction of the lag length issue.

Another limitation comes from Prasad (2004), who noticed that there has been a growing process of internationalization of R&D, where multinational firms set up their R&D centres in different countries away from their home country. We cannot assess this, as we have just the accounting data for Norway. So we do not know whether a firm sets up a R&D centre in another country. If it happens, we may be *overestimating* the effect of R&D on success. The opposite problem (foreign firms that come in Norway only to perform R&D) is avoided, as in the data cleaning phase all the firms that had, in any year, larger R&D expenditures than sales were removed. In order to know whether we are overestimating or underestimating the impact of R&D on the success indicators we should have more detailed data (in particular R&D for each year, foreign sales, foreign R&D centres and, possibly, more years of observations). An analysis of this goes beyond the scope of this work, but it could be an interesting development for future research.

4 Conclusions

I have analyzed a dataset of firms operating in Norway covered since 1995 to 2005. As the largest part of the literature states (Cohen-Klepper, 1996, Klepper, 1996, Klette-Griliches 2000, Klette-Kortum (2001)), I found an almost linear relationship between sales and R&D too, which is at odds with Jaruzelski (2005), who found a decreasing relationship.

Sectorial dummies had an important impact in explaining R&D variance across firms, while time dummies were not significantly different from zero, but even though showed a decreasing trend, according to the descriptive statistics. We also saw the effects of the explanatory variables both on the expected invested amount, provided that it is positive, as well as on the probability of investing.

Past profits never had a significant impact neither on the invested amount, provided that R&D>0 (both using GLS and Random Effects), neither on the probability of investing. This gives additional strength to the argumentation of Lach-Schankerman (1989) and Lach-Rob (1996) on one hand and Kandybin-Kihn (2004) and Wakelin (2001) on the other one. Firms invest in R&D for its expected return and, normally, they do not update their expectations in time (otherwise past successful research, and then profits, should increase current R&D) as the expected return of R&D, the so-called also "effectiveness curve", is very stable within each firm.

Liquidity, on the contrary, shows some importance, in particular on the invested amount. Both in the GLS and in the RE regressions its coefficients was significant, suggesting that liquidity constraints can exist in R&D market. It does not have a significant effect, on the other hand, on the probability of investing. So, basically, if a firm decides to invest, it does because of higher expected returns with respect to its investments and liquidity does not seem a crucial variable. But, having invested, a firm can be cash constrained and could be not able to invest as much as it would like. Firms in the LI seem to rely more on these financial variables than firms in HI, suggesting that they rely more on routines than HI in determining their own R&D expenditures.

We have seen that here it comes the important finding of the foreign dummy: while it has no impact on E[R&D|R&D>0], it has a strong negative impact on the probability of investing. This makes it unfeasible to run a consistent Tobit regression, but also the two-step Heckman procedure has serious problems. The best possible model is then a two-part model, i.e. a probit for the probability of investing and then a regression on the positive R&D. This behaviour of the foreign dummy can have important policy implications and can also suggest the existence of sunk costs in beginning R&D investments (Sutton, 1991, Santos, 2008). A policy aimed at increasing R&D, then, should probably focus more on the sunk part of the costs. On the other hand, the clarity of this finding could seem troublesome for the not significant impact of liquidity in determining the probability of investing, but one explanation is that a firm may decide to invest considering not only the short term liquidity (considered in deciding how much to invest), but the long term expected returns and costs of investing in R&D. If this is the case, it is logical to find that liquidity has an impact on the invested amount but not on the decision whether investing or not.

I analyzed then the relationship between R&D and physical investments. I have found, according to Lach-Schankerman and Lach-Rob, that past R&D can explain an important part of current investments, while the opposite does not hold. We can think to R&D as a random innovation process that, when a successful innovation occurs, in order for it to be profitable, must be embodied in physical capital.

I also moved my attention from the explanations of R&D to the effects of R&D. Unfortunately the dataset did not have any measures of productivity of R&D (for example, patents), so I had to analyze the relationship between R&D and sales growth or profits, without having an intermediate measure of innovation. R&D did not show a solid behaviour in increasing the performance of the firm. The only relationship that was found was with increase in sales, but not with profits nor increase in profits. In the high-investing sector there seems to be a somewhat stronger positive relationship between R&D and firm's success indicators, but rarely statistically significant. At least in the short term, as Jaruzelski states, “success cannot be bought”.

Appendix 1: R&D regression, HI-LI Random Effects regressions

High- investing sectors:

Random-effects GLS regression Number of obs = 373 (123 firms)

R-sq: within = 0.0401 between = 0.2116 overall = 0.0822

R&D	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
profitdlag1	-.0074533	.0161604	-0.46	0.645	-.039127	.0242204
salesdlag1	.0158834	.0040821	3.89	0.000	.0078826	.0238843
moneydlag1	-.0131537	.0086489	-1.52	0.128	-.0301052	.0037978
foreign	23602.51	23256.61	1.01	0.310	-21979.61	69184.63
d1997	28057.88	12928.43	2.17	0.030	2718.619	53397.13
d1999	13115.53	12977.86	1.01	0.312	-12320.61	38551.67
d2001	10544.75	11854.42	0.89	0.374	-12689.5	33778.99
d2002	-3651.969	11677.26	-0.31	0.754	-26538.97	19235.03
d2003	-4726.596	11413.2	-0.41	0.679	-27096.06	17642.86
d2004	378.6389	11754.29	0.03	0.974	-22659.36	23416.63
_cons	21393.9	13371.53	1.60	0.110	-4813.822	47601.62

Low-investing sectors:

Random-effects GLS regression Number of obs = 1131 (402 firms)

R-sq: within = 0.0109 between = 0.6720 overall = 0.4837

R&Dd	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
profitdlag1	.0023235	.002455	0.95	0.344	-.0024881	.0071351
salesdlag1	.0047043	.000248	18.97	0.000	.0042182	.0051904
moneydlag1	.0052266	.0006622	7.89	0.000	.0039288	.0065244
foreign	3431.622	3642.165	0.94	0.346	-3706.891	10570.13
d1997	1369.218	1721.402	0.80	0.426	-2004.667	4743.104
d2001	-2729.61	1687.726	-1.62	0.106	-6037.492	578.2723
d2002	-2607.076	1748.561	-1.49	0.136	-6034.192	820.0411
d2003	-1395.782	1759.568	-0.79	0.428	-4844.471	2052.907
d2004	-1934.631	1786.709	-1.08	0.279	-5436.517	1567.254
d2005	-1083.305	1834.154	-0.59	0.555	-4678.181	2511.571
_cons	6937.753	1957.993	3.54	0.000	3100.158	10775.35

Appendix 2: Probability of investing, HI-LI

High-sector:

Marginal effects after probit

y = Pr(antall_fou) (predict) = 0.70689085

variable	dy/dx	Std. Err.	z	P>|z|	[95% C.I.]		X
pr~dlag1	3.19e-07	.00000	1.86	0.063	-1.7e-08	6.6e-07	41100.1
omsdlag1	4.20e-08	.00000	1.17	0.242	-2.8e-08	1.1e-07	939821
moneyd~1	-1.31e-07	.00000	-1.91	0.056	-2.7e-07	3.2e-09	-32110.4
foreign*	-.2741765	.08784	-3.12	0.002	-.446337	-.102016	.258621
d1997*	.1022135	.06354	1.61	0.108	-.022327	.226754	.122414
d1999*	-.0034989	.07665	-0.05	0.964	-.153721	.146724	.117241
d2001*	-.0110713	.06571	-0.17	0.866	-.139865	.117723	.160345
d2002*	.012208	.05894	0.21	0.836	-.103321	.127736	.177586
d2003*	.0385301	.05877	0.66	0.512	-.076649	.15371	.184483
d2004*	.0152951	.0442	0.35	0.729	-.071339	.101929	.12931

Low-sector:

Marginal effects after probit

y = Pr(antall_fou) (predict) = 0.53212854

variable	dy/dx	Std. Err.	z	P>|z|	[95% C.I.]		X
pr~dlag1	3.33e-07	.00000	1.78	0.074	-3.3e-08	7.0e-07	38854.8
omsdlag1	9.22e-08	.00000	3.41	0.001	3.9e-08	1.5e-07	828797
moneyd~1	-7.76e-08	.00000	-1.17	0.243	-2.1e-07	5.3e-08	-56193.6
foreign*	-.0581538	.05138	-1.13	0.258	-.158855	.042547	.184169
d1997*	-.0705581	.03708	-1.90	0.057	-.143226	.00211	.149165
d1999*	-.1736018	.03733	-4.65	0.000	-.246775	-.100429	.110581
d2001*	-.0719919	.03225	-2.23	0.026	-.135194	-.00879	.165076
d2002*	-.1018752	.0313	-3.25	0.001	-.16323	-.040521	.160302
d2003*	.0067492	.02823	0.24	0.811	-.048585	.062084	.15712
d2004*	-.0010853	.02246	-0.05	0.961	-.045108	.042937	.130867

Appendix 3: R&D/sales regression, Random Effects

Random-effects GLS regression Number of obs = 1507

Group variable: org_nrn Number of groups = 525

R-sq: within = 0.0540 between = 0.1551 overall = 0.1851

fou_sales	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
profitdlag1	-8.22e-09	5.56e-09	-1.48	0.139	-1.91e-08	2.68e-09
omsdlag1	4.18e-11	6.11e-10	0.07	0.945	-1.16e-09	1.24e-09
moneydlag1	-1.90e-09	1.69e-09	-1.12	0.261	-5.22e-09	1.42e-09
foreign	.0196708	.0083977	2.34	0.019	.0032116	.03613
chemical	.0243902	.0136868	1.78	0.075	-.0024355	.0512158
office_cm~r	-.0664212	.0358263	-1.85	0.064	-.1366394	.003797
electric_a~s	.0357636	.01663	2.15	0.032	.0031694	.0683578
radio_comn	.0965225	.0179911	5.37	0.000	.0612607	.1317844
medical_pd	.0609496	.0181012	3.37	0.001	.0254719	.0964274
sea_transpt	.0413294	.0180987	2.28	0.022	.0058565	.0768022
post_telecom	.0348776	.0178586	1.95	0.051	-.0001245	.0698798
data_proce~g	.1056897	.0141832	7.45	0.000	.0778911	.1334882
d1997	.0087397	.0040357	2.17	0.030	.0008299	.0166494
d1999	.0060639	.0042603	1.42	0.155	-.0022861	.0144139
d2001	.0043173	.0035988	1.20	0.230	-.0027363	.0113709
d2002	.0024437	.0036429	0.67	0.502	-.0046963	.0095838
d2003	.0074101	.0035805	2.07	0.038	.0003925	.0144277
d2004	.0037365	.0034529	1.08	0.279	-.0030311	.0105041
_cons	.0093818	.0079166	1.19	0.236	-.0061344	.024898

Appendix 4: Effects of R&D, HI-LI

High-investing sectors:

Fixed-effects (within) regression Number of obs = 120 (59 firms)

R-sq: within = 0.1741 between = 0.0194 overall = 0.0434

profitabil~d	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
foudlag1	1.558066	.8213446	1.90	0.063	-.0866479	3.20278
foudlag2	1.233069	.7357252	1.68	0.099	-.2401948	2.706334
invdlag1	-.1924995	.126459	-1.52	0.133	-.4457293	.0607303
invdlag2	.1716694	.0987467	1.74	0.088	-.0260675	.3694063
_cons	36818.07	43251.4	0.85	0.398	-49791.37	123427.5

F test that all u_i=0: F(58, 57) = 15.44 Prob > F = 0.0000

Low-investing sector:

Fixed-effects (within) regression Number of obs = 338 (173 firms)

R-sq: within = 0.6122 between = 0.0013 overall = 0.0868

F(4,161) = 63.53

corr(u_i, Xb) = -0.7010 Prob > F = 0.0000

profitabil~d	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
foudlag1	.1347367	1.470934	0.09	0.927	-2.770076	3.039549
foudlag2	-1.780081	.6818795	-2.61	0.010	-3.126662	-.4335
invdlag1	-.7235185	.1979282	-3.66	0.000	-1.114389	-.3326483
invdlag2	.7938411	.1610583	4.93	0.000	.4757818	1.1119
_cons	54396.3	32230.9	1.69	0.093	-9253.53	118046.1

F test that all u_i=0: F(172, 161) = 2.57 Prob > F = 0.0000

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