The effects of institutional change on innovation and productivity growth in the Swedish pharmaceutical industry

Malmberg, Claes

2007

Paper no. 2007/02

The effects of institutional change on innovation and productivity growth in the Swedish pharmaceutical industry

Malmberg, Claes (claes.malmberg@circle.lu.se)
CIRCLE, Lund University

Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE)
Lund University
P.O. Box 117, Sölvegatan 16, S-221 00 Lund, SWEDEN
http://www.circle.lu.se/publications
ISSN 1654-3149

WP 2007/02

The effects of institutional change on innovation and productivity growth in the Swedish pharmaceutical industry

Malmberg, Claes

Abstract

The relation between innovative output from the R&D process and total factor productivity (TFP) in the Swedish pharmaceutical industry has been investigated. The focus has been on the 1960s when the institutional conditions for innovation changed drastically in the pharmaceutical industry through new and stricter regulation. The short term effect of the new regulation was a shift towards quality products. Patenting increased and there were an increasing number of economically successful drugs based on new substances (NCEs). This had a positive impact on TFP growth.

Keywords: institutional change, innovation, imitation, productivity, patents, pharmaceutical industry, longitudinal

The effects of institutional change on innovation and productivity growth in the Swedish pharmaceutical industry

Claes Malmberg[1]
CIRCLE and Department of Economic History, Lund University, Sweden

Abstract
The relation between innovative output from the R&D process and total factor productivity (TFP) in the Swedish pharmaceutical industry has been investigated. The focus has been on the 1960s when the institutional conditions for innovation changed drastically in the pharmaceutical industry through new and stricter regulation. OLS regressions for the period 1952-77 based on a standard Cobb-Douglas production function were used for the analysis. Both the growth of the patent stock and the stock of drugs (of any quality) proved to have a strong positive impact on TFP growth. The drug stock growth made a positive contribution in the 1950s, while the patent stock growth made a strong contribution in the 1960s. The short term effect of the new regulation was a shift towards quality products. Patenting increased and there were an increasing number of economically successful drugs based on new substances (NCEs). This had a positive impact on TFP growth.

Keywords: institutional change, innovation, imitation, productivity, patents, pharmaceutical industry, longitudinal

1. Introduction

This study revisits the 1960s to investigate the relation between innovation and productivity growth when institutional conditions are changing. During the 1960s the research output of the pharmaceutical industry in terms of new drug substances (new chemical entities, NCE) and new drugs fell dramatically. This has been the subject of several studies of the US industry. In general the fall is attributed to the stricter regulation for drugs introduced in the first years of the decade.

New regulation was introduced in Sweden a couple of years later, and the industry experienced a similar fall in the number of new products. The present study takes a look at the Swedish pharmaceutical industry and asks what effect the regulation had on the

[1] I thank Olof Ejermo (CIRCLE) for useful comments on an earlier version of this paper.

quality of drugs and on the total factor productivity. The empirical framework is based on the commonly used Cobb-Douglas production function where labour and effective capital is used together with different measures of innovation to explain the growth in real value added. The framework is used for regressions covering the period 1952-77.

The total factor productivity (TFP) is assumed to depend on the quantity and average quality of products. The former is measured as the stock of drugs registered with the Swedish Medical Products Agency (*Läkemedelverket*). The quality is measured as the number of patents per drug in this stock. This measure of product quality has been validated against the risk of drugs suffering early deregistration (a sign of low quality). A Cox regression estimating the relative risk of different cohorts of drugs was compared to the number of patents per drug for each cohort.

In addition, a specially compiled list of economically successful drugs has been used to check that the conclusions are valid also for the top selling products.

The quantity-quality based specification above implies that both the growth of the patent stock and the stock of drugs are important to explain TFP growth. That is also what the results of the production function regression show. The growth of the patent stock could not alone explain TFP growth, but in combination with the growth of the stock of drugs both proved to have a strong impact. The drug stock growth made a positive contribution in the 1950s, while the patent stock growth made a strong contribution in the 1960s. The number of patents per drug increased steadily during the 1960s.

The Swedish pharmaceutical industry seems to have behaved differently in the 1960s than the US industry. Although the number of new products and new drug substances (NCEs) fell in a similar way as in the US, there was a shift towards quality products in Sweden. This shift had a positive impact on TFP growth.

Swedish pharmaceutical patents are especially suitable as innovation indicators, since product patents for drugs were not allowed before 1978. Instead firms patented the manufacturing process, which provided a much weaker protection. To compensate, firms developed several alternative processes for their more important drugs and patented these as well.[2] This introduced a kind of quality adjustment to the patent count. A more common way to adjust patent statistics for quality is through the citations received from other patents. Since no such database is available for Swedish patents for the period of this study, the Swedish patent count has been compared with the citation weighted patenting in the US by Swedish inventors. The comparison shows a significant correlation before 1978 and a distinct change in the pattern of patenting once product patents became allowed, which confirms the quality adjusting effect (see Appendix C).

The paper is organized in the following way. The next section provides a description of the decline of new drugs in the 1960s. Section 3 discusses innovations and total factor productivity. Then the regression analysis of the study follows. These results are then used in section 5 to characterize the effects of the new regulation on the quality of drugs and TFP growth. Section 6 presents the analysis of drugs' risk of deregistration and the

[2] See e.g. Lindqvist and Sundling (1993:111-114) for an example.

comparison with patent statistics. Section 7 presents the investigation of economically successful drugs and conclusions are discussed in Section 8. Finally, four appendices provide supporting information.

2. The decline of new drugs in the 1960s

The literature concerning the decline of new pharmaceutical products in the 1960s has mainly been focusing on the US development[3], but the fall in new Swedish products followed a similar path. The stricter US regulation was introduced in 1962 and the Swedish in 1964.

Figure 1 shows the number of new drugs registered by Swedish firms and identified by unique brand names in the Medical Products Agency's register, as well as so-called *pharmaceutical specialties*, which is the primary unit of registration and includes different dosage forms and strengths.[4] The ratio between pharmaceutical specialties and new drugs was fairly constant until the 1980s when it increased somewhat. Both of these series include both original products from Swedish firms as well as licensed or acquired products from other firms. It can be seen that there was a substantial increase in the yearly number of new drugs from the mid 1940s until about 1960. But thereafter the annual count fell quite sharply and reached a lower level in the first half of the 1970s. This general pattern is in its main features similar to the total number of NCE introductions in USA (Wiggins 1982).[5] New drugs as defined here is of course a more encompassing measure than NCEs, but there is as we shall see a relation between their numbers. The number of products started to fall slightly before the dates of the new regulations in both countries (Figure 1 and Temin 1980), but gained pace after their introduction.

The number of NCE introductions in Sweden by Swedish firms is only available for a limited time period (Berlin and Jönsson 1984, Berlin 1979, 1981, 1982). The available data is shown in Figure 2. The figure shows the total number of NCE introductions by Swedish firms, i.e. of Swedish origin as well as licensed or acquired foreign products. The fall in total NCEs is highly consistent with the pattern of new drugs in Figure 1. In addition, Figure 2 shows an estimated series of NCEs originating in Sweden.[6]

---

[3] The UK industry, were the regulation in the 1960s was less strict, has been used for comparative purposes in e.g. Grabowski et al (1978).

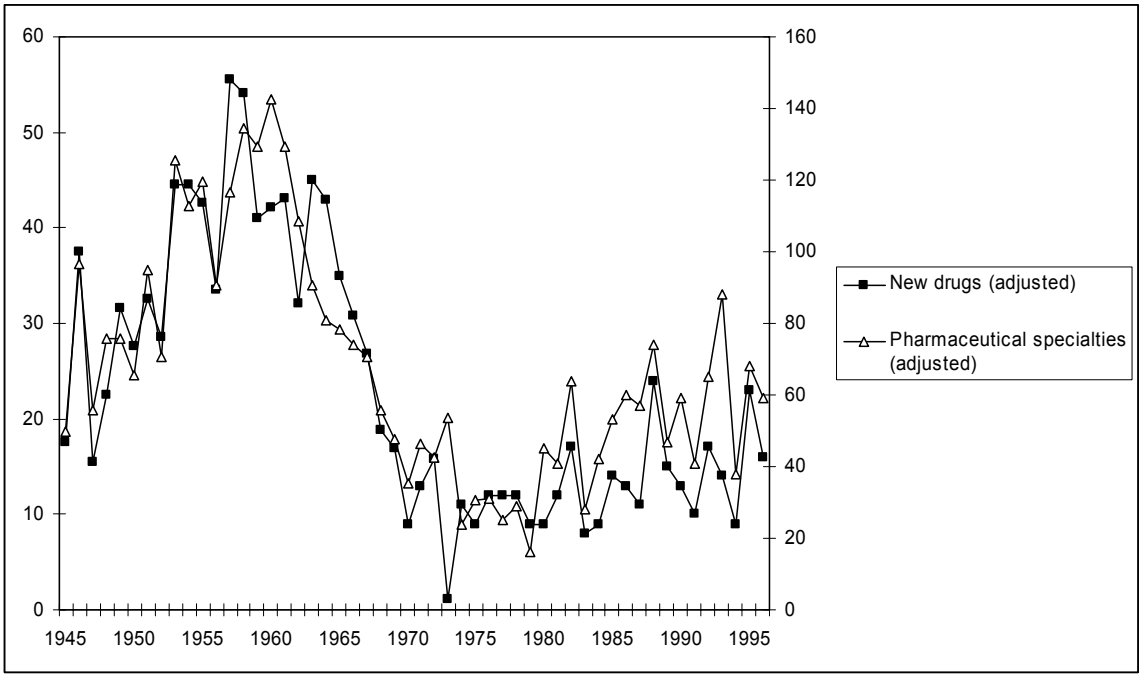
[4] Both the number of new drugs and the number of pharmaceutical specialties have been adjusted to account for changed registration rules, e.g. registration requirement for previously exempt products, which caused registration peaks in 1963-4 and around 1973. These adjustments are further described in Appendix A.

[5] The differences are that there were comparatively more new Swedish products introduced during the war than NCEs in USA (in relative terms) and that the more dramatic part of fall occurred somewhat later in Sweden than in USA.

[6] The number of NCEs of Swedish origin has been estimated using the year of registration in Sweden, France, West Germany, Italy, the UK and USA for NCEs registered by Swedish firms (Berlin and Jönsson 1984, Appendix 2, pp.123-135, the foreign registrations are only available from 1960). If an NCE has only been registered in Sweden it has been regarded as 'country specific' NCE used only in Sweden and hence

This estimation has not been regarded as reliable before 1964, but the development thereafter largely follows the falling pattern of the total number of NCEs.

Figure 1 Annual number of new pharmaceutical specialties and new drugs 1945-1995.



Source: MPA (2006), Number of new drugs extracted by the author based on brand name. See also Appendix A (drug stock) regarding adjustments.

Of the different reasons suggested for the US decline in NCEs, the stricter regulation has featured as either as the main or a key contributing factor in most studies (Bailey 1972, Peltzman 1973, Grabowski et al. 1978). Many studies were mainly concerned with the immediate effect of stricter regulation, but Wiggins (1981, 1983) separated the effect of regulation into a *direct* effect on the number of NCEs and an *indirect* effect working via decreased R&D expenditures. He found that an impact of the indirect effect only occurred after a long delay in the 1970s (he did not study the direct effect in the 1960s).

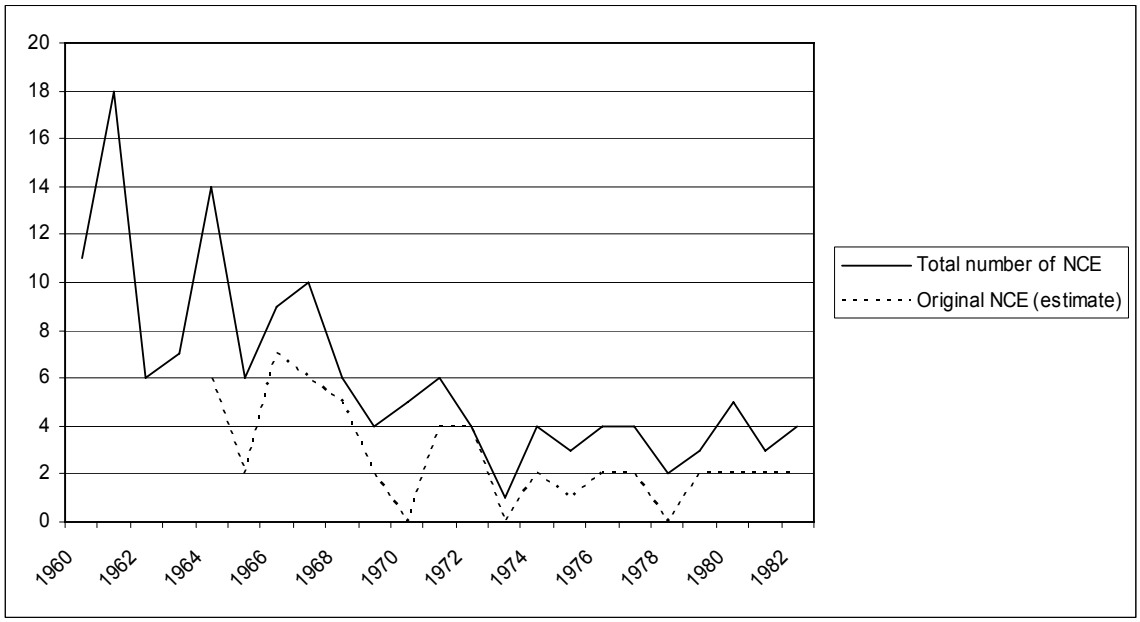
---

of Swedish origin (but probably not of very high technical quality, Berlin and Jönsson 1984:103). For registrations in Sweden in the early years of the 1960s, there is a risk that unavailable registrations have occurred before 1960 in other countries. An NCE has also been classified as originating in Sweden if the first registration occurred in Sweden. With this method there are a number of possible sources of error: there is a risk that NCEs may have been registered first in a countries that has not been checked or before 1960, the Swedish firm may have chosen to register an original NCE in a foreign county first, or that the approval process in the different countries have distorted the registration years so that they do not reflect the application year. However, the displayed results seem to give a reasonable picture of the general development over time and are for the most part consistent with information in business histories of the respective firms. The values of Sweden originating NCEs in the first couple of years of the 1960s, though, practically coincide with the total number of NCEs which is unrealistic, hence the truncation before 1964.

Also Jensen (1987) found a negative impact of regulatory stringency on the number of NCE introductions in the 1970s.[7]

The US regulatory body advanced the hypothesis that the fall would be limited to less important NCEs (Grabowski et al. 1978), but this has largely been dismissed by later research (e.g Pelzman 1973, Wiggins 1981). But there seems to have been differences among firms. Thomas (1990) found that the research productivity of smaller US firms were much more affected by the 1962 regulation than of larger, and that the latter were able to increase their sales per NCE in the 1960s due to lowered competition.

Figure 2 Annual total number of NCE registrations in Sweden (1960-82) and estimated number of NCEs of Swedish origin (1964-82).



Source: Berlin and Jönsson (1984). Original NCEs estimated by the author based on Berlin and Jönsson (1984).

There is no doubt that the thalidomide disaster had an important impact on the industry. Thalidomide, the sleeping-drug hailed as entirely safe compared to previous products and even sold without prescription in Germany, turned out to cause serious birth defects when the mother had taken the drug during a specific period of the pregnancy. It was withdrawn in late 1961 (Östholm 1995: 65-81). However, new regulatory frameworks were already being worked upon both in USA and Sweden at the time of the disaster (Pelzman 1973, Lönngren et al. 1999, Bd I: 326-327). It did influence the regulations to some extent, but was not the primary cause of it. It is of course very plausible that it made both prescribing doctors and drug firms more cautious (Grabowski et al. 1978), but it is difficult to quantify these effects.

[7] The indirect effect is not part of the present study, but will be treated in the study covering the research process. The same is valid for the role of changing technical research opportunities which e.g. according to Wiggins (1982: 141-151) played a non-negligible part.

3. Innovation and total factor productivity

The relation between innovation and productivity growth has been studied extensively (Wieser 2005 provides a survey). However, the vast majority of these studies have investigated the productivity effects of changing levels of *input* into research and development (e.g. R&D expenditure). The relation between the *output* from the R&D process and total factor productivity has not been studied as much.[8] This study divides the 'black box' between R&D input and productivity growth into two; first a research process turning R&D input into innovative output, and a second process that turns innovative output into total factor productivity growth. The second process, which is the subject of the present paper, is related to the manufacturing of products as well as their commercial exploitation. The research process, for which a richer literature exists, will be the subject of a coming paper which will also connect the two processes.

Total factor productivity is the part of real output (value added) that cannot be explained by the amount of labour and capital used in the production. There are a number of sources of measurable total factor productivity growth, some which are related to new and improved production processes and others which are the effects of new products (Griliches 1979). First, the industry's own improvements of its manufacturing processes, including organizational improvements, have an impact. Some of these may be improvements to already existing production lines with the intention of reducing production costs. Others are the results of the implementation of production lines for new products, thereby introducing the latest knowledge in manufacturing. These therefore serve the double purpose of increasing efficiency as well as enabling the new product to be produced. To the extent that these process innovations are patented, they will be captured in the patent statistics of the pharmaceutical industry. That is, however, not the case for innovations performed by the producers of purchased manufacturing equipment. Since patents for such improvements would have been filed by the equipment manufacturer, they will not be included in the patent statistics of the pharmaceutical companies. A way to take such technical change that is embodied in machinery into account is to make a quality adjustment of the capital stock (Hulten 1992). Such an adjustment has not been possible to make in the present study, and it has instead been assumed that the quality improvements of purchased equipment have been fully reflected in the real price of the equipment.

While the introduction of new products may lead to new and better production processes and through this affect the productivity, i.e. an indirect effect of new products,

[8] Studies that have done this are Bailey et al 1985 and Geroski (1989, 1991) all using databases of important innovations. Neither of them is at the same time longitudinal and using econometrics as this study is. There is also a more recent strand of cross-sectional studies using simultaneous equation frameworks and data from innovation surveys (see Hall and Mairesse 2006).
Endogenous growth theories (e.g. Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1992) use innovative output ('ideas') as the source of productivity growth.

there is also a direct effect. This is caused by new products commanding higher margins early in their life. Under competitive conditions, these margins would rapidly be competed away, but many drugs are protected by patents and trademarks enabling the industry to appropriate a part of the total social gains of the innovations. A part of the appropriated gains will be used for long term investments in research and development and another part will be profits. It can of course be suspected that patented products enjoy a higher degree of such market power than non-patented products or products with expired patents. Trademarks are often used in the latter case to extend the period of market power beyond the maximum patent validity (Rujas 1999). However, the Swedish pharmaceutical industry also used trademarks extensively for their products in the 1930s, i.e. well before the late 1940s when they started to develop patentable products at a larger scale (Malmberg 2005). This indicates that the industry has a tradition of using trademarks to achieve market power also for non-patented products.

Against the attempts of the industry to achieve market power operates the price control of pharmaceutical products. There has been a surveillance of drug prices by Swedish authorities since 1934 and the price must fulfill a criterion of being 'reasonable' (*skäligt*).[9] This evaluation was done as a part of the approval process for new drugs and was based on a proposed price from the manufacturer. However, according to an official study this control seems to have had only limited effect in reality and then mainly for standard products (SOU 1969:36, pp.91-93). The study also found price differences between countries (p.85). This may partly be attributed to different price control policies. The principles for the price control in Sweden were modernized in the early 1970s and more emphasis was put on international price comparisons and the therapeutic value of new drugs. (Lönngren et al. 1999, bd III, p.29-34). The quantitative analysis will include a control variable for potential differences in pricing between Sweden and other markets.

To summarize, the measured total factor productivity will consist of one component related to process improvements (of which some indirectly related to new product introductions), which is related to more efficient use of resources. It will also include another component directly related to new products and reflecting the appropriation by the industry, which is important for industrial success and partly invested in its R&D.

4. Regression analysis

The empirical analysis is divided into four parts. In this section, an OLS regression is carried out to evaluate the effect of the quantity and quality of new drugs on TFP growth. These results are then used to characterize the effects of the new regulation on innovation and productivity. Thereafter, the relative risk of early deregistration of pharmaceutical specialties is studied using a Cox regression to validate the use of the number of patents per drugs as a measure of product quality. In the last section, a list of economically

[9] Price control of pharmacy prices started much earlier, in the 17th century (Lönngren et al 1999 bd III, p.21).

important drugs and NCEs is evaluated to check that the conclusions from the other sections are valid also for the top selling products.

Production function
The production function is based on the Cobb-Douglas production function.

$$Y_t = A_t C_t^{\alpha} L_t^{\beta} \tag{1}$$

Where Y_t is value added in real terms, L_t is labour (hours worked), C_t is the effective real total capital stock, A_t is the total factor productivity (TFP), α and β elasticities of C and L, respectively. The data used is described in Appendix A.

TFP is assumed to depend on the quantity (stock) of drugs as well as the average quality of this stock measured as the number of patents per drug.

$$A_t = D_t^{\varphi} \cdot \left(\frac{P_t}{D_t} \right)^{\gamma} \tag{2}$$

where P_t is the stock of granted patents organized by application year, D_t the stock of registered drugs.
Note that the average number of patents per drug is not simply the share of patented products. That would be the case if there were exactly one patent per product. However, the patent count here is influenced by the fact that 'product patents' were not allowed for drugs in Sweden and protection was achieved by patenting the manufacturing process. The patent stock therefore includes protective 'process patents' which are not actively used, but only exist to achieve the protective power of a proper 'product patent'. This makes the patent count a measure of quality (see Appendix C) and the ratio between patent stock and drug stock reflects the average quality of the drug stock rather than the share of patented products. Equation 2 can be rewritten in growth form using first differences of logarithms.

$$a_t = \varphi \cdot \Delta \ln(D_t) + \gamma \cdot \Delta \ln(P_t) - \gamma \cdot \Delta \ln(D_t) = \gamma \cdot \Delta \ln(P_t) + (\varphi - \gamma) \cdot \Delta \ln(D_t) \tag{3}$$

Where $a_t = \Delta ln(A_t)$. Equation 1 can also be rewritten in growth form and the above expression for a_t (Eq. 3) inserted.

$$\Delta \ln(Y_t) = \gamma \cdot \Delta \ln(P_t) + \lambda \cdot \Delta \ln(D_t) + \alpha \cdot \Delta \ln(C_t) + \beta \cdot \Delta \ln(L_t) \tag{4}$$

Where $\lambda = (\varphi - \gamma)$. This equation is then rearranged according to the principles used by Griliches and Mairesse (1984:344) and a constant term c is introduced.

$$\begin{aligned} \Delta \ln(Y_t / L_t) = c + \gamma \cdot \Delta \ln(P_t / L_t) + \lambda \cdot \Delta \ln(D_t / L_t) + \alpha \cdot \Delta \ln(C_t / L_t) + \\ + ((\alpha + \beta + \lambda + \gamma) - 1) \cdot \Delta \ln(L_t) \end{aligned} \tag{5}$$

This formulation has the advantage that the coefficient for the labour term should be zero if there is constant returns to scale ($\alpha+\beta+\lambda+\gamma=1$). Finally, the regression equation can be written after introducing lag structures for the patent and drug stocks and adding two control variables. Lag structures have been used since it is reasonable to assume a delayed effect of innovative output on the output of production. One control variable accounts for the possibility that governmental price controls on drugs work differently in different countries (see Appendix A, export share). This has been done by using the export share of the Swedish pharmaceutical production. A difference in market power between domestic and export markets would influence measured TFP growth when the export share changes. The second control variable is the total factor productivity growth of Swedish knowledge intensive industries (excluding pharmaceuticals). Any major macroeconomic influences on productivity would be included in this variable.

$$\Delta \ln(Y_t / L_t) = \beta_0 + \sum_{i=0}^{n} \beta_{i+1} \Delta \ln(P_{t-i} / L_t) + \sum_{j=0}^{m} \beta_{j+n+2} \Delta \ln(D_{t-j} / L_t) + \beta_{n+m+3} \Delta \ln(C_t / L_t) + \\ + \beta_{n+m+4} \Delta \ln(L_t) + \beta_{n+m+5} \Delta(E_t) + \beta_{n+m+6} m_t + \varepsilon_t \quad (6)$$

where E_t is the export share of the Swedish pharmaceutical production, m_t the total factor productivity growth of non-pharmaceutical Swedish knowledge intensive industry, and ε_t a normally distributed error term. The reason that the export share term does not include a logarithm is that it is expressed as percentage change already. The term including m_t is already a growth measure analogous to a_t.

The regression was performed for the period 1952-77. The starting point is limited by the availability of reliable data, such as value added. The end point has been chosen based on the validation of patent data against citation weighted US patenting (Appendix C).

The research and development has been excluded from the calculation along the lines of Schankerman (1981). This prevents double counting since the innovative output is already used in the calculation. The R&D staff was excluded from the amount of labour used and the stock of capital for R&D purposes was removed from the total capital stock. Also, the non-labour R&D expenditure (materials etc.), which would have been regarded as costs in the calculation of value added in the industry statistics, has been added back into the value added figures. It could be noted, though, that these adjustments only had a marginal influence on the results and that the results do not crucially depend on the assumptions regarding R&D expenditure etc. made in Appendix A.

Correlation matrix

To ensure that any potential multicollinearity does not distort the results the pairwise correlation between the explanatory variables was checked (Table 1). In the interest of clarity the presented table has been restricted to the variables that will be of most interest for the end result of the regression. It can be seen that the highest correlation, which is

not extremely high, is between the drug stock without lag and the drug stock lagged one year. This combination can be avoided in the final regression and is therefore not a problem. There are also other cases of moderate correlation, but these can also be avoided in the reduced set of variables used in the final regression. In most cases the correlations between the variables are very low.

Table 1 Pairwise correlation between variables 1952-77.

	Δln(patst(t)	Δln(patst(t-1)	Δln(patst(t-3)	Δln(drugst (t))	Δln(drugst(t-1))
Δln(patst(t))	1.00	0.03	0.11	0.09	0.05
Δln(patst(t-1))		1.00	-0.08	-0.07	0.10
Δln(patst(t-3))			1.00	-0.34	-0.02
Δln(drugst(t))				1.00	0.60
Δln(drugst(t-1))					1.00

Sources: Calculation based on data from MPA (2006), PRV (1910-1999), SCB Trade Statistics.

Results

Regressions based on Eq.6 were performed for the period 1952-77. Tests with different lengths of the lag structures were done and through stepwise elimination of non-significant variables in order of insignificance, the reduced model in Table 2 was reached.[10] In particular, the two control variables turned out be among the more insignificant, and were consequently eliminated at an early stage. The model has good test results in terms of normal distribution of residuals (Jarque-Bera test), serial correlation (Breusch-Godfrey test) and heteroscedasticity (White test). It also explains a large part of the variation in the dependent variable (adjusted R^2=0.73).

The one year lag for one of the patent term may seem short, but could be explained by that patented processes for incremental improvements and for patent protection would have been developed shortly after the original invention.

The sum of the two patent stock coefficients is higher than the coefficient for the drug stock. This is in line with the expectation that returns to increases in patenting would be higher than for the number of new drugs, but the difference is not very large. It can not be rejected at the 5 % level that they both are equal to one.

The elasticities with respect to the patent and drugs stocks show the impact on TFP growth when these respective terms are varied and all other kept constant. However, it is also possible to recalculate the coefficients into the quantity-quality formulation in Eq.2. Such a recalculation yields γ=1.34 and φ=2.59. The latter elasticity shows the impact on TFP growth of increasing the stock of drugs while keeping the quality, i.e. the patent to drug ratio, constant. This, of course, requires some patenting to keep the ratio constant. The high φ elasticity seems to suggest that the industry could have chosen to focus on products' quantity while keeping the quality level constant with high impact on TFP growth.[11] The question is, however, if that would have been realistic given the quite small 'home market', consisting of the Nordic countries, which would have limited the

[10] Wald tests of setting a stepwise increased set of variables jointly to zero yielded the same result.
[11] This 'choice' is of course fictitious, especially since R&D costs are not considered.

revenue of medium quality products. In addition, the new regulation would have prevented lower quality products from being launched. We will see in the next section that the industry instead chose to focus on higher quality products during the 1960s.

The coefficient for labour alone, which should be zero if constant return to scale is present, indicates that the sum of elasticities α, β, λ and γ is significantly larger than one. The proper labour coefficient (β) can be calculated using the other coefficients (see Eq.5) and amounts to 0.36. The sum of the capital/labour coefficient (α) and β consequently becomes 0.87.

It should be noted, though, that the increasing returns to innovation and new drugs are based on fully developed and commercialized ideas. Considerable R&D expenditures have been spent to produce these and the elasticity with regards to the innovative input (stock of R&D expenditure) would to be much smaller since it is very likely to be decreasing returns in the research process.

Chow tests for structural breaks were not significant at the 5 % level. This suggests that the coefficients of the production function are stable over time.

Finally, it should be noted that it has not been possible to reach any reasonable results when excluding the drug stock term.[12] That is, patents alone cannot explain the productivity growth in this case.

Table 2 Regression results (Equation 6).

1952-77 Dependent variable: Δln(Y(t) / L(t)) Included observations: 22 after adjusting endpoints		
Independent variables	coefficient	p-value
constant	0.06	0.005
Δln(C(t) / L(t))	0.51	0.221
Δln(patent stock(t-1)/L(t))	0.67	0.010
Δln(patent stock(t-3)/L(t))	0.68	0.006
Δln(drug stock last(t-1)/L(t))	1.24	0.005
Δln(L(t))	2.46	0.004
Adjusted R^2	0.73	
Durbin-Watson	2.52	
Jarque-Bera normality test p-value	0.65	
White test (cross terms, p-value)	0.35	
Breusch-Godfrey test (worst of 1-5 lags, p-value)	0.11	

[12] Excluding the drug stock term causes a negative capital/labour-coefficient and very bad results in tests for misspecification (Ramsey RESET).

5. The effects of the regulatory changes

To understand the effects on the industry, it is useful to look at the longer term variations of the parameters that have proved important in the previous section.
A series for total factor productivity growth was constructed using a regression based on Eq. 1 and imposing constant returns to capital and labour, i.e. $(\alpha+\beta)=1$.[13]

$$\Delta \ln\left(\frac{Y_t}{L_t}\right) = \alpha \cdot \Delta \ln\left(\frac{C_t}{L_t}\right) + \eta_t \qquad (7)$$

Where the residual series η_t provides an estimate of the total factor productivity growth $\Delta ln(A_t)=a_t$. This regression was done for the period 1952-80.

Figure 3 shows five year centered moving averages of the growth rates of TFP, drug stock(t-1), and patent stock(t-1), respectively.[14] It gives a visual impression of how different factors have influenced TFP growth in different periods.

The TFP growth largely followed the drug stock growth before ca 1964. The drug stock growth rate was fairly high in the mid 1950s, but then declined gradually. The growth of the patent stock did not change much before 1964. Lower quality products obviously played an important role for productivity growth in the late 1950s and early 1960s. But the market for new such products seems to gradually have become saturated.

This pattern changed dramatically around the middle of the decade. The patent stock started to grow at a higher rate having a positive effect on the TFP growth in a period when the drug stock had zero or negative growth rate. The industry started to launch fewer but higher quality products. The innovative product launches in the 1960s were often based on basic research made earlier, predominantly in the 1950s, but the important point is that these projects were brought to commercial conclusion in spite of the stricter regulation. Also, several new research projects were started in the 1960s (SOU 1969:36, pp. 264-186). In the 1970s, the growth of the patent stock decreased and so did the TFP growth rate.

The behaviour in Sweden in the 1960s was different from what has been reported from the US pharmaceutical industry, which seems to have reduced the number of new products at all quality levels (Grabowski et al. 1978). The observation of Thomas (1990) that small US firms were more affected by the higher R&D costs than larger ones may have been the case also in Sweden. Consolidation in the Swedish industry gained pace in the early 1970s (Appendix D). This will be further studied in the context of R&D process.

However, there is no visible pattern in the yearly patenting for different firm sizes suggesting that smaller firms would have decreased their innovative activities directly

[13] This has been seen as a reasonable restriction given the results in the previous section. There $(\alpha+\beta)=0.87$, but it can not be rejected at the 5 % level that $(\alpha+\beta)=1$.
[14] The reader will have to imagine another patent stock growth curve shifted two years (i.e. (t-3)).

due to the changes in the 1960s. The two largest companies, Astra and Pharmacia, produced ca 55 % of the (later granted) patents applied each year in the 1960s, and this share was stable throughout the decade (PRV1910-99).[15]

Figure 3 5 year average of TFP growth(t), drug stock growth(t-1) and patent stock growth(t-1) 1956-77.

Sources: Calculations based on data from MPA (2006), PRV (1910-1999), SCB Industry Statistics.

6. Drug quality and the risk of deregistration

The life span of drugs in Sweden has previously been studied by Berlin and Jönsson (1984).[16] Through a survey among Swedish pharmaceutical firm and agents of foreign firms, they found that the main reasons that drugs are deregistered are either low sales or that the product has been replaced by a better one (Berlin and Jönsson 1984: 59-63). Berlin and Jönsson did not interpret the life span in quality terms, but this can be done in two ways. First, low sales are likely to be due to low demand which can be seen as an indication of low product quality. Second, an early replacement by a better product

[15] Hässle, Draco and Tika have been excluded from Astra here since they were very independent in their research and strategy (although manufacturing centralized) and not seldom competing with similar products within the group until the early 1970s when the product portfolios were coordinated (Sundling 2003: 125-126). Including these the average share was 65 % but still stable during the 1960s. Bofors was a large arms and chemicals company but its pharmaceutical division was small at the time.

[16] Berlin and Jönsson's study as well as the study in this section are based on the primary unit of drug registration, pharmaceutical specialties. A drug may consist of several pharmaceutical specialties (dosage forms and strengths). The life of a drug is sometimes extended by new improved dosage forms (e.g. tablets slowly releasing the active substance). This has not been seen as a problem since the life span is censored at 10 years which excludes the very long lived drugs having such improvements. The ratio between new drugs and pharmaceutical specialties is also quite constant in the studied period (see Figure 1).

indicates that the therapeutic efficacy of the initial drug was not too high in the first place.

Berlin and Jönsson's primary interest was ageing and renewal of the total Swedish drug stock, i.e. including drugs from both Swedish and foreign firms. However, they included a study of the survival function of products registered by Swedish and foreign firms. They found that the median time from registration to deregistration of Swedish products was 11-12 years during the 1960s.

This study uses the quality interpretation of the life span of drugs and compares it with the type of quality measure used previously; patents per drug.[17] The parameter studied is the risk of deregistration of a drug in the first ten year of its life. A high such risk is likely to reflect a larger incidence of lower quality products and a lower average product quality.

Cox (1972) regressions were used for the analysis. This type of regression assumes that the risk (hazard) of "death", i.e. deregistration, is affected by the explanatory variables in a proportional way. The hazard function for the *i*th product is then $h_i(t) = exp(f_i) \cdot h_0(t)$, were $[exp(f_i)]$ is the proportionality constant (relative risk) to be estimated by the regression, f_i is a function of the explanatory variables and $h_0(t)$ is the reference hazard function.[18] The explanatory variables in this case are the registration cohorts categorized into five year periods (1940-44, 1945-49, etc.).[19] The reference hazard function is the hazard for products registered in the period 1940-44 and the risk of deregistration for the other cohorts is expressed relative to the risk of this particular cohort.

Table 3 Results from Cox regression

Period	Rel.risk	p-value
1940-44	1.00	Ref period
1945-49	0.84	0.08
1950-54	0.79	0.01
1955-59	0.88	0.13
1960-64	0.72	0.00
1965-69	0.57	0.00
1970-74	0.48	0.00
1975-79	0.44	0.00

Note: All periods fulfill the Grambsch-Therneau (1994) test for proportionality at the 5 % level.

Table 3 presents the result of the Cox regression based on the just over 3000 pharmaceutical specialties registered in the studied periods. The relative risks obtained

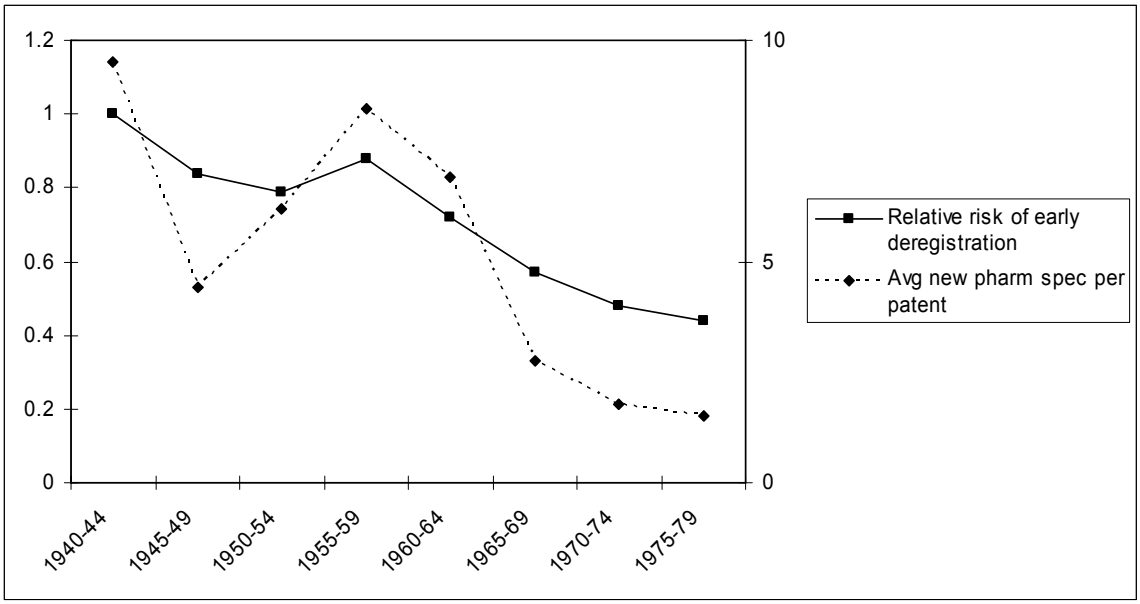
[17] Note that here the yearly flow of products and patents are studied, not the stocks as in the previous section.

[18] To avoid several products having exactly the same life span, so-called ties, which causes problems in the regression, a random variable $-0.5<x<0.5$ was added to each life span. Several different random sets were checked to ensure stable results. A discrete ML regression also gave the same results.

[19] A small proportion of the registrations were made by smaller firms (e.g. pharmacies with some industrial production). These were marked 'one' in a one-zero variable that was used for stratification in the regression since they could be suspected to have different characteristics than the products of the larger firms.

are highly significant except the periods 1945-49 and 1955-59. The proportionality assumption that underlies Cox regressions was tested using the Grambsch-Therneau (1994) test and was fulfilled at the 5 % level for all time periods.

Figure 4 Relative risk of early deregistration of pharmaceutical specialties (left scale) and number of pharmaceutical specialties per patent, five year periods 1940-79.



Sources: Table 3, PRV (1910-1999), MPA (2006).

Figure 4 shows the relative risks of Table 3 in diagram form, high risk corresponding to low quality of the drugs. It also shows the average number of drugs (strictly speaking pharmaceutical specialties) per patent application in each five year period. The quality measure patents/drug used in the last section has been inverted to become a measure of low quality compatible with the relative risk. There is a clear similarity between the two measures in the figure, and this supports the validity of the patent series as well as the measure patents/drug.

It can be seen in Figure 4 that quality improved all through the 1960s, but that there was a temporary decline during the 1950s, especially during the second half. This is consistent with the conclusions in the previous section. The quality then flattened out during the 1970s. It can also be seen that the 1940s on average had quite low quality, but quality improved in the second half. The industry had two very important commercial successes registered in that half-decade (the tranquilizer Xylocaine and the ulcerous colitis drug Salazopyrine).

7. Economically important drugs

So far the conclusions have been based on average drug quality. However, since it is possible that changes in the average could be driven mainly by the amount of low end products, it is necessary to check that the conclusions are valid for the very successful drugs as well.

Success can be measured in several ways. This study applies a turnover threshold, and products passing the threshold are labeled 'economically important'. There are two potential problems with this. Some products may not yet have reached their life cycle's maximum at the end of the study period, but this is partly compensated by that the life cycle of drugs seems to have shortened in more recent times (Grabowski and Vernon 1990: 805 footnote 4). Another potential problem is that the overall market growth over time makes it easier for later products to achieve high sales in absolute terms. However, the economically important drugs identified in this study were all very long lived. Only one such product registered before 1980 was deregistered before the end of the 1990s, so they would typically have experienced the same general market growth.

The set of products considered is drugs registered in Sweden by Swedish firms from 1934 through 1994.[20] The drugs must pass the threshold before 1998 to be considered for the list of economically important drugs. The reason for the extended period is to allow the drugs with very late registrations a couple of years to increase their sales. The turnover threshold was set to 40 MSEK (ca 9.5 MUSD) in 1980 prices. This level has partly been influenced by the availability of historical turnover data. Often only the turnover of the top selling products is reported in the sources. The level is for instance twice the level used by Wallmark and McQueen (1986) in their study of major Swedish innovations 1945-80. The threshold has been deflated using the deflator for pharmaceutical described in Appendix A. The sales figures refers to world wide sales and includes any license fees received. However, the drugs need not necessarily be originating in Sweden; they may also be licensed or purchased from foreign firms. Also, the list contains both patented and unpatented drugs. In total, the list encompasses 45 products. The earliest was registered in 1945 and the latest in 1993.

The list has been compiled using a wide range of sources: earlier studies, information in the literature, annual reports as well as information received from industrial organizations and companies.[21]

Substantial effort has been spent to make the list exhaustive. It has been confirmed to be exhaustive for all products from the Astra group (Astra, Hässle, Draco, Tika, Bofors)

[20] This means that some Pharmacia products, e.g. in the field of separation and allergy diagnostics, are not included since they were not drugs requiring registration.

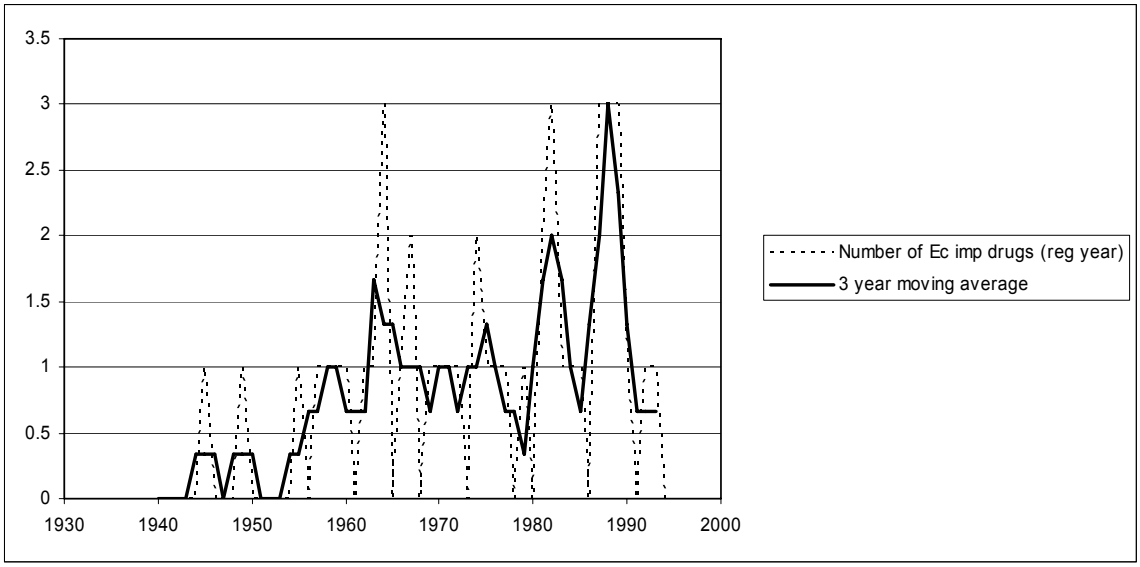
[21] SOU 1969:36 tab 3:13 p.50-52, SOU 1980:33 bil.2 tab.8 p.31-33, LIND 1978 del2 bil.10 tab.4 p.18, Wallmark and McQueen (1986), Holm (1992:90), Frankelius (1999:161, 436), Norgren (1989:89), Nyquist (1992:25), Astra (1982, 1984, 1991, 1997), Pharmacia (1984, 1985, 1988), Kabi Pharmacia (1992), Kabi Vitrum (1979), Leo (1985), Ferring (1987), LIF (1980, 1982-85, 1987-93), Nordisk Läkemedelstatistik (1982), AstraZeneca (2006), Apoteket (2006), IMS Health (2006), Ferring (2006).

for the entire period, for products from Leo until 1985 and for products from any company until 1964 (cf. Appendix D). However, the probability is high that also the other parts are exhaustive.

Figure 5 shows the number of economically important drugs per registration year as well as the three year moving average to make the diagram easier to read. The peak in 1964 is possibly somewhat overstated due to the abolishment of 'provisional approval' (see Appendix A, drug stock), but probably not by much since the approval times of these particular drugs were fairly normal (MPA 2007).

Nearly 80 % of the products in the list are original products, 35 out of 45 drugs. Five products are based on previously known substances or are incremental improvements of such substances. These products are mainly clustered in the period 1957-62. The remaining five drugs are licensed from foreign companies. These are scattered over the entire period with a slight tendency to cluster in the late 1980s.

Figure 5 Number of economically successful drugs (annual sales >40 MSEK 1980 prices) per Swedish registration year 1934-94.



Sources: Author's list of economically important products.

It can be seen in Figure 5 that the number of economically important products increased during the second half of the 1950s but some of these belonged to the previously mentioned cluster of products based on known substances in 1957-62. However, after that a clear majority of the economically important drugs were original Swedish products. The second half of the 1970s saw fewer economically important drugs, but those were still mainly original products. The number of successes increased during the 1980s.

Table 4 shows the number of economically important NCEs of Swedish origin. The number of such NCEs increased throughout the 1960s and the pace only slowed in the second half of the 1970s. This is also largely consistent with the picture given previously in this study.

Table 4 Number of economically successful NCEs of Swedish origin 1960-82.

Period	Economically important NCEs (Swedish origin)
1956-61	1
1962-66	2
1967-71	3
1972-76	4
1977-81	3

Sources: Author's list of economically important products, NCE: Berlin and Jönsson (1984).

8. Conclusions

This study has investigated the effects on innovation and total factor productivity growth of the stricter drug regulation introduced in Sweden in 1964. The innovative output in terms of the number of new drugs fell in a similar way as in the US where stricter regulation had been introduced in 1962.

The study uses patents as indicators of innovation. This is validated in two ways. First, the risk of drugs experiencing early deregistration (a sign of low quality) is compared to the number of drugs per patent. Second, a comparison between Swedish patents statistics and citation weighted patenting in the US by Swedish inventors is made.

To ensure that the conclusions reached on the basis of average drug quality is valid also for the economically most important products an evaluation of these is made as well.

OLS regressions for the period 1952-77 based on a standard Cobb-Douglas production function were used for the analysis. The growth of patent and drug stocks proved have a strong positive impact on TFP growth with slightly increasing returns to patent stock and drug stock growth, respectively. The patent stock elasticity was somewhat higher than the drug stock elasticity. Note that these are returns to fully developed and commercialized products. The return to R&D expenditure is likely to be considerably lower.

Although the impact of the patent stock growth is larger, the stock of drugs of any quality has a substantial impact and cannot be neglected. Its contribution was positive in the 1950s. The growth of the patent stock made a dominating contribution to TFP growth from 1964 and for the rest of the decade. The relation between research output and TFP growth did not show any structural breaks.

The Swedish industry behaved differently in the 1960s than the US industry. Although the number of new products and new drug substances (NCEs) fell in a similar way as in the US, there was a focus on quality products in Sweden, and ongoing research projects were carried thought to drug approval in spite of increasing testing costs. The quality of products increased in the 1960s, and there were an increasing number of economically successful drugs based on NCEs. This had a positive impact on TFP growth.

Appendix A

Data descriptions

The data set has been produced for the period 1952-95, although only the period 1952-77 is used in the present study.

Value added

The value added in current prices has been taken from the Swedish industry statistics (SCB Industry Statistics 1952-1996). To avoid a discontinuity in the series, a minor adjustment was done to the values before 1962 (when an industrial re-classification was done).[22]

The deflation was performed using a producer price index (PPI) for pharmaceuticals (class 3522) (SCB Statistics database 2005) for the period 1968-1995, and an index for the chemical industry before 1968. The chemical industry index was composed by a series provided by SCB (2004) 1950-68 and a series from the Swedish Historical National Accounts (Ljungberg 1990, App.2, p.525) 1935-68. In the overlap period 1950-68, an arithmetic average between the two series was used. The resulting series was compared to Astra´s price index for their domestic pharmaceutical products (Astra 1966:7, 1968:9) and was found to provide a reasonable picture of the development in the period 1958-68.

The non-labour R&D costs (i.e. materials), which were added back to the value added as described in the main text, were taken from the Swedish research statistics (SCB Research Statistics) for the period 1967-95. The expenditure was deflated using the pharmaceutical deflator above. For the sub-periods when the expenditure is only given biennially, linear interpolation was used to construct annual values. For the period before 1967, non-labour R&D expenditure has been calculated as a constant share of value added. This share was fairly constant from 1967 to 1983 (ca 8 %) but rose after that. It has been assumed that the constant ratio can be applied to the period before 1967.

Labour

The amount of labour used has been calculated in man-hours and consists of blue and white collar labour with the deduction of efforts by R&D staff as was described above. The hours worked by blue collar staff was taken from the Swedish industry statistics (SCB Industry Statistics).

The number of white collar employees given in the industry statistics has been recalculated to man-hours by using an estimate of the average weekly number of hours worked based on Isidorsson (2001:66-67), SOU 1992:27, pp.76-81, and SOU 2003:54, pp.59-60. This includes changes in the nominal working week as well as holidays. The resulting average number of hours per week per employee has been linearly smoothed 1944-1979, a period of stepwise decline in working time, to allow for that workers may

[22] Values before 1962 were multiplied by 0.908.

use overtime to bridge the steps in nominal working time caused by changing regulations. Since 1980 the average working week per employees has been unchanged.

The R&D staff has been treated in a similar way using the estimate of average working week. The number of R&D employees is provided by the SCB Research Statistics for the period 1967-95.[23] Before that the number of staff has been estimated by using the number of 'technical white collar staff' provided by the industry statistics. This has been multiplied by its average ratio to R&D staff in the overlapping period 1967-76. The ratio is roughly constant (about 0.8) in that period and this has been assumed to be valid also in the previous period.

Capital stock

The calculated total capital stock for the pharmaceutical industry is provided by the Swedish national accounts (SCB National Accounts 1952-96). However, for this purpose the utilization of capital should be included. This has been done by constructing a proxy based on the electricity consumption. This is possible since the pharmaceutical industry is a very light industry. In heavier, more energy consuming, industries, increasing electricity prices steer the investments towards more energy efficient machinery and this makes electric energy unsuitable as an indicator of the capital stock. Appendix B provides a more detailed description of the proxy and the rationale behind it.

The R&D capital stock was constructed by cumulating the annual capital investments in R&D (deflated by a GDP deflator, Krantz and Schön 2007) using a depreciation rate of 15 % p.a. from 1967 onwards. The capital stock in the first year (K_1) was estimated by assuming a 14 % annual growth rate (g) in R&D capital investments (the average growth rate 1967-77) and 15 % depreciation[24] (δ) and using the formula $K_1=R_1/(g+\delta)$ which calculates a perpetual sum of the growing investments (g) and the depreciation (δ) (Hall and Mairesse 1995). The ratio between the estimated R&D capital stock and the total capital stock is on average 2.5 % until the late 1970s, and this figure has been used to extrapolate the R&D capital stock back to 1952.

Drug stock

The stock of drugs is based on registration and deregistration of pharmaceutical specialties (new drugs including different dosage forms and strengths) back to 1934, the first year of such registrations (MPA 2006). The pharmaceutical specialties of Swedish firms were first selected using the firm name and country, excluding subsidiaries of foreign corporations (ca 5000 specialties). The number of new drugs (excluding different dosage form and strengths) was then filtered out based on the brand name (ca 2000 drugs).[25] The stock was calculated as cumulated registrations of new drugs minus

[23] The figures are given biennially. These have been linearly interpolated to achieve annual values.

[24] The figure 15 % has been selected since it is commonly used as a depreciation factor for private R&D (e.g. Griliches and Mairesse 1984).

[25] This method was previously used by Norgren 1989: 33. The number of new drugs is not the same as NCEs, although the two measures develop similarly over time as can be seen in Section 2.

cumulated deregistration. A de-registration was defined as the last deregistration of any pharmaceutical specialty of a particular brand name.

Both the series of pharmaceutical specialties and new drugs have spurious peaks in 1964 and 1973-75 due to regulatory changes. Before 1964 a system of provisional approval was used, whereby drugs were 'provisionally approved' (*frilistade*) and allowed to be sold in parallel to the approval procedure. This system was abolished in the new regulatory framework of 1964 and the buffer of free listed drugs was approved as soon as possible. Also, a number of previously exempt drugs by ACO were being registered in 1964 (Berlin 1981). To adjust for the changes, these ACO registrations have been spread over time back to 1939 when ACO was founded (see Appendix D) and an estimation of the buffer size of free listed drugs has been spread over the previous 5 years.[26] The 1973-1975 peaks were also due to older ACO products (Berlin 1979) and a similar operation as for 1964 has been done for these.

Patent stock

The annual patent count has been extracted from the printed records of the Swedish Patent Office (PRV 1910-1999) on a per firm basis. The firms considered are the thirteen larger pharmaceutical firms. The other firms were very small and it has not been possible to find any patents for these. The thirteen firms consolidated over time and were reduced to two major firms and one smaller in the 1990s. Appendix D gives a graphical representation of this process. The patent count is the number of granted patents organized by the year of application, in total ca 1000 patents. The stock has been compiled from 1910 using 10 % depreciation. The rate has been selected to give an approximate fit to the average patent life time in Sweden while at the same time not giving too many patents surviving the maximum validity of 17 years[27] This tail has been assumed to consist of more valuable products that have their effective protected life time extended beyond the maximum patent validity though the use of branding and trademarks.

Export share

The export share has been calculated as pharmaceutical exports from Sweden (SCB Trade Statistics 1952-95) divided by the output of the Swedish pharmaceutical industry, both in 1980 prices deflated by the deflator used for value added. The output has been adjusted for the 1962 reclassification in a similar way as the value added (see above).

Control for macroeconomic influence

To cater for potential influence of macroeconomic factors, the TFP growth rate for other knowledge intensive Swedish industries (excluding pharmaceuticals) is used as a control variable. This series has been taken from Josephson (2005, Appendix A, Table A.3).

[26] This is a best guess for the time of their origination based on Berlin (1979, 1981, 1982).
[27] 20 years from 1983 (Reiland 1984).

Appendix B

Electric energy consumption as indicator for effective capital stock

There are several potential sources of the capital stock to be used in the calculation of the total factor productivity. The Swedish national accounts (SCB National Accounts 1963-83) provide information calculated according to the perpetual inventory method (PIM). This is broken down to the pharmaceutical industry's level (3522 in the Swedish industrial classification system) during the period 1963-1983. Fire insurance values are available for some periods, but not broken down to the four digit level. The Swedish national business statistics also provide information on the capital stock, but this has proven to be unreliable since changing tax rules have affected how firms depreciate their stock over time (SCB Business Statistics 1984:7-9). The national accounts seem to provide the most reliable source, although the period is limited.

An issue when using the capital stock for productivity calculations is that it should include the utilization, i.e. it should measure the *effective* capital stock (Åberg 1969: 59). This requires the use of some kind of proxy that responds to shorter term variations in utilization. Åberg (1969: 82-109) used the capital income as an indicator of the effective stock under the assumption that the rate of return on new investments is approximately constant over time. Unfortunately, the wage sums are not broken down to the four digit level in the national accounts so this method can not be used for the pharmaceutical industry.

Another potential option is to use electric energy consumption as a proxy.[28] Figure B.1 compares capital income[29] and electric energy consumption for the chemical industry as a whole (SNI 35) for which salary and wage data is available. It can be seen that electric energy captures well the variations in utilization indicated by the swings in the capital income. However, the long term slope is different (hence the need for dual scales despite the normalization of both parameters to index=100 in 1954). This is a well known phenomenon that can be attributed to substitution of capital for energy, improved energy efficiency of machinery as technology advances, or both. This is generally related to changes in the relative price of energy, e.g. in the 1970s. Kander and Schön (2005) show that the increasing energy efficiency of machinery and other equipment has been an important component in the long term and that the ratio of capital to the final services of energy (heat, motive power) has been constant, while the capital to consumed energy ratio has increased.

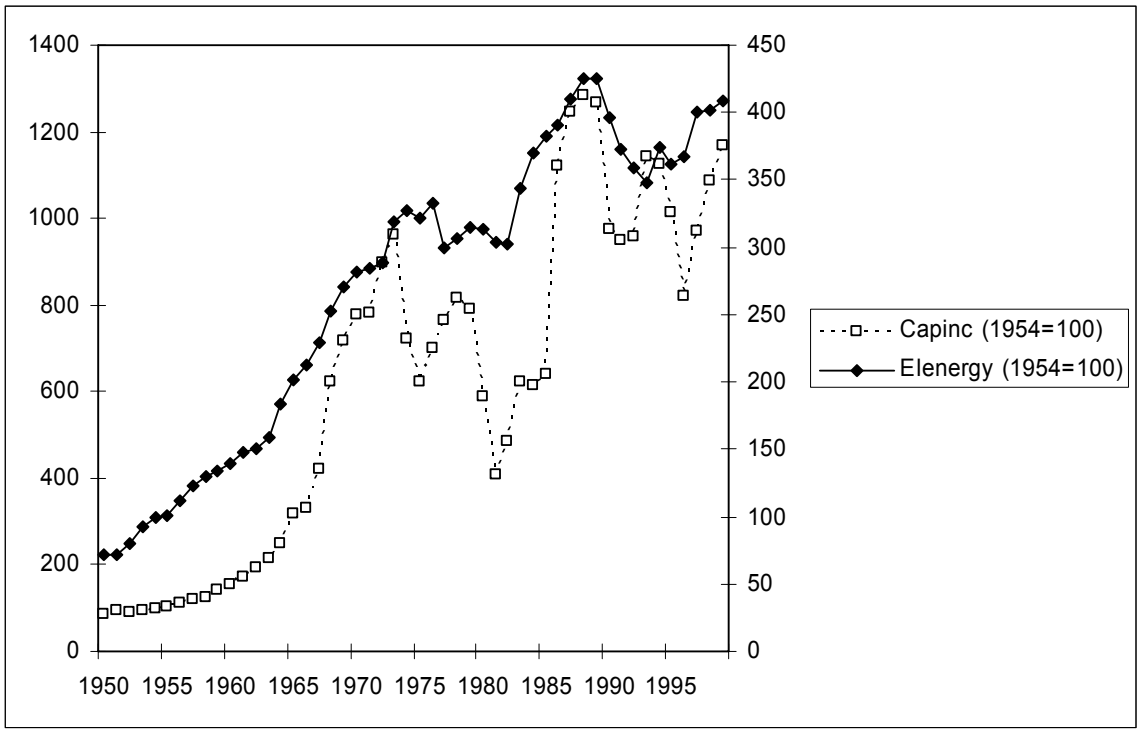
The 1970s energy price shocks had a clear influence also on the Swedish chemical industry. An econometric evaluation shows that the stock of machinery capital and the

[28] Installed power, yet another option, turned out to work less well as an indicator of effective capital and is in addition only available until 1979.
[29] Real value added less real salary and wage costs.

consumption of electric energy were co-integrated at the 5 % level between 1950 and 1973, but not during the period 1974-1995 (> 10 % level).

Overall, this makes energy consumption less suited as a proxy for capital in the chemical industry as well as in most other more energy intensive industries. The situation, as we shall see, is different in the pharmaceutical industry.

Figure B.1 Capital income (index=100 in 1954, left scale) and electric energy consumption (index=100 in 1954) in the Swedish chemical industry (SNI 35).



Source: SCB National Accounts, SCB Industry Statistics.

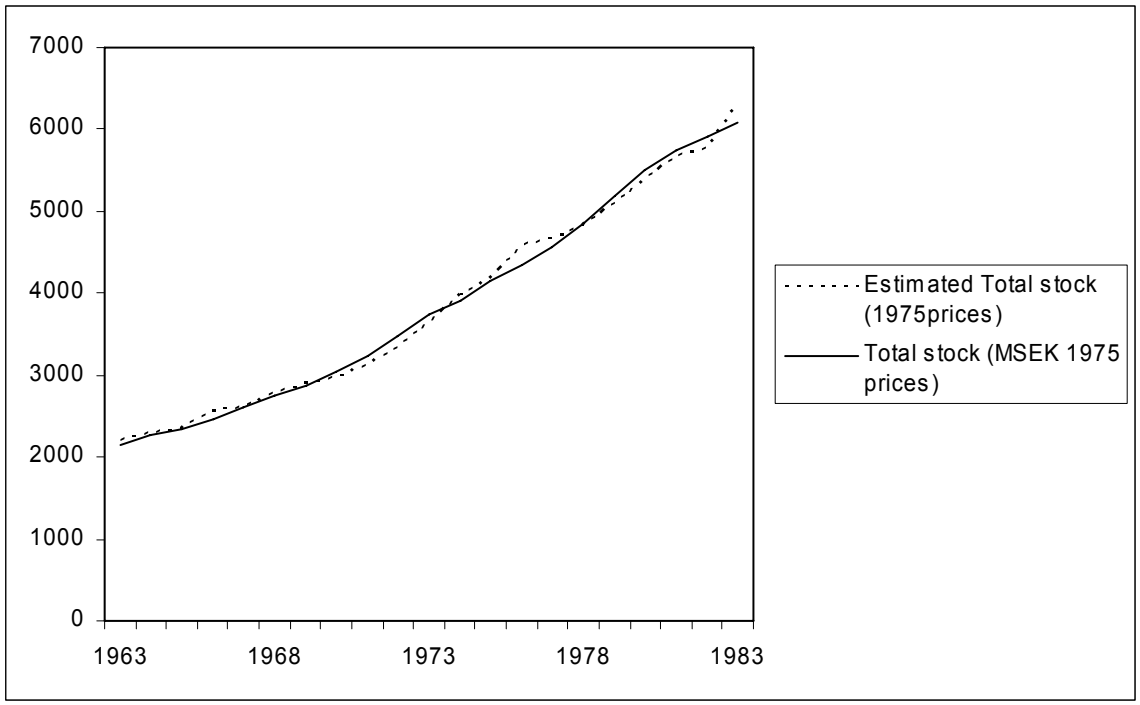
Although the pharmaceutical industry is a subset of the chemical industry, the latter is dominated by heavier, more energy intensive, process industries. The pharmaceutical industry is a considerably less energy intensive industry, and the need to increase the efficiency in energy use has been less pressing. This is reflected in the relation between capital and electric energy consumption. Here, the consumption of electric energy and the total capital stock are mutually co-integrated with very high significance (1% level) over the time period for which capital stocks are available in the national accounts (1963-83). The two regressions and the stationarity properties of the respective residuals are:

$$K_t = \beta_0 + \beta_1 \cdot E_t + \varepsilon_t \qquad \textit{ADF t-statistics for } \varepsilon_t\textit{: -4.24} \qquad (1)$$

$$E_t = \beta_0 + \beta_1 \cdot K_t + \varepsilon_t \qquad \textit{ADF t-statistics for } \varepsilon_t\textit{: -3.99} \qquad (2)$$

where K_t represents total capital stock, E_t the consumption of electric energy, β_0 constants[30] and ε_t the residual series. The 1% asymptotic critical value for the ADF t-statistics for co-integration is -3.90 (Davidson and McKinnon 1993:722). There are no signs of a changing relation in the 1970s.

Figure B.2 Total capital stock (from national accounts) and estimated total stock (based on electric energy consumption) for the Swedish pharmaceutical industry (SNI 3522).



Source: SCB National Accounts, SCB Industry Statistics.

Figure B.2 shows the total capital stock from the national accounts compared to the estimation derived from Equation 1 using the coefficients found in the regression. While the two variables are following each other in the long run, the estimated stock based on electric energy includes variations which are reasonable to attribute to varying utilization. It could be argued that this proxy for efficient capital stock should be shifted downwards so that the total stock from the national accounts forms the upper limit, corresponding to 100% utilization. However, such a shift would only have a negligible impact on the percentage changes, or more specifically first differences of logarithms (Δln), that is used in the calculation of the total factor productivity. It is also possible to assume that the

[30] It could be noted that the presence of a constant term (i.e. that a part of the capital is not consuming electricity) in the relation between capital and energy causes the capital to electric energy ratio (K/E) to fall slightly over time (asymptotically towards β_1) as the energy consumption is growing. This is different from the major parts of the Swedish manufacturing industry studied by Kander and Schön (2006) where it rose substantially. However, they found that lighter industries had a lower growth in K/E-ratio than heavier (more energy intensive) in the very long run. The pharmaceutical industry is apparently even less energy intensive than their category *light industries* consisting of engineering, saw mills, food industries, textiles and clothing.

utilization of capital may exceed 100 % of nominal capacity during shorter periods, although this would harm the machinery in the long run. The proxy is therefore used without any shift, as it is shown in Figure B.2. The reason for using an estimated stock rather than the energy consumption directly is that the co-integration relation (Eq.1 in this appendix) includes a constant which makes the percentage changes of energy consumption (in MWh) slightly different from the percentage changes of the capital stock (in MSEK). By recalculating the energy consumption into an estimated capital stock this issue is avoided.

The consumption of electric energy is available for the pharmaceutical industry for the period 1940-1995, and has been used to estimate the effective total capital stock in the calculation of total factor productivity in this study.

Appendix C

Validation of Swedish patent statistics against citation weighted pharmaceutical patenting in USA by Swedish inventors

Introduction

The purpose of this Appendix is to compare the 'raw' yearly patent count of national patents for the Swedish pharmaceutical industry with the US citation weighted patent statistics for patents filed by Swedish inventors.

It has been shown by Lanjouw and Schankerman (2004) that among the different methods suggested for quality adjustment of patent statistics, the number of received citations (also called forward citations) is the most relevant indicator for the stock market value of pharmaceutical firms (and therefore indirectly with their discounted expected profit flows). This is different from other US manufacturing industries, where the number of claims[31] appears to be more important.

The use of patent citations as a way to estimate the economic and technical quality of patents was pioneered by Trajtenberg (1990) who showed that the social value (measured as estimated gain in consumer surplus) of innovations in the field of computer tomography (CT) scanners was related to the citation weighted patents statistics rather than the raw patent count.[32] Harhoff et al. (1999) looked at the private economic value of innovations rather than the social value (which includes externalities). They asked holders of German patents that had been renewed until the full 18 year term and that had corresponding patents in USA about the estimated value of their innovations. They compared this with the number of citations received by both the German and the US patents and found that more valuable innovations had more citations in both cases. Hall et al. (2005) has further shown that a high ratio between a firm's stock of citations to their patent stock is positively associated with a high market value of the firm.

The reason for not using the citation weighted statistics directly in this study is that the available database only starts in 1963 for patent grants (1967 for applications) and hence is not covering the critical period of investigation. However, there are reasons to believe that the raw national patent count may work sufficiently well as an innovation indicator in the pharmaceutical industry as pointed out by Reekie (1973). First, since the study is only concerning one industry, the problem with differences in inter-industry propensity to patent is avoided. Second, the pharmaceutical industry is the most intensive user of patents as a way to protect their intellectual property of all industries. A study (Arundel and Kalba 1998) of the propensity to patent among major European firms (in 1993) shows that the pharmaceutical industry applied for patents for almost 80 % of its product

[31] Each patent document includes claims which delineate in detail the extent of the patent protection. It can be argued that more claims indicate a wider applicability of the patent. Other factors used in this study were backward citations and the number of countries patents are filed in.

[32] Patent citations are also used to trace knowledge flows (e.g. Jaffe et al. 1993) and to identify General Purpose Technologies (Hall and Trajtenberg 2004). This aspect will not be treated here.

innovations. This was higher than in any other industry. The importance of patents as a tool to appropriate the returns of research investments is due to the relatively short time and low cost required copying drugs (Levin et al. 1987). But even more importantly, key innovations may be further protected by surrounding patents preventing competitors to develop close substitutes. This was especially important in Sweden before 1978 when it was not possible to patent pharmaceutical products. These had instead to be protected by patents concerning the process to produce the drugs. The consequence was that a number of alternative processes had to be patented in order to achieve protection. It is likely that more important and valuable innovations had more such protective patents.

These three reasons suggest that the raw national patent count may be a more reliable innovation indicator in the pharmaceutical industry than in any other. Although it should be noted that even though citation weighted patent statistics are not exact measures of innovation, a correspondence between the Swedish patent count and the citation weighted US statistics will provide a quantitative underpinning for the use of the national count in this study.

Citation weighted patent data

The US patent and citation data has been taken from the NBER database described in Hall et al. (2001). A subset of this database was extracted based on the technology class of the patents (Subclass 31 Drugs including patent classes 424 and 514) and the first inventor's nationality (Swedish). The citation weighted patent count was calculated based on the number of citations:[33]

$$\textit{Citation weighted patent count}_t = \sum_{i=1}^{n_t} C_i \qquad (1)$$

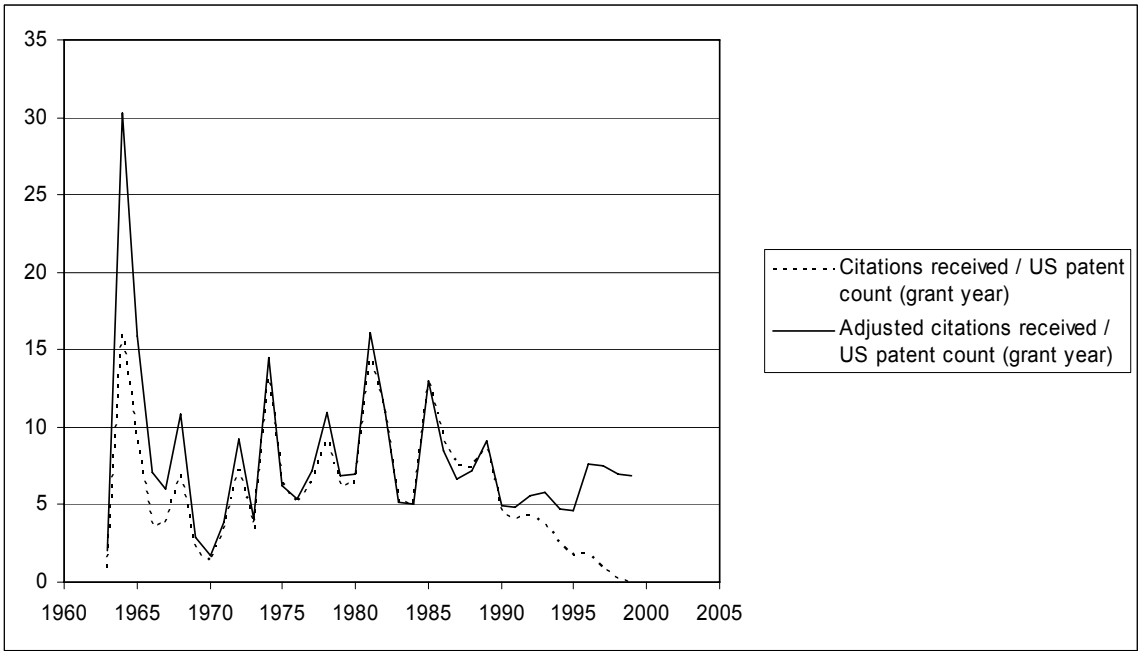
where C_i is the number of citations received for patent i and n_t is the number of patents during year t.

There are a number of issues connected with the use of time series of patent citations that needs to be taken into account (Hall et al. 2001). First, the number of citations suffers from truncation in two ways. The citation data is recorded for patents granted in 1975 and onwards. This means that patents applied for before that date would have lost some citations. Also, since many citations are made to considerably older patents (50 % to patents 10 year older or more), there will be a loss of citations for more recent patents. These would not yet have had time to receive all their citations. Second, the US Patent Office was computerized in the 1980s which made it easier to find patents to cite. This increased the propensity to cite and it affects the number of citations. Third, as patenting increases over time (even with a constant propensity to cite) there will be an increase in the number of citations since the stock of patents to cite grows. Overall, there will be a kind of 'inflation' in citations in addition to the truncation issues. This can be

[33] Trajtenberg (1990) also adds the patents themselves (i.e. $\Sigma(1+C_i)$). This has not been done here to avoid that any correlation between the raw US and Swedish patent counts influences the regression.

compensated for by dividing the citation count for our selected subset of patents by the average number of citations received by all patents of the same cohort and technology class. This removes all systematic influences of the three sources of error mentioned.[34] The impact of this adjustment can be seen in Figure C.1. Here, the average number of citations per US patents in our subset is shown, with and without the adjustment.[35] It is clear that the impact is largest in the early and late parts of the period, where the truncation is most severe. It can also be noted that the average number of citations in the mid part of the period has been fluctuating around a fairly stable mean of about eight citations per patent. This is close to the average level for patents in general during this period (Hall et al 2001).

Figure C.1 Average citations received per US granted drug patent by Swedish inventors (organized by grant year) with and without adjustment 1963-99.



Sources: NBER database Hall et al. 2001.

Another issue regarding patent statistics is the lag between application and grant. The time the patent office needs to handle the patent application is typically between 2-5 years, but may be longer. The application year is therefore a more accurate dating of the invention. It is also especially important to use application years when comparing patents

[34] A disadvantage of this method is that it also removes systematic changes for the entire technology class in the importance of patents. This has been regarded as acceptable since the alternative option would be to introduce assumptions about the distribution of citation lags etc. It has not been clear that this would have been more reliable for the current purpose.

[35] The average number of citations per cohort and technology class (Drugs & Medical, Table 2b in Hall et al. 2001valid for grant years), which the number of citations for our studied subset is divided with, has been normalized to have a maximum value of one. The citation count used in the regressions is based on application year and has been adjusted in a similar way using Table 2a.

granted in different countries, as in this Appendix, since their handling time may differ considerably. However, the use of application years leads to another form of truncation, as the data is based on granted patents (to avoid counting applications of too low quality to be granted). Patents applied for in the last couple of years of the period would consequently not have had time to be granted. This effect restrict the reliable patent application years for the Swedish national patent series to 1992. The first year for which the NBER database provides patent application data is 1967. This gives the usable period for an econometric comparison to 1967-92. However, data organized per grant year is available 1963-99, and in used in Figure C.1.[36]

Comparison

To compare the national patent count and the citation weighted US series organized by application year, a regression of first differences of the two series was run for the period 1967-92. Since it could be suspected that the introduction of pharmaceutical product patents might have reduced the need for protective patenting of alternative production processes, an additional term was introduced. This term consisted of the citation weighted US patent applications multiplied by a dummy taking the value one for the period from 1978 (and zero elsewhere).

$$\Delta(\text{Swe pat app}_{t-2}) = \beta_1 \cdot \Delta(\text{cit weight US pat app}_t) + \beta_2 \cdot \text{dummy}_{1978} \cdot \Delta(\text{cit weight US pat app}_t) \quad (2)$$

A two year lag between the Swedish and US application dates provided the best correlation. That the size of this lag is realistic is supported by a random sampling of patents using Google Patents. The average lag was 1.9 years for a sample of 35 patent applications made by Astra, Pharmacia, Kabi, Hässle, Draco and Leo.

The result of the regression showed a significant correlation and acceptable test results (Table C.1). Both β_1 *and* β_2 were clearly significant and β_2 had a negative sign and was only slightly smaller than β_1. This means that the overall coefficient for the period 1978-92 was close to zero. The results show that there was indeed a change in patenting behaviour when product patents became allowed. It also supports that the national patent count can be regarded as quality adjusted before the introduction of product patents.

[36] Figure C.1 uses grant years to provide a picture of the entire period. This is not so critical since the figure exclusively deals with US patents and its citations.

Table C.1 Regression results 1967-92, with dummy for 1978-92.

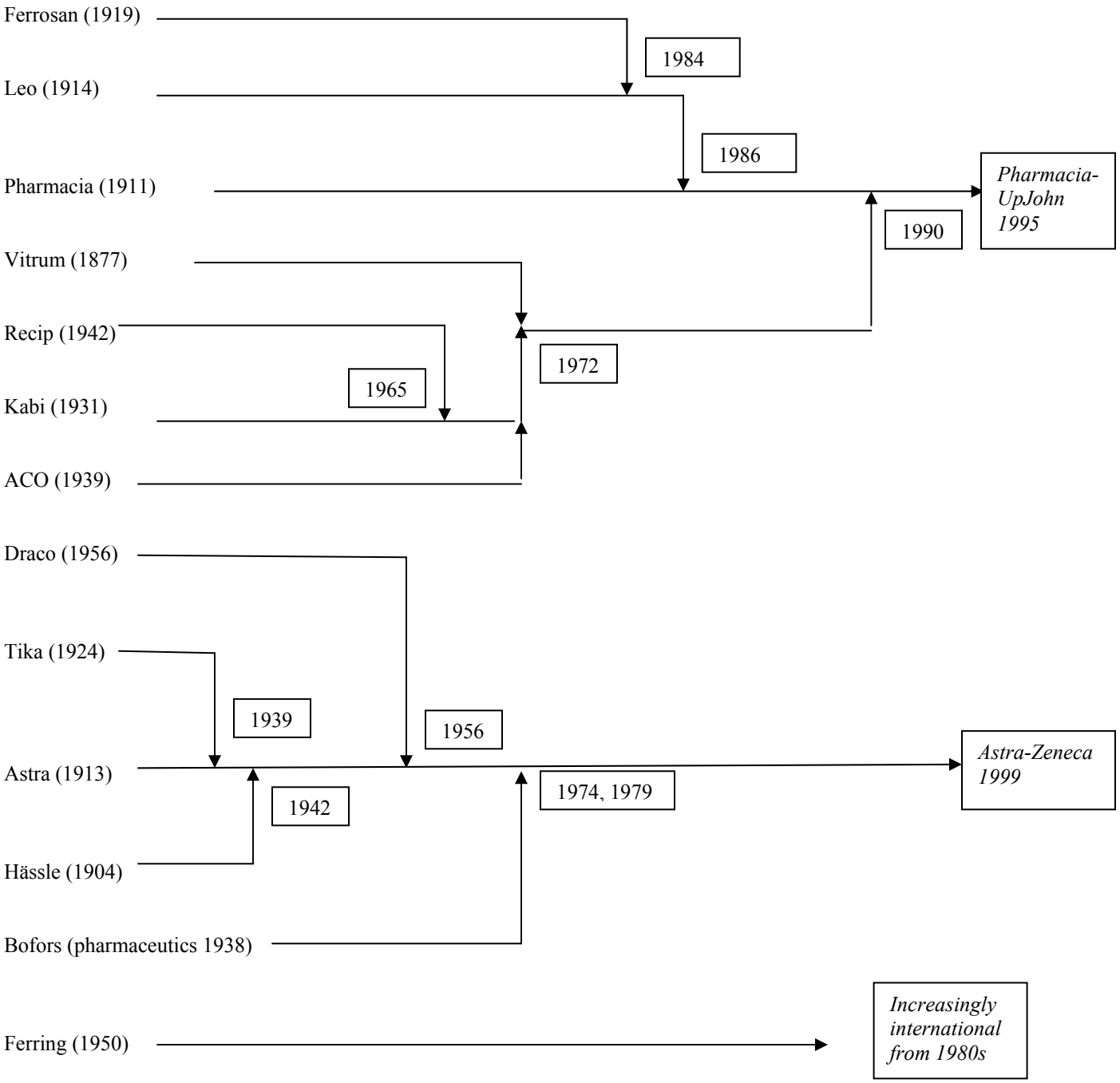
1967-1992
Dependent variable: Δ(Swe pat app (t-2))
Included observations: 25 after adjusting endpoints

Independent variables

	coefficient	p-value
Δ(cit weight US pat app (t))	0.137	0.000
Dummy1978 * Δ(cit weight US pat app (t))	-0.130	0.007
Adjusted R^2	0.42	
Durbin-Watson	2.37	
Jarque-Bera normality test p-value	0.59	
White test (cross terms, p-value)	0.59	
Breusch-Godfrey (worst of 1-5 lags, p-value)	0.11	

Appendix D

Concentration of the Swedish Pharmaceutical Industry



Sources: Norgren 1989: 43-47, Sundling 2003: 1-5, Fransson 1996: 174, 263, Ferring (2005), Larsson 1990: 7-9, SoU 1969:36 : 31-48, Ahlin and Lundgren 2002: 279, 297.

Note: The diagram is showing the principles of the concentration only. Companies may have changed name and ultimate owners over time and acquired companies may or may not have continued to use their old names.

References

Aghion, P. and Howitt, P. (1992), A model of growth through creative destruction", *Econometrica* 60(2): 323-351.

Ahlin J. and Lundgren, R. (2002), *Från Leopiller till Nicorette*, Helsingborg.

Apoteket (2006), Information received from Apoteket AB (H.Johansson), 2006-10-13.

Arundel A. and Kabla, I. (1998), "What percentage of innovations are patented? Empirical estimates for European firms", *Research Policy* (27:127-141.

Astra (1966, 1968), *Årsredovisning* (annual report), Södertälje.

Astra (1982, 1984, 1991, 1997), *Årsredovisning* (annual report), Södertälje.

AstraZeneca (2006), Information received from AstraZeneca (E.Ahlzén) 2006-09-20, 2006-09-27.

Bailey, M. (1972), "Research and development costs and returns: the US pharmaceutical industry", *Journal of Political Economy* 80(1): 70-85.

Bailey, M., Chakrabarti, A. (1985),"Innovation and productivity in the US industry", *Brookings Papers on Economic Activity* 1985(2): 609-639.

Berlin, H. (1979), *Läkemedelsregistreringar i Sverige under 1970-talet*, KabiVitrum Meddelande 1979:4.

Berlin, H. (1981), *Approval of drugs in Sweden during the 1960s*, KabiVitrum Report 1981:5.

Berlin, H (1982), *Läkemedelsregistreringar i Sverige 1979-1981,* KabiVitrum Meddelande 1982:5.

Berlin, H and Jönsson, B. (1984), *Livslängd, ålder, förnyelse – en analys av det svenska läkemedelssortimentet*, Liber Förlag, Stockholm.

Comanor, W. (1986), "The political economy of the pharmaceutical industry", *Journal of Economic Literature* 24(3):1178-1217.

Cox, D.R. (1972), "Regression Models and Life-Tables", *Journal of the Royal Statistical Society*, Series B (Methodological), Vol.34, No.2, pp.187-220.

Davidson, R. and McKinnon, J. (1993), *Estimation and Inference in Econometrics*, Oxford University Press.

Ferring (1987), *Årsredovisning* (annual report), Malmö.

Ferring (2005), Homepage of Ferring Pharmaceuticals, http://www.ferring.com/aboutus/history/Timeline/, 2005-08-30.

Ferring (2006), Information received from Ferring AB (R.Ratilainen), 2006-10-10.

Frankelius, P. (1999), *Pharmacia & Upjohn: Erfarenheter från ett världsföretags utveckling, Företagande över tid* Vol.2, Liber Ekonomi.

Fransson, S. (1996), *Bofors 350 år*, Stockholm.

Geroski, P. (1989), "Entry, innovation and productivity growth", *Review of Economics and Statistics* 71(4): 572-578.

Geroski, P. (1991), "Innovation and the sectoral sources of UK productivity growth", *Economic Journal* 101(409): 1438-1451.

Grabowski, H. and Vernon, J. (1990), "A new look at the returns and risks to pharmaceutical R&D", *Management Science* 36(7): 804-821.

Grabowski, H., Vernon, J., Thomas, L.G. (1978), "Estimating the effects of regulation on innovation: an international comparative analysis of the pharmaceutical industry", *Journal of Law and Economics* XXI(1): 133-163.

Grambsch, P., Therneau, T. (1994), "Proportional Hazards Tests and Diagnostics Based on Weighted Residuals", *Biometrika,* Vol.81, No.3, pp.515-526.

Griliches, Z. (1979), "Issues in assessing the contribution of research and development to productivity growth", *Bell Journal of Economics* 10(1):92-116.

Griliches, Z. (1990), "Patent Statistics as Economic Indicators: A Survey", *Journal of Economic Literature*, Vol.XXVIII (December), pp.1661-1707.

Griliches, Z. and Mairesse, J. (1984), "Productivity and R&D at the firm level", in Griliches, Z. (ed.), *R&D, patents and productivity*, The University of Chicago Press.

Grossman G. and Helpman, E. (1991), "Quality Ladders in the Theory of Growth", *Review of Economic Studies,* Vol.58, No.1:43-61.

Hall, B., Jaffe, A. and Trajtenberg, M. (2001), "The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools", *NBER Working Paper* 8498, NBER.

Hall, B., Jaffe, A. and Trajtenberg, M. (2005), "Market value and patent citations", *RAND Journal of Economics* 36(1):16-38.

Hall, B. and Mairesse, J. (1995), "Exploring the relationship between R&D and productivity in French manufacturing firms", *Journal of Econometrics* 65: 263-293.

Hall, B. and Mairesse, J. (2006), "Empirical studies of innovation in the knowledge-driven economy", *Economics of Innovation and New Technology* 15(4/5): 289-299.

Hall, B., Trajtenberg, M. (2004), "Uncovering GPTS with Patent Data", *NBER Working Paper* 10901, NBER.

Harhoff, D., Narin, F. Scherer, F.M. and Vopel, K. (1999), "Citation Frequency and the Value of Patented Inventions", *Review of Economics and Statistics* 81(3):511-515.

Holm, E. (1992), *Hässle 1904-1988 : en berättelse om hur apotekslaboratoriet i Hässleholm utvecklades till ett internationellt forskningsföretag*, Astra Hässle.

Hulten C. (1992), "Growth Accounting When Technical Change is Embodied in Capital", *American Economic Review*, Vol.82, No.4:964-980.

IMS Health (2006), Information received from IMS Health (M.Jacobsson), November.

Isidorsson, T. (2001), *Striden om tiden - arbetstidens utveckling i Sverige under 100 år i ett internationellt perspektiv*, Göteborg.

Jaffe, A., Trajtenberg, M. and Henderson, R. (1993), ”Geographic localization of Knowledge Spillovers as Evidenced by Patent Citations”, *Quarterly Journal of Economics* 108(3):577-598.

Jensen, E. (1987), “Research expenditure and the discovery of new drugs”, *Journal of Industrial Economics* 36(1): 83-95.

Josephson, C. (2005), *Growth and Business Cycles -Swedish Manufacturing Industry 1952-2001*, Lund Studies in Economic History No.37, Lund.

Kabi Pharmacia (1992), *Årsredovisning* (annual report), Uppsala.

Kabi Vitrum (1979), *Årsredovisning* (annual report), Stockholm.

Kander, A. and Schön, L. (2005), *The energy – capital relation, Sweden 1870-2000*, Paper for the Sixth Conference of the European Historical Economics Society, Istanbul.

Krantz, O. and Schön, L. (2007), *Swedish Historical National Accounts 1800-2000*, *http://www.ehl.lu.se/database/LU-MADD, 2007-01-25*.

Lanjouw, J. and Schankerman, M. (2004), “Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators”, *Economic Journal* 114:441-465.

Larsson, H.A. (1990), *Draco - Astras forskningsföretag i Lund*, Lund.

Leo (1985), *Årsredovisning* (annual report), Helsingborg.

Levin, R., Klevorick, A., Nelson, R. and Winter, S. (1987), “Appropriating the Returns from Industrial Research and Development”, *Brookings Papers on Economic Activity* 1987(4):242-279.

LIF (1980, 1982-85, 1987-93), *LIF Fakta*, Läkemedelsindustriföreningen, Stockholm.

LIND 1978, *Svensk läkemedelsindustri – några synpunkter, Delrapport från Läkemedelsdelegationen (LIND)*, Industridepartementet Ds I 1978:18.

Lindqvist K., Sundling, S. (1993), *Xylocaine – a discovery – a drama – an industry*, Astra, Södertälje.

Ljungberg J. (1990), *Priser och marknadskrafter i Sverige 1885-1969 : en prishistorisk studie*, Studentlitteratur, Lund.

Lönngren et al. (1999), *Svensk Farmaci under 1900-talet,* Apotekarsocietéten, AB Boktryck, Helsingborg.

Malmberg, C. (2005), *Trademarks statistics as innovation indicators – A micro study*, CIRCLE Working Paper 2005/17, http://www.circle.lu.se/html/working_papers.aspx , 2006-06-01.

MPA (2006), extract from the Swedish Medical Products Agency’s (*Läkemedelsverket*) database of registered pharmaceutical specialties, received 2006-08-28.

MPA (2007), Information received from the Swedish Medical Products Agency (*Läkemedelsverket*) 2007-01-26.

Nordisk Läkemedelsstatistik (1982), *Nordisk Läkemedelsstatistik 1978-80:2*, NLN publication, Helsingfors.

Norgren, L. (1989), *Kunskapsöverföring från universitet till företag- En studie av universitetsforskningens betydelse för de svenska läkemedelsföretagens produktlanseringar 1945-1984*, Stockholm.

Nyquist, S. (1992), *Kärnbolaget AB - Kabi : nedslag i Kabis historia och utveckling från Vitrum 1877 till Kabi Pharmacia 1990* , Uppsala.

Peltzman, S. (1973), "An evaluation of consumer protection legislation: The 1962 Drug Amendments", *Journal of Political Economy* 81(5): 1049-1091.

Pharmacia (1984, 1985, 1988), *Årsredovisning* (annual report), Uppsala.

PRV (1910-1999), *Patent* , information about granted patents issued each year, Patent och Registreringsverket (PRV), Stockholm.

Reekie, W.D. (1973), "Patent data as a guide to industrial activity", *Research Policy* 2:246-264.

Reiland, G. (1984), *Patenthandboken – om patentering och patentskydd i Sverige*, Avesta.

Romer P. (1990), "Endogenous Technological Change", Journal *of Political Economy* 98 (October), S71-S102.

Rujas, J. (1999), "Trade marks: complementary to patents", *World Patent Information,* Vol. 21, pp.35-39.

SCB (2004), Specially ordered statistics, Statistiska Centralbyrån, Stockholm.

SCB Statistics database (2005), Statistikdatabasen, www.scb.se, 2005-12-05.

Schankerman, M. (1981) "The effects of double-counting and expensing on the measured returns to R&D", *Review of Economics and Statistics* 63(3): 454-459.

SCB Research Statistics (1969-97), *Forskningsstatistik*, Statistiska Meddelanden Serie U, Statistiska Centralbyrån, Stockholm.

SCB Business Statistics (1984), *Sveriges Officiella Statistik, Företagen – ekonomisk redovisning*, Statistiska Centralbyrån, Stockholm.

SCB Industry Statistics (1952-96), *Sveriges Officiella Statistik, Industri*, Kommerskollegium/Statistiska Centralbyrån, Stockholm.

SCB National Accounts (1963-83), *Nationalräkenskaper*, Statistiska Meddelanden Serie N, Statistiska Centralbyrån, Stockholm.

SCB Trade Statistics (1952-96), *Sveriges Officiella Statistik, Handel/Utrikeshandel*, Kommerskollegium/Statistiska Centralbyrån.

SOU 1969:36, *Läkemedelsindustrin, Betänkande avgivet av koncentrationsutrredningen 1969*, Finansdepartementet, Stockholm.

SOU 1980:33, *Svensk läkemedelsindustri: Betänkande av Läkemedelsindustridelegationen*, Stockholm.

SOU 2003:54, *Semesterlagen och övriga ledighetslagar - översyn och förenklingar: slutbetänkande / av Kommittén för nya arbetstids- och semesterregler (Knas)*, Stockholm.

SOU1992:27, *Årsarbetstid : ny lag om arbetstid och semester för produktivitet och valfrihet : betänkande / av Utredningen om flexibla arbetstidsregler m.m.,* Stockholm.

Sundling, S. (2003), *Per aspera ad Astra, Astra 1913-1999*, Ekerlids Förlag.

Temin, P. (1980), *Taking your medicine – drug regulation in the United States*, Harvard University Press.

Thomas, L.G. (1990), "Regulation and firm size: FDA impacts on innovation", *RAND Journal of Economics* 21(4):497-517.

Trajtenberg, M. (1990), "A Penny for Your Quotes: Patent Citations and the Value of Innovations", *RAND Journal of Economics 2*1(1):172-187.

Wallmark, T. and McQueen, D. (1986), *100 viktiga svenska innovationer under tiden 1945-1980*, Lund.

Wieser, R. (2005), "Research and development productivity and spillovers: empirical evidence at the firm level", *Journal of Economic Surveys* 19(4): 587-621.

Wiggins, S. (1981), "Product quality regulation and new drug introductions: some new evidence form the 1970s", *Review of Economics and Statistics* 63(4): 615-619.

Wiggins, S. (1983), "The impact of regulation on pharmaceutical research expenditures: a dynamic approach", *Economic Inquiry* XXI: 115-128.

Wiggins, S. (1982), "The effect of US pharmaceutical regulation on new introductions", in Lindgren, B. (ed.), *Pharmaceutical Economics – paper presented at the 6th Arne Ryde Symposium Helsingborg 1982*, Liber Förlag, Malmö.

Åberg, Y. (1969), *Produktion och produktivitet i Sverige 1861-1965*, Industriens Utredninginstitut, Almqvist & Wiksell, Stockholm.

Östholm, I. (1995), *Drug discovery – a pharmacists story*, Swedish Pharmaceutical Press, Stockholm.

CIRCLE ELECTRONIC WORKING PAPERS SERIES (EWP)

CIRCLE (Centre for Innovation, Research and Competence in the Learning Economy) is a multidisciplinary research centre set off by several faculties at Lund University and Blekinge Institute of Technology. The founding fathers of CIRCLE include Lund Institute of Technology, Administrative, Economic and Social Sciences, Department of Business Administration, and Research Center for Urban Management and Regional Development.

The CIRCLE Electronic Working Paper Series are intended to be an instrument for early dissemination of the research undertaken by CIRCLE researchers, associates and visiting scholars and stimulate discussion and critical comment.

The working papers present research results that in whole or in part are suitable for submission to a refereed journal or to the editor of a book or have already been submitted and/or accepted for publication.

CIRCLE EWPs are available on-line at: http://www.circle.lu.se/publications

Available papers:

2007

WP 2007/01
Path-following or Leapfrogging in Catching-up: the Case of Chinese Telecommunication Equipment Industry
Liu, Xielin

WP 2007/02
The effects of institutional change on innovation and productivity growth in the Swedish pharmaceutical industry
Malmberg, Claes

2006

WP 2006/01
The Swedish Paradox
Ejermo, Olof; Kander, Astrid

WP 2006/02
Building RIS in Developing Countries: Policy Lessons from Bangalore, India
Vang, Jan; Chaminade, Cristina

WP 2006/03
Innovation Policy for Asian SMEs: Exploring cluster differences
Chaminade, Cristina; Vang, Jan.

WP 2006/04
Rationales for public intervention from a system of innovation approach: the case of VINNOVA.
Chaminade, Cristina; Edquist, Charles

WP 2006/05

Technology and Trade: an analysis of technology specialization and export flows
Andersson, Martin; Ejermo, Olof

WP 2006/06
A Knowledge-based Categorization of Research-based Spin-off Creation
Gabrielsson, Jonas; Landström, Hans; Brunsnes, E. Thomas

WP2006/07
Board control and corporate innovation: an empirical study of small technology-based firms
Gabrielsson, Jonas; Politis, Diamanto

WP2006/08
On and Off the Beaten Path:
Transferring Knowledge through Formal and Informal Networks
Rick Aalbers; Otto Koppius; Wilfred Dolfsma

WP2006/09
Trends in R&D, innovation and productivity in Sweden 1985-2002
Ejermo, Olof; Kander, Astrid

WP2006/10
Development Blocks and the Second Industrial Revolution, Sweden 1900-1974
Enflo, Kerstin; Kander, Astrid; Schön, Lennart

WP 2006/11
The uneven and selective nature of cluster knowledge networks: evidence from the wine industry
Giuliani, Elisa

WP 2006/12
Informal investors and value added: The contribution of investors' experientially acquired resources in the entrepreneurial process
Politis, Diamanto; Gabrielsson, Jonas

WP 2006/13
Informal investors and value added: What do we know and where do we go?
Politis, Diamanto; Gabrielsson, Jonas

WP 2006/14
Inventive and innovative activity over time and geographical space: the case of Sweden
Ejermo, Olof

2005

WP 2005/1
Constructing Regional Advantage at the Northern Edge
Coenen, Lars; Asheim, Bjørn

WP 2005/02
From Theory to Practice: The Use of the Systems of Innovation Approach for Innovation Policy
Chaminade, Cristina; Edquist, Charles

WP 2005/03
The Role of Regional Innovation Systems in a Globalising Economy: Comparing Knowledge Bases and Institutional Frameworks in Nordic Clusters
Asheim, Bjørn; Coenen, Lars

WP 2005/04
How does Accessibility to Knowledge Sources Affect the Innovativeness of Corporations? Evidence from Sweden
Andersson, Martin; Ejermo, Olof

WP 2005/05
Contextualizing Regional Innovation Systems in a Globalizing Learning Economy: On Knowledge Bases and Institutional Frameworks
Asheim, Bjørn; Coenen, Lars

WP 2005/06
Innovation Policies for Asian SMEs: An Innovation Systems Perspective
Chaminade, Cristina; Vang, Jan

WP 2005/07
Re-norming the Science-Society Relation
Jacob, Merle

WP 2005/08
Corporate innovation and competitive environment
Huse, Morten; Neubaum, Donald O.; Gabrielsson, Jonas

WP 2005/09
Knowledge and accountability: Outside directors' contribution in the corporate value chain
Huse, Morten, Gabrielsson, Jonas; Minichilli, Alessandro

WP 2005/10
Rethinking the Spatial Organization of Creative Industries
Vang, Jan

WP 2005/11
Interregional Inventor Networks as Studied by Patent Co-inventorships
Ejermo, Olof; Karlsson, Charlie

WP 2005/12
Knowledge Bases and Spatial Patterns of Collaboration: Comparing the Pharma and Agro-Food Bioregions Scania and Saskatoon
Coenen, Lars; Moodysson, Jerker; Ryan, Camille; Asheim, Bjørn; Phillips, Peter

WP 2005/13
Regional Innovation System Policy: a Knowledge-based Approach
Asheim, Bjørn; Coenen, Lars; Moodysson, Jerker; Vang, Jan

WP 2005/14
Face-to-Face, Buzz and Knowledge Bases: Socio-spatial implications for learning and innovation policy
Asheim, Bjørn; Coenen, Lars, Vang, Jan

WP 2005/15
The Creative Class and Regional Growth: Towards a Knowledge Based Approach
Kalsø Hansen, Høgni; Vang, Jan; Bjørn T. Asheim

WP 2005/16
Emergence and Growth of Mjärdevi Science Park in Linköping, Sweden
Hommen, Leif; Doloreux, David; Larsson, Emma

WP 2005/17
Trademark Statistics as Innovation Indicators? – A Micro Study
Malmberg, Claes