Paper no. 2008/01

R&D and financial systems: the determinants of R&Dexpenditures in the Swedish pharmaceutical industry

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http://www.circle.lu.se/publications
ISSN 1654-3149

WP 2008/01
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Keywords: R&D expenditures, R&D investments, innovation, financial systems, bank based system, market based system, pharmaceutical industry, Sweden.

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Abstract
This study investigates the determinants of R&D expenditures in the Swedish pharmaceutical industry from the 1960s to the mid 1990s. Various proxies for the rate of return of R&D (e.g. expected profit, sales and R&D productivity) as well as the availability of internal funding (proxied by past cash flows) have been used as explanatory variables in time series regressions. Past cash flow comes out as significant in regressions both at industry level and at firm level (made for each of the two largest companies). Another factor that is significant in most cases is expected sales. However, productivity of the R&D process does not seem to influence R&D expenditures. A comparison of these conclusions with studies of the pharmaceutical industries in countries with different financial systems; the US (with a market based financial system) and Japan (with a more bank based financial system) shows that Sweden (also leaning towards a bank based financial system) has the insensitivity to R&D productivity in common with Japan. This may be interpreted as these industries' are taking a 'longer term view' on their research than the US'. The sensitivity to cash flow, however, is possibly more pronounced in Sweden than in Japan and suggesst an important role of internal financing of R&D.

Introduction

The impact of the financial system on economic growth has been discussed for a long time (Levine 2002). This study does not deal directly with growth, but focuses on the possible influence of financial systems on R&D investments[2]. Although the relation between R&D investments and growth is not always direct, such investments are still important for growth in the long run. The study looks at the characteristics of the Swedish pharmaceutical industry and compares the conclusions with previous studies of pharmaceutical industries in two different financial settings, the US and Japan. The pharmaceutical industry has been chosen

[1] I thank Martin Andersson (CESIS and CIRCLE), Olof Ejermo, Jonas Gabrielsson and Lennart Schön (all CIRCLE) for helpful comments.
[2] The literature tends to use R&D investments and expenditures interchangeably, the latter being the sum of operational R&D expenditures and investments in scientific equipment etc. This will also be done in the introduction of this paper. Later, in the empirical section, a more stringent division between operational expenditures and investments in equipment will be made.

since it relies heavily on formal R&D for its product development. As all of the pharmaceutical companies in this study conduct R&D, the study does not deal with the question whether to engage in R&D activities or not, but is rather studying factors determining the dynamics of the R&D investments.

There is a large literature regarding the factors determining the level of investment in general. Apart from market demand, the focus is generally on the sourcing of funds for the investment and in particular the use of internal funding (retained earnings or cash flow). The studies typically find a correlation between investment in physical capital and the availability of internal funds (Hubbard 1998). Since the theoretical explanations for this relation is largely based on information asymmetries between firms and external financiers the linkage has been assumed to be even more pronounced for R&D investments than for physical investments since the former type of investment is more risky than investments in fixed assets. In addition, it is also more difficult to collateralize. This is also what the empirical literature on the determinants of R&D investments (surveyed by Hall 2002) concludes. Debt is a disfavored source of funding for R&D. Instead this type of investment is sensitive to cash flow variations and the sensitivity is often greater in market based economies (e.g. USA) than in bank based (e.g. France, Japan) (Mairesse et al.1999). This is attributed to that the information asymmetries are smaller when firms and banks have trustful and long standing relations. The sensitivity of R&D investments to cash flow is often seen as a sign of that firms are financially constrained due to financial market imperfections. Studies also show that small hi-tech firms are particularly vulnerable to such imperfections (Himmelberg and Petersen 1994). This implies a potential underinvestment in R&D and that research opportunities consequently may not be fully exploited. On the other hand Bond et al. (2003) do not find cash flow sensitivity for R&D investments either in the UK or in Germany. They mean that this is due to high adjustment costs since a large part of R&D expenditure is wages for highly qualified staff that cannot be hired or fired fast and that firms that decide to engage in R&D have made this decision knowing that they are not financially constrained.

Many studies of the cash flow effect on R&D have been made for aggregated industries, e.g. the entire manufacturing industry or a main branch. There are however a number of studies investigating the pharmaceutical industry specifically (Table 1).

A key stream originates from Grabowski (1968) who studied the determinants of R&D expenditures in the US chemical, drug and petroleum industries. The framework used in this cross-sectional study was later refined in subsequent panel data studies by Grabowski and Vernon (1981, 1997, 2000) looking specifically at the US pharmaceutical industry. Vernon (2004, 2005) follow the same principles but make use of data for the top-selling pharmaceutical firms world-wide.[3] Recently, Mahlich and Roediger-Schluga (2006) have used the Grabowski and Vernon framework to contrast the Japanese pharmaceutical industry, as an example of an industry in a bank based economy, with the US industry in a market based setting. The Grabowski and Vernon framework also forms the basis for the present study, although the empirical application is modified to use time series regressions.

Giacotto et al. (2005) performed time series regressions on industry level to enable firms diversification into non-pharmaceutical R&D to be excluded. They used the lagged price of drugs relative to other products as a proxy for past cash flow and found that this parameter had a significant impact on R&D expenditures.

[3] Among the 30 top-selling companies in 1993, 12 were US firms and 18 were non-US firms (Chandler 2005:15)

Table 1. Studies of cash flow effect on R&D investment in the pharmaceutical industry.

Study	Country	Period	Type of data
Grabowski 1968	US	1959-1962	Cross sectional
Grabowski and Vernon 1981	US	1962-1975	Panel data
Scherer 1996	US	1962-1991	Time series
Grabowski and Vernon 1997	US	1974-1989	Panel data
Grabowski and Vernon 2000	US	1974-1994	Panel data
Scherer 2001	US	1962-1996	Time series
Achilladelis and Antonakis 2001	US	1950-1989	Panel data
Vernon 2004	Top-40 firms worldwide[a]	1994-2001	Panel data
Giacotto, Santerre and Vernon 2005	US	1952-2001	Time series
Vernon 2005	Top-30 firms worldwide[a]	1994-1997	Panel data
Mahlich and Roediger-Schluga 2006	Japan	1987-1998	Panel data

[a)] A smaller number of these firms were excluded in the analysis due to data limitations.

Scherer (1996, 2001) noted that aggregated US pharmaceutical R&D expenditure correlates with cash flow variations and suggest that the pharmaceutical industry follows a 'virtuous rent-seeking model', in which firms compete to exploit research opportunities until supranormal profit returns are more or less dissipated. He did not attempt to separate the role of cash flow as a source of funding and the role as a proxy for profit expectations. The same is valid for Achilladelis and Antonakis (2001) who made separate regressions for the larger US companies having sales and net profits as proxies for cash flow. Both Scherer and Achilladelis and Antonakis found significant correlations between R&D expenditures and cash flow.

As can be seen in Table 1, which lists the studies of the cash flow effect in the pharmaceutical industry, most studies have been concerned with the US. The studies of world-wide companies, which would include a number of non-US firms, have been based on quite recent data. Japan is the only other country that has been studied specifically.

The aim of the present study is to contribute to the theoretical discussion about determinants of R&D activity by examining the R&D investments of the Swedish pharmaceutical industry from the late 1960s until the mid 1990s.[4] Time series regressions are made for the Swedish pharmaceutical industry for the period 1967-1995 as well as for two of the major groups of companies. The motivation for the study is that there are a number of factors that may potentially counteract the theoretical expectation of cash flow sensitivity. The Swedish economy could be classified as a bank based system according to a ranking made by Levine (2002) and that would point towards less sensitivity of cash flow. Also, the tax system exhibited some peculiarities that were different from many other countries. The corporate tax rate was very high in Sweden until the 1990s, but there were a number of ways to make allocations for future investments that would lower the tax rate. Such allocations and their subsequent use for investments would lower the immediate sensitivity to cash flow. These contingencies call for a closer examination of determinants of R&D expenditures in the Swedish context. The contribution of the present study's contribution is therefore to provide results for another bank based country, in addition to Mahlich and Roediger-Schlugas's study of Japan, and for a longer time period, as well as putting the conclusions in relation to the previous studies.

[4] In this period the Swedish pharmaceutical industry was dominated by medium to large maturing companies. Start-ups did not play a significant role.

The rest of the paper starts with the theoretical foundations of cash flow sensitivity of R&D expenditures. The empirical section then discusses some methodological issues followed by the result of industry level and firm level regressions. A final section discusses the conclusions.

Theory

It is generally assumed that R&D expenditures are dependent on the returns to R&D activities (which include research opportunities and possibilities for spillovers from other companies) and the cost of funding the research. It is also often found that internal funding is favored as a source of funds for research, and, as was noted above, several studies have found a relation between R&D expenditure and past cash flow. The theoretical reasons for this are described below (Hall 2002).

R&D financing

R&D is different from investments in physical assets in a number of ways. A large part of the R&D expenditures consist of wages for highly skilled staff that are both difficult to recruit and to fire. Since the output of their work is knowledge which to a large extent is embodied in the researchers, firing R&D staff may lead to an undesired transfer of staff and knowledge to competitors. Consequently, R&D expenditures tend to be smoothened out compared to ordinary investments. There is also a much higher degree of uncertainty of the results of investments in R&D projects than in investments in physical production equipment.

Since the knowledge produced in the R&D process is non-rival and may potentially spill over to others, there will be an underinvestment in R&D unless there are ways to protect the knowledge from being used by competing firms (through patenting, secrecy, etc.). But even if that problem is overcome, there is likely to be an additional issue that may cause too low R&D investments. Since R&D projects are risky, the firms conducting the R&D would have more information about the probability of success than an external financier, for instance a bank or potential holders of new equity. This would lead to a higher cost of external funds for R&D investments than cost of internal funds (retained earnings). This is an imperfection of the financial markets and would contradict the predictions of Modigliani and Miller (1958) that the optimal investments levels should be indifferent to the choice between internal and external funding.

Asymmetric information between inventor and external financier is the most salient issue causing external capital to be more expensive than internal. To the extent that the outcome of R&D projects are at all predictable, the firm conducting the research has substantially more information than any external supplier of funds, either banks or purchasers of new equity issues. In addition, firms are likely to be reluctant to disclose information regarding their research projects since the information may reach competitors, and hence lower the potential value of the project. This leads to that the market for R&D projects may be very limited or even non-existent. Venture capital is often seen as one way to create such markets.

There may also be a split of interest between shareholders and managers creating a *moral hazard situation.* Managers may to be more risk averse than shareholders[5] since the managers have heavily invested their human and reputational capital in one company. Relying on

[5] This is another type of principal-agent problem than the more common tendency for managers to grow the firm beyond efficient scale or spend money on nice offices (Hall 2002).

retained earnings for highly uncertain R&D projects may be a way to avoid a risk level for the company that is too high for the managers' taste. On the other hand, reliance on internal funding is not necessarily a sign of moral hazard. It may well be that owners are risk averse in this sense as well.

Banks tend to prefer *collateral* for their lending that easily could be sold and redeployed, should it be necessary. R&D, or rather the resulting knowledge, is often very difficult to redeploy, even in the presence of patents or other more tangible assets. This would make banks reluctant to finance R&D projects and therefore make it more costly to borrow for that purpose.

Some countries, for example the US, have had special *tax relief* for investments in R&D. Such rules would make internal funding more favorable compared to debt and new equity financing. Other countries, such as the UK, have not got such rules. Sweden, the subject of the current study, did also have some special tax features, in particular the possibility to make tax exempt allocations for future investments. The so-called investment funds (*investeringsfonder)* introduced in 1955 and finally abolished in 1996, where money was deposited in a special account of the Swedish central bank, was one such possibility.

The difference in costs of internal versus external financing is likely to be especially large in the pharmaceutical industry due to the very high uncertainty of the outcome of R&D projects and the long development time for new drugs. The effects of the information asymmetry is also likely to be particularly pronounced in pharmaceuticals since a new successful drug may yield extremely high returns, so the incentives to keep information about the projects secret are very high.

Influence of the financial system

There has long been a discussion whether so-called market based financial systems (typically represented by USA and the UK) or bank based systems (with Japan, France and Germany as typical examples) are more conducive to innovation. Proponents of the bank based view argue, among other things, that the long-standing relations between firms and their banks reduce some of the financial market imperfections mentioned above. The information asymmetry is reduced and closer monitoring reduces the risk of moral hazard on behalf of the management against the owners. The need to publicly disclose sensitive information regarding research projects is also reduced.

Proponents of the market based view, on the other hand, point at the risk of banks favoring established companies with which they have strong ties. In addition there are views that argue that both banks and markets are important and that the key parameter is how developed the financial systems are overall. It would lead too far to review all arguments for the different views here. Levine (2002) provides an overview. However, the investigation of whether the R&D investment in the Swedish pharmaceutical industry is sensitive to cash flow variations is made in this institutional context. That is also the focus of Mahlich and Roediger-Schluga's (2006) study of the Japanese pharmaceutical industry mentioned in the literature review.

Looking at the aggregate ranking of the financial structure in different countries, based on data for 1980-95 by Levine (2002)[6], the market based US and UK economies hold the fourth and fifth position, respectively. Sweden, ranked number eleven, ends up between Japan (ranked number eight) and two other examples of bank based systems, Germany in position

[6] The measure used is called "Structure-Aggregate" and is composed of indicators for activity, size and efficiency of stock markets vs. banks.

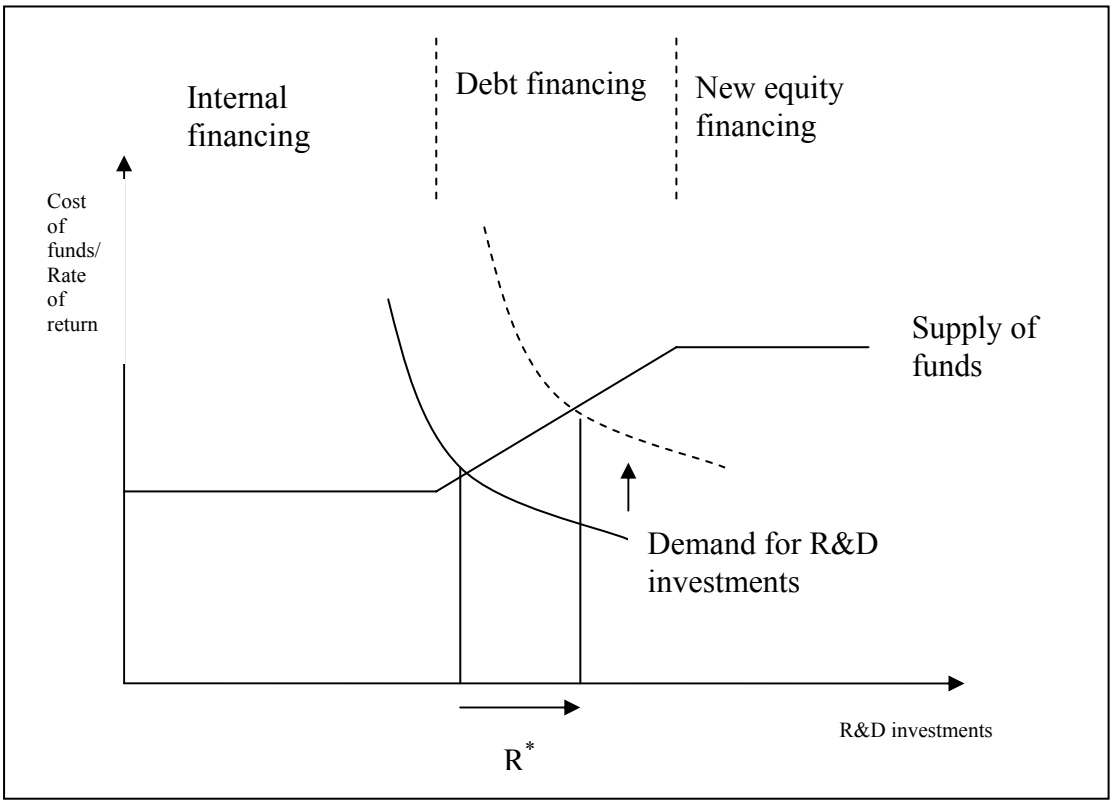
22 and France in position 29. This may point to that the cash flow sensitivity would be small or non-existent in Sweden. In addition, there were the mentioned possibilities in Sweden for companies to lower their tax by making allocations for future investments. That could also contribute to lowering any cash flow sensitivity.

Optimal level of R&D investment

Following Grabowski and Vernon (2000), the determination of the optimal level of R&D investment (R^*) according to basic economic theory depends on the marginal rate of return on the investment (mrr) and the marginal cost of capital (mcc).

The mrr-curve (demand for R&D investments) is derived by arranging potential R&D projects in order of decreasing return, and forms a demand curve for R&D. The mcc-curve is the curve describing the supply of funds and is reflecting the opportunity cost of alternative investments for the firm. Figure 1 show these curves graphically. As has been argued above, there are good reasons why internal financing should be cheaper than both debt and new equity. However, at some point internal funds are exhausted and need to be complemented by debt. This point is shown in the figure by the mcc curve bending up towards higher cost of capital. New equity is likely to be the most expensive form due to the information asymmetry between firm and new shareholders and the mcc curve flattens out at this level when the borrowing is replaced by new equity.

Figure 1 Determination of the optimal R&D investment level, demand curve shift.



Source: Adapted from Grabowski and Vernon (2000).

The optimal level of R&D investments R^* is found by solving:

$$mrr(R, \mathbf{X}) = mcc(R, \mathbf{Z}) \quad (1)$$

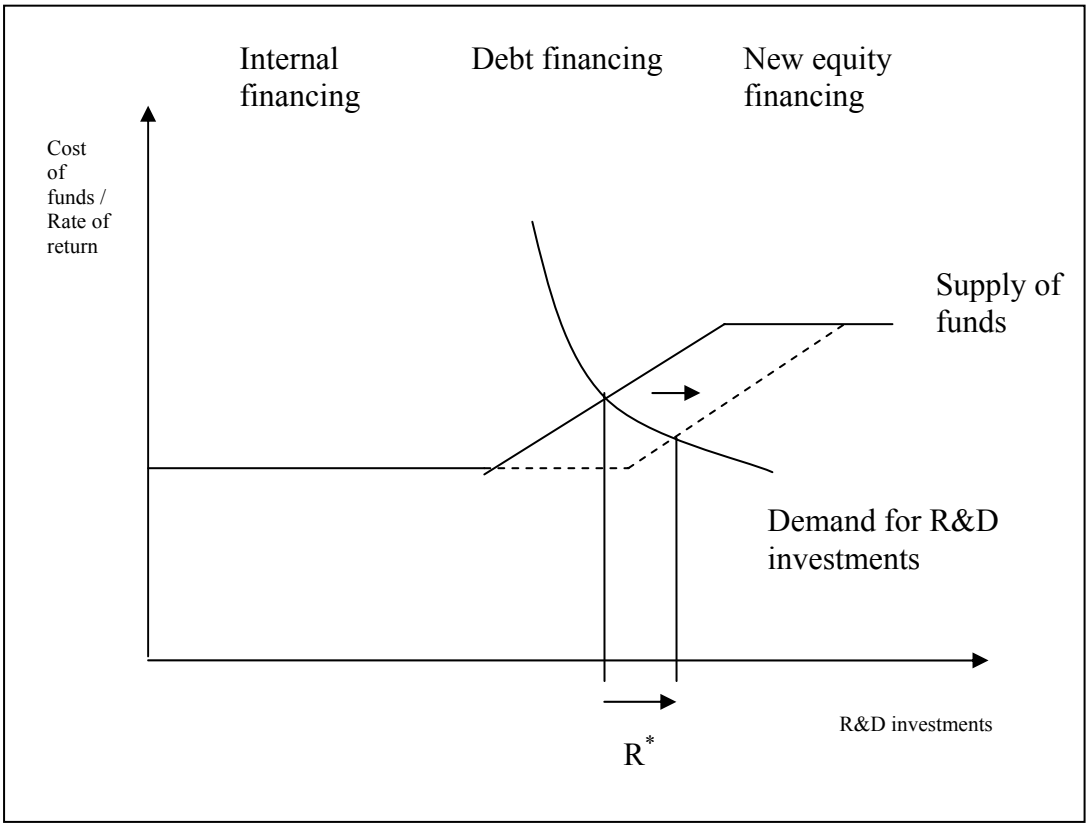
where R is R&D investments, **X** is a vector of variables influencing the return from new drug R&D, and **Z** a vector of variables influencing the cost of capital, i.e. the opportunity cost of investing in new drug R&D. The optimal level can be expressed in a reduced form as a function of **X** and **Z**.

$$R^* = f(\mathbf{X}, \mathbf{Z}) \quad (2)$$

Increased returns to R&D shift the demand curve outwards and results in a higher optimal R&D level (Fig.1). However, an increased optimal level will also be the result of increased availability of internal funds. The sloping part of the supply curve is then shifted outwards as is shown in Figure 2. It is such shifts that form the theoretical explanation behind cash flow sensitivity of R&D investments. It should be noted, thought, that if there is an abundance of internal funds compared to the demand for R&D investments (i.e. the demand curve crosses the supply curve well to the left of the sloping part) the optimal level will not be affected by shifts of supply of internal funds (Hall 2002).

Hence, a sensitivity of the level of R&D investments to the availability of internal funds (cash flow) may potentially be interpreted as a sign of financial constraints. However, it is also a sign that internal funds are important for R&D.

Figure 2 Determination of the optimal R&D investment level, supply curve shift.



Source: Adapted from Grabowski and Vernon (2000).

Empirical analysis

Time series vs. panel data

This study uses time series econometrics to investigate the determinants of R&D expenditures based on the theory in the previous section. The majority of earlier studies have been using panel data (Table 1)[7]. It is clear that panel regressions offer advantages in terms of controlling for firm specific effects. On the other hand, the panel studies typically cover a relatively short time period. The Swedish pharmaceutical industry is small in terms of the number of firms. Over time the thirteen more substantial firms merged to become two major groups and one smaller company. Unfortunately, it has only been possible to retrieve detailed firm level data for the largest firms. The solution used in this study is instead to make time series regressions on industry level data, but to complement this analysis with separate time series analyses of the two major groups (Astra and Fortia/Pharmacia). The industry level data has been taken from Statistics Sweden's Business Statistics[8] (*Företagsstatistiken*). It should be noted that the firm data for the large companies are not strictly a subset of the Business Statistics, since the latter is covering the Swedish firms only, while the former also includes the companies' overseas subsidiary firms as well as non-pharmaceutical activities.

The firms included in the industry level data are quite homogenous, though. To be included in the statistics for the pharmaceutical industry, the firms are required to have 60% or more of their turnover from pharmaceuticals (SCB Business Statistics 1971:33).

Measuring returns to R&D

The literature that deals with investments in a broader sense and over a wide range of industries has often used Tobin's Q as a measure of investment opportunities (Hall 1992). Tobin's Q is in this context the ratio between the market price of a company (stock market value) and the replacement value of its capital and knowledge stock. This measure is not entirely unproblematic and may be affected by excessive volatility in stock markets as well as difficulties to estimate the capital stock (especially with regards to knowledge). Also, which is problematic for applications to the pharmaceutical industry, the measure assumes perfect competition in the product and factor markets (Hubbard 1998: 202). Perfect competition is generally not the case in pharmaceuticals since products are typically protected by patents and trademarks and various forms of price controls may be applied. Maybe partly because of these issues, the literature that more specifically deals with R&D in the pharmaceutical industry tends to use measures for the returns to R&D instead.

Many studies of the pharmaceutical industries have used the turnover of new products (typically the products launched in the last five years) divided by lagged real R&D expenditure as a measure of the returns to R&D, sometimes labeled 'R&D productivity'.[9] As is evident from the definition, this is a measure of the 'productivity' of the R&D process only. It should not be confused with the productivity derived from standard production functions including labor and capital.

Sufficient information regarding yearly sales per new product has not been possible to obtain for this study, and a measure based on patent citations is used instead. The number of

[7] The time series regressions in Table 1 typically use first differences of logarithms while the panel studies use level.
[8] The Business Statistics are aggregated firm level statistics.
[9] Grabowski (1968) used an average of the number of US patents divided by R&D staff instead.

citations received by patents from subsequent ones (so-called forward citations) has been shown to reflect the economic value of patents, particularly in pharmaceuticals (Lanjouw and Schankerman 2004, Harhoff 1999, Trajtenberg 1990, Hall et al. 2005). Since the new product sales are intended to reflect the value of new products, patent citations can be used as a proxy for new product value since most pharmaceutical products are patented.[10] The citation measure being closely related to *patented* products is an advantage, since these are more closely tied to R&D activities, as opposed to the sales of new products which may partly be attributable to imitative or licensed products that are less closely linked to R&D. The risk of a close correlation with total sales is also lower with a citation based measure than a measure based on sales of new products.

The total number of forward citations for the Swedish pharmaceutical firms' patents in the US (including subsidiaries) has been calculated annually and then been divided by the real R&D expenditures in the previous year (*t-1*).

It has not been possible to perform a complete comparison between this citation based productivity and the corresponding R&D productivity based on new product sales. However, a coarse comparison has been done for the largest company, Astra. New product sales were defined as the deflated sales sum of all top selling products launched in the last five years (*t* to *t-4*)[11]. In the same way as for the citation based productivity measure, this sum was divided by real R&D expenditures in the previous year. For the most part the comparison roughly makes sense. There is, however, one clear deviation. In the citation based productivity a distinct upturn occurs around 1992, which is about three years later than in the turnover based measure. The upturn is caused by Astra's highly successful ulcer drug *Losec*, which was launched in 1988. It has therefore been investigated in different ways if this deviation could cause the regression results to differ, but that does not seem to be the case.

Many different versions of the R&D productivity measure in terms of lags and averages have been tested in regressions, giving similar results. The one presented in the paper has been chosen based on the time between patent application and product launch. It has been shown in a previous paper (Malmberg 2007) that the US application on average is submitted two years after the application in Sweden for a national patent. If a three year period is assumed between the Swedish application and product launch, then the US application occurs one year before launch (i.e. *t-1*, if *t* is the product launch year). The number of forward citations for patents belonging to Swedish pharmaceutical firms (including subsidiaries) that year was adjusted using the fixed effects method described in Hall et al. (2001)[12], and then divided by the industry's real R&D expenditure in the previous year (i.e. *t-2*).

'Normalization' of R&D expenditures

Previous studies have often, but not always, in effect 'normalized' the R&D expenditures with either the capital and knowledge stock (in the case of Tobins Q) or sales[13] (as in most studies

[10] The pharmaceutical industry is using patenting more than any other industry for their product innovations (Arundel and Kalba 1998). The importance of patents in this industry is due to the relatively short time and low cost of copying drugs (Levine et al. 1987).

[11] Top ten lists were used. Not all years have been available and the comparison is therefore far from complete. Astra (1982, 1984, 1991, 1997), AstraZeneca (2006), Sundling (2003:282).

[12] The adjustment corrects for systematic problems related to the use of citation data (see Hall et al. 2001). The adjustment factor for technological category 3 (Drugs & Medical) in Table 2a in Hall et al. (2001) was used.

[13] This means that the dependent variable becomes R&D-to-sales. Some independent variables are also divided by sales (e.g. cash flow-to-sales, profit-to-sales), while R&D productivity is not.

of pharmaceuticals). Normalization offers clear advantages in cross-sectional or panel studies since it tends to reduce heteroscedasticity (Hall 1992). Since there has been less need for such reduction in the time series regressions of this study, the R&D expenditures have not been normalized, but sales have instead been used as an additional independent variable. This gives more freedom since the relation between R&D and sales value is not fixed. Versions having R&D/sales as the dependent variable did not yield any significant results. There are, however, no theoretical reasons why R&D-to-sales should be a more appropriate variable than real R&D expenditures.

Industry level regressions

The Swedish pharmaceutical started to conduct formal R&D in the 1930s. Despite the success of a couple of original products in the 1940s (e.g. the tranquilizer Xylocain from Astra and the anti-inflammatory drug Salazopyrin from Pharmacia), the industry relied to a large extent on less innovative products until the 1960s. However, the stricter safety regulation enforced in the mid 1960s after the Thalidomide disaster made the industry to focus their efforts. There was a clear shift from the quantity of new products to higher quality (Malmberg 2007).

The data in the industry level part of this study is based on Statistics Sweden's Business Statistics (SCB Business Statistics 1966-83, SCB 2007). These statistics are based on firm level data that is aggregated per industry. As was mentioned earlier, a firm needs to have at least 60 % of its turnover from pharmaceutical products to be included in this statistics under the pharmaceutical industry category. The pharmaceutical division of the arms manufacturer Bofors is therefore not included, but this only had a 3% share of the Swedish pharmaceutical turnover in 1968 (Ehrlén et al.1999: 114) and was taken over by Astra during the 1970s. The statistics cover all firms with more than 50 employees. The threshold was 20 employees during parts of the period, but since the industry output is dominated by a small number of medium size and larger firms, the data is not very sensitive to such changes. Missing survey responses have been imputed by Statistics Sweden using data from the annual report of the missing firm. Smaller firms have been sampled. For the period 1984-96 unpublished statistics corresponding to the Business Statistics have been provided by Statistics Sweden.

The R&D data is taken from Statistics Sweden's R&D Statistics (SCB Research Statistics 1969-97). Data on R&D expenditure started to be collected in 1965, and is available for the pharmaceutical industry from 1967. The R&D statistics and business statistics are coordinated from 1973 in terms of the firms included. However, since the pharmaceutical industry has been dominated by a set of medium and large companies that have all been surveyed, it seems reasonable to assume that the two statistics are comparable also before 1973 since any differences are likely to concern smaller firms that would not influence the aggregate numbers very much.

The overall investments in R&D are for the most part expensed in the accounts. Swedish law has in principle allowed R&D to be treated as immaterial assets, but that has seldom been utilized in practice (SFS 1976:125 §17, ÅRL 4 kap §2, Artsberg 2005:235-9, 374). Statistics Sweden's R&D Statistics offer both 'operational costs'[14] and 'investments'. The latter mainly

[14] Excluding capital costs. (Capital costs are only given for 1967-1979 in the statistics)

consists of buildings and certain equipment. In the period of this study, such investments fluctuated around 15 % of the sum of operational costs and investment.

The industry level regressions are based on R&D expenditures (i.e. the sum of operational costs and investments). The R&D surveys of the R&D Statistics are conducted every second year. However, estimated figures for the intermediate years are available for most years before 1974. These have been used as far as possible and linear interpolation has been used for the remaining missing years. The expenditures have been deflated by a GDP deflator based on the Swedish Historical National Accounts (Krantz and Schön 2007).[15]

Regression equation

The basic regression equation is based on first differences of logarithms.

$$\Delta \ln(R_t) = \beta_0 + \sum_{i=0}^{3} \beta_{i+1} \Delta \ln(CF_{t-i}) + \beta_5 \Delta \ln(PROFIT_t) + \beta_6 \Delta \ln(RPROD_{t-1}) + \beta_7 \Delta \ln(SALES_t) + \varepsilon_t \quad (3)$$

where $\Delta \ln R_t = (\ln(R_t)-(R_{t-1}))$, R_t = real R&D expenditures in year t, CF_{t-i} = expected real cash flow in year t as well as past cash flow in years *(t-1)* to *(t-3)* , $PROFIT_t$ = expected real profit in year t, $RPROD_{t-1}$ = R&D productivity in year *t-1* and $SALES_t$ = expected real sales in year t. Note that the word 'expected' refers to the expectations at the end of year *t-1* (when the decision on R&D expenditures for year t is taken) for the result at year t's end. In addition to the terms above, two autoregressive terms have been included in the one of the estimations.

Unlagged cash flow *(CF_t), $PROFIT_t$* and $SALES_t$ can be regarded as proxies for the expected profits and forms, together with the R&D productivity ($RPROD_{t-1}$) the **X**-vector in Equation 2. The cost of capital (the **Z**-vector in Eq.2) depends on the availability of internal funding and is proxied by the past (lagged) cash flows.

Since the reason for conducting R&D is to generate profits which in turn may influence future R&D expenditures, there is a theoretical endogeneity between R&D and profit variables. However, this is unlikely to seriously affect the regression results since the link from R&D expenditures to profits is extremely blurred by the often very long and uncertain research and development process in the pharmaceutical industry (on average 8-10 years between the start of research and commercialization for more radical innovations, Achilladelis 1999:20).[16] The linkage in the other direction, from profits to R&D expenditures, is much more direct since it concerns yearly budget decisions, and can therefore be well captured by the yearly variations in the regression.

Profits

The Swedish tax rules makes the measurement of profits somewhat complicated. The Swedish corporate tax was very high before the 1990s (52 %, Ekonomifakta 2007), but there were many ways to reduce tax through allocations and other accounting methods. However, that also leads to artificially low *net profits.* It was therefore argued at the time that the profit

[15] GDP deflators are often used for R&D expenditures in the absence of more elaborated deflators for R&D (Griliches 1979).

[16] There is no significant correlation in the current data set between first differences of logarithms of profits, cash flow and sales, respectively, as dependent variables and the terms in a sum of first differenced logarithms of R&D expenditures (as independent variables). Up to six years lag were included in these tests.

before such allocations and tax was the most appropriate measure of profit in the pharmaceutical industry (Fortia 1982:9-11). That is also the measure that has been used in this study.[17] The profits have been deflated using the mentioned GDP deflator.

Cash flow

Unlagged cash flow is both as a measure of profit expectations (before paying R&D expenditures) and a source of funds. To avoid exaggerating the cash flow sensitivity, the unlagged cash flow has been treated purely as a profit expectation variable in this study. Only the *lagged* cash flows have been regarded as potential sources of funding for R&D, and hence affecting the cost of capital.

Cash flow has been calculated as profit before allocations and tax, plus depreciation, minus tax, plus after tax R&D expenditure[18]. The actual effective tax rate (not the nominal tax rate) has been used to calculate the R&D expenditure including the tax effect. The effective tax rate has been calculated as taxes paid divided by net profit before tax. Since the effective tax rate varies from year to year, it makes the fact that cash flow includes a component related to R&D expenditure less likely to cause spurious correlation between R&D and cash flow.

Sales

Sales can be seen as measures of demand. They are only indirectly related to expected profits, but easier for companies to forecast than profits since the latter also include cost estimations. The sales used in the regressions are totals for the firms in the pharmaceutical industry.

R&D productivity

The proxy for R&D productivity was described in the previous section. Several versions employing various averaging were tested in the regressions, but did not produce substantially different results from the chosen (not averaged) formulation.

Correlation matrix

Table 2 shows the simple pair wise correlations between the different independent variables. The only case of higher correlation is between unlagged cash flow and profit. It will be shown in the regression results section that this does not affect the results substantially.

Table 2. Correlation matrix, industry level, 1967-95.

	Δln(CF(t))	Δln(CF(t-1))	Δln(CF(t-2))	Δln(CF(t-3))	Δln(RPROD(t-1))	Δln(SALES(t))	Δln(PROFIT(t))	Δln(R(t-1))	Δln(R(t-2))
Δln(CF(t))	1.00								
Δln(CF(t-1))	-0.24	1.00							
Δln(CF(t-2))	-0.28	-0.25	1.00						
Δln(CF(t-3))	0.06	-0.28	-0.23	1.00					
Δln(RPROD(t-1))	-0.27	0.39	-0.09	0.17	1.00				
Δln(SALES(t))	0.32	0.05	-0.05	-0.04	0.10	1.00			
Δln(PROFIT(t))	0.79	-0.09	-0.24	-0.06	-0.21	0.05	1.00		
Δln(R(t-1))	-0.39	0.25	0.04	0.26	0.29	-0.17	-0.20	1.00	
Δln(R(t-2))	-0.28	-0.39	0.29	0.02	-0.36	-0.29	-0.11	0.20	1.00

Note: CF=cash flow, *RPROD*=R&D-productivity, *R*=R&D expenditures. All variables have been deflated using a GDP-deflator based on Krantz and Schön (2007).

[17] *Resultat före bokslutsdispositioner och skatt.*

[18] Calculated as R&D * (1-τ) where τ is the effective tax rate. It is assumed that R&D is expensed and hence reduces the overall tax paid. (Hall 1992).

Regression results

Table 3 shows the regression results of two alternative formulations, Model A and B. Model B is the more extensive one while Model A is a reduced version. The models pass Ramsey RESET stability tests and Chow tests for structural breaks at the 5 % level. The Durbin-Watson serial correlation tests are inconclusive for both models, but they pass the more encompassing Breusch-Godfrey serial correlation test without problems. It can therefore be questioned if the use of autoregressive terms is necessary, but it has been done in Model B anyway to control for the facts that R&D expenditures have been interpolated for some years. The correlation matrix (Table 2) showed a fairly high correlation between *Δln(CF(t))* and *Δln(PROFIT(t))*. This appears to be the reason for the profit term becoming negative when both these variables are included in the same model. The *CF(t)* term is closest to significant in Model B, and therefore the profit term has been excluded in the reduced Model A.

The regression results show quite clearly that the variations in R&D expenditures are correlated with the yearly sales variations. This makes sense as sales are probably easier to forecast than profits or cash flow as an indicator of demand and profits. The sensitivity to cash flow variations lagged two years is very distinct. It would have been more natural if it would have been the cash flow lagged one year (i.e. cash flow in the previous year) that influenced R&D expenditure. However, it can still be explained by that it is last year's final profit and loss reports that are available at the time of budgeting for next years R&D efforts. It may also be related to a time consuming recruitment process for R&D staff and reluctance to make R&D staff redundant. Although most previous studies focus on the cash flow lagged one year, there are examples of significant two year lags (Fazzari et al. 1988).

Table 3. Regression results, industry level, 1967-1995.

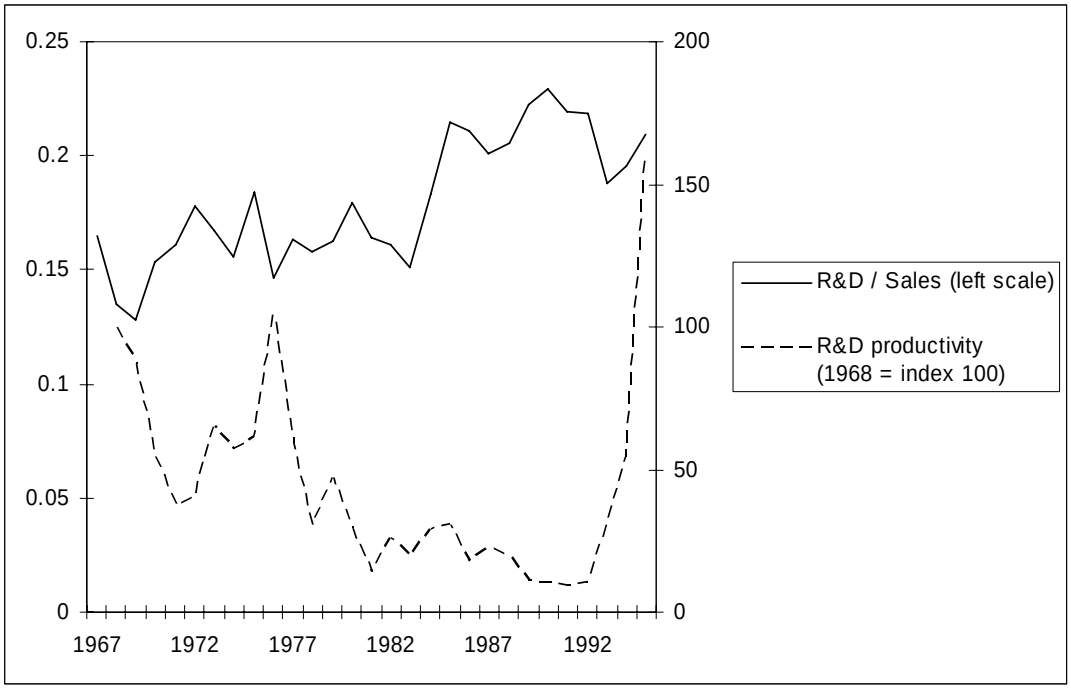
1967-1995
Dependent Variable: Δln(R(t))
Included observations: 25 after adjusting endpoints

Independent variables	Variable type	Model A		Model B	
		coefficient	p-value	coefficient	p-value
constant		-0.01	0.839	0.01	0.820
Δln(CF(t))	expected profits	0.14	0.130	0.28	0.063
Δln(CF(t-1))	internal funds	0.12	0.203	0.03	0.731
Δln(CF(t-2))	internal funds	0.23*	0.014	0.22**	0.006
Δln(CF(t-3))	internal funds	0.16	0.068	0.08	0.308
Δln(RPROD(t-1))	r&d productivity	0.02	0.589	-0.01	0.840
Δln(SALES(t))	expected profits	0.32*	0.028	0.26*	0.041
Δln(PROFIT(t))	expected profits			-0.10	0.131
Δln(R(t-1))	autoregressive			0.44*	0.017
Δln(R(t-2))	autoregressive			-0.37	0.061
Adjusted R^2		0.40		0.61	
Durbin-Watson		1.75		2.10	
Jarque-Bera normality test (p-value)		0.94		0.28	
RESET test (worst of 1-3 fitted terms, p-value)		0.21		0.09	
White test (no cross terms, p-value)		0.31		0.18	
Breusch-Godfrey (worst of 1-4 lags, p-value)		0.42		0.17	

Note:, **: $p \leq 1$ %, *: 1 %< $p \leq 5$ %.

So far the results are largely in line with what could be expected from theory. Expected profits, here in the form of expected demand, and availability of internal cash flow have turned out to be key factors in the determination of R&D expenditures. More unexpected is that research productivity comes out highly insignificant and with a coefficient very close to zero. This is in line with the study of the Japanese pharmaceutical industry (Mahlich and Roediger-Schluga 2006) where the coefficient for R&D productivity came out slightly negative or insignificant. This may therefore potentially be another characteristic of R&D in bank based systems. In studies of the US industry (Grabowski 1968, Grabowski and Vernon 1981, 2000), on the other hand, the coefficient was positive and significant.[19] The Swedish (and Japanese) behavior could be due to the difficulty of predicting success and hopes for major breakthroughs in research projects where large costs have already been sunk, i.e. taking a longer term view. It could be noted that the Swedish R&D-to-sales ratio started to increase in the early 1980s (Fig.3), just a couple of years after a similar rise in the US (Grabowski and Vernon 2000). This may suggest that the Swedish industry looked at research opportunities opening up elsewhere rather than at their own current R&D productivity when deciding their R&D expenditures, which is another aspect of a 'long term view'.

Figure 3. R&D productivity (measured as number of forward patent citations divided by real R&D expenditures in the previous year) and R&D-to-sales ratio, industry level, 1967-1996.



Source: Patent citation data Hall et al. (2001), SCB Research Statistics (1969-97), SCB Business Statistics (1966-83), SCB (2007).

Firm level regressions

The firm level regressions are based on data from annual reports on group level. This means that also subsidiaries outside Sweden as well as non-pharmaceutical subsidiaries are included,

[19] Both the study of Japan and the studies of the US are panel data studies using R&D/sales as the dependent variable.

which is not the case in the business statistics that was used for the industry level. The two largest groups have been studied: Astra and Pharmacia, although the available consistent time series for the latter is quite short and the results will only be briefly touched upon.

It has not been possible to strictly use R&D expenditure since the definition used in the annual reports is the sum of current costs related to R&D and *capital costs* (instead of investments). Given that the share of capital costs is fairly small (approximately 15% of current costs plus capital costs), this is not necessarily a large problem.

Since the data includes non-Swedish subsidiaries, those subsidiaries have also been included in the aggregation of patent citation data when calculating the R&D productivity at firm level.

Astra

Astra's history dates back to 1913. In 1939 and 1942, the companies Tika and Hässle were acquired and in 1956 Draco was established as a part of the group (Sundling 2003: 1-5). The Astra group was less affected by mergers than other parts of the industry in the period for which R&D statistics are available. They took over the pharmaceutical division of Bofors in a couple of steps during the 1970s (Fransson 1996: 174, 263), but those were relatively small changes compared to the group's size. Therefore a fairly consistent time series can be compiled based on annual reports for the period from 1961 to just before the merger with Zeneca in the end 1990s (Astra 1961-97).

Table 4. Regression results, Astra 1967-1997.

1967-1997
Dependent Variable: Δln(R(t))
Included observations: 28 after adjusting endpoints

Independent variables	Variable type	Model I		Model II	
		coefficient	p-value	coefficient	p-value
constant		0.05**	0.003	0.05**	0.004
Δln(CF(t))	expected profits	0.09	0.170	0.12	0.240
Δln(CF(t-1))	internal funds	0.10	0.120	0.11	0.115
Δln(CF(t-2))	internal funds	0.13*	0.016	0.13*	0.016
Δln(CF(t-3))	internal funds	0.07	0.133	0.07	0.137
Δln(RPROD(t-1))	r&d productivity	0.00	0.797	0.00	0.973
Δln(SALES(t))	expected profits	0.18	0.166	0.19	0.160
Δln(PROFIT(t))	expected profits			-0.05	0.662
Adjusted R^2		0.49		0.47	
Durbin-Watson		2.01		1.93	
Jarque-Bera normality test (p-value)		0.99		0.98	
RESET test (worst of 1-3 fitted terms, p-value)		0.36		0.35	
White test (no cross terms, p-value)		0.27		0.30	
Breusch-Godfrey (worst of 1-4 lags, p-value)		0.12		0.15	

Note:, **: $p \leq 1$ %, *: 1 %< $p \leq 5$ %.

The Astra group was responsible for ca 51-57 % of the Swedish industry's pharmaceutical turnover in the period 1958-94 (Ehrlén et al. 1999:114). Interestingly, in the context of financial systems, Astra have had close bank ties since the 1920s when the well known Swedish banker family Wallenberg became an important shareholder. At face value this

should reduce the information asymmetry and reduce the reliance on internal funding for R&D. However, Jacob Wallenberg, chairman of the board 1957-75, was firmly of the opinion that investments in general and R&D investments in particular should be funded internally. There were nevertheless a number of new equity issues in that period, but largely to finance the expansion of the production and sales organizations. (Sjögren 2005: 53- 57, 67-68, 72, 80).

The regression results in Table 4 show a significant influence of past cash flow. Autoregressive terms where insignificant and were therefore not included. This also suggests that the significance of the first autoregressive term in the industry level regression was due to the interpolation of R&D data. The cash flow coefficient is lower than for the industry level, but the difference may be due to that the firm level regression is not restricted to Swedish operations[20] while the industry level regression is, or it may be an aggregation issue.

A reason for the Sales term being insignificant could be that strictly pharmaceutical sales[21] would be a better proxy than group sales which are used in Table 4. Regressions using pharmaceutical sales give results with the sales term closer to significance (p-values of about 7 %). Cash flow terms lagged two years are still significant in these regressions with a coefficient of 0.12. However, the latter regressions suffer from serial correlation in the residuals and do not pass Breusch-Godfrey test at 5% level and should therefore be treated with some care. The important point, however, is that there is a clear correlation between R&D and cash flow lagged two years in both cases, and the size of the *CF*(*t-2*) coefficient is about the same. Similarly to the industry level regressions, the coefficient for R&D productivity is clearly insignificant.

Table 5. Regression results, Astra 1961-1997.

1961-1997
Dependent Variable: Δln(R(t))
Included observations: 33 after adjusting endpoints

Independent variables	Variable type	coefficient	p-value
constant		0.05**	0.000
Δln(CF(t))	expected profits	0.07	0.113
Δln(CF(t-1))	internal funds	0.09	0.071
Δln(CF(t-2))	internal funds	0.14**	0.003
Δln(CF(t-3))	internal funds	0.07	0.066
Δln(SALES(t))	expected profits	0.21	0.079
Adjusted R^2		0.50	
Durbin-Watson		1.85	
Jarque-Bera normality test (p-value)		0.95	
RESET test (worst of 1-3 fitted terms, p-value)		0.55	
White test (no cross terms, p-value)		0.11	
Breusch-Godfrey (worst of 1-4 lags, p-value)		0.14	

Note:, **: $p \leq 1$ %, *: 1 %< $p \leq 5$ %.

[20] Around 1980 ca 35% of Astra's value added was produced in non-Swedish factories, while ca 10% of the R&D staff was located abroad. Sundling (2003: 240), Astra (1981: 22).

[21] For the years 1967-68 the pharmaceutical sales figures were not explicitly stated in the annual reports and these have been estimated based on group sales and the ratio between pharmaceutical and group sales.

The use of patent citation data limits the time period for the regressions since the other variables are available from 1961. Since the R&D productivity term is very insignificant, a regression for a longer time period without the R&D productivity term was evaluated. The result is presented in Table 5. Here the group sales term is closer to significance than in Table 4, but more importantly, the *CF*(*t-2*) term is highly significant with a coefficient of 0.14.

Overall, the different types of regressions made for Astra give a very consistent picture of sensitivity to past cash flow in R&D. Whether the elasticity should be seen as high or low must be left for further study. Also, R&D productivity does not influence the R&D expenditures.

Fortia/Pharmacia

The other major pharmaceutical company was Pharmacia, a part of the Fortia group. Pharmacia's share of the Swedish industry's pharmaceutical sales was only 12 % in 1958, but rose to 21% in 1988 and 42% in 1994 (Ehrlén et al.1999: 114). However, Pharmacia did also have products in the field of diagnostics and chemical separation. In 1986 they acquired another Swedish pharmaceutical firm, Leo, which had merged with Ferrosan two years earlier (Ahlin and Lundgren 2002: 279, 297). Later, in 1990, government owned Procordia acquired Pharmacia and merged it with the Kabi group that it already owned. Both these events roughly doubled Pharmacia's share of the pharmaceutical turnover, as can be seen in the numbers above. The mergers make it difficult to create a consistent time series. However, an attempt has been made anyway for the period 1969-1989 (Fortia 1969-80, Pharmacia 1983, 1989). Regressions using the formulation of Model I in Table 4 show a just about significant coefficient (5 %) for the *CF*(*t-2*) term as well as a highly significant Sales term. The other terms were insignificant, including the R&D productivity. The Cash flow coefficient was 0.13, in line with Astra's results, but the group level Sales coefficient quite high (0.94). The number of samples in this regression was only 17 (after adjustments) which is a very small sample. This, of course, makes the results less reliable. However, it would seem strange if the significance of the *CF*(*t-2*) terms would be just a coincidence given the results of the industry level regressions and the regressions for Astra.

Conclusions

This study has investigated factors influencing R&D expenditures. It has followed the theoretical framework from previous studies of pharmaceutical industries in the US and Japan. It is possible to draw some conclusion that can be compared to previous studies of determinants of R&D expenditures. The regressions using real R&D expenditure as the dependent variable has shown a significant influence of past cash flow, both at the industry level and firm level. Such sensitivity is in line previous studies based on US data. The study of Japan (Mahlich and Roediger-Schluga 2006), on the other hand, had insignificant coefficients for past cash flow in their more elaborate models and a much lower elasticity than the US in others. Expected sales, a proxy for market demand and indirectly profit expectations have also been significant at the industry level and in some of the firm level regressions. Due

to data limitations it has not been possible to perform a more detailed comparison of regression coefficient sizes.[22]

Common to all the regressions for Sweden, both at industry and firm level, is that influence of current R&D productivity has been clearly insignificant. This is in line with the study of the Japanese pharmaceutical industry where this factor was concluded to be unimportant. However, the studies from the US show a positive and significant influence of R&D productivity on R&D expenditures. The Swedish and Japanese behavior could be due to the industry taking a longer term view on their research.

The study has related the results to differences in financial systems. Japan and Sweden were both leaning towards bank based systems while the US was clearly market based in a ranking for 1980-95 by Levine (2002). It is possible that the longer term view on research is made easier by close bank ties. However, while R&D productivity is unimportant for R&D expenditures in both the Swedish industry and the Japanese, the Swedish industry may possibly have been more reliant on re-investment of internal funds (cash flow) than the Japanese. Past cash flow was highly significant in the regressions for the Swedish industry.

The merits of short and long term views are difficult to evaluate. A key problem with concepts like short and long term views is that they are generally judged afterwards. A company that relentlessly pursues a research project that it believes in and turns out successful in the end is likely to be hailed for its visionary endurance. Would, on the other hand, the company fail, the verdict would rather be its inability to give up unprofitable projects. Similarly will companies applying short term business principles to its long term research projects may be labeled victims of 'short-termism' if they fail, but lauded for their sensible business practices if successful.

Chandler (2005) studied the business histories of several industries (with emphasis on the US), including pharmaceuticals. He concluded that in the latter industry differences in strategy separated winners from losers (Chandler 2005:310). The strategy proving successful in the long run was companies' reinvesting profits and learning to develop new products within their strategically defined field. Companies engaging extensively in unrelated diversification, on the other hand, tended not to be the long term leaders. The reason is that such diversification leads decreased focus on capabilities in the core areas in favor of others, which may result in that these firms miss the boat when new research opportunities arise. Diversification is one way to adjust to decreasing productivity in the pharmaceutical R&D process. In that respect, a long term view would be consistent with Chandlers "virtuous strategy". On the other hand, there is always the risk that the scientific sources for further product development dries up, another of Chandler's findings (but from other industries), which of course may create a very different situation. New research opportunities may also appear in entirely new areas where the older core capabilities are less useful. In addition, a long term view includes the risk of escalating commitment to failing projects (Staw 1976). While it seems reasonable to assume that more radical innovations would require at least some endurance, the question whether an optimal trade-off exists must be left for future study.

[22] This study has used time series regressions since it has not been possible to compile suitable panel data. In these time series regressions it has found significant results when using the real R&D expenditure as the dependent variable while controlling for sales, but not when using R&D-to-sales ratio, which is used as dependent variable in several other studies.

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