Innovation matters

An empirical analysis of innovation 2002–2004 and its impact on productivity

Hans-Olof Hagén, Caroline Ahlstrand, Martin Daniels, Emma Nilsson and Adrian Adermon

Conclusions

In this study we have found that the choice for a firm to be innovative is very dependant on its markets. If a firm's primary market is local the probability that it has chosen to be innovative is very small, or the other way round, the probability for the firm to be successful outside the local market if it do not innovative is limited. For those firms which operate on the world market outside Europe it is even more important to be innovative, especially the large and medium sized firms. Size and being part of a group also helps. We have also found that a high proportion of the staff with at least three years university education is essential. For the medium sized and larger firms it seems like their ICT use also matters (there are very few observation on both ICT and innovation for the small firms)

For the innovative firms their market orientation is influenced not only if they invest in new products and services, but also by how much they invest per employee. Even more important is their innovation cooperation. Of this cooperation; those with customers, competitors and consultants seem to be of most value. Generally the cooperation stimulates the innovation even more for larger firms. However innovation investments per employee decrease with size. This could be due to an existence of return to scale in the innovation process, in other words it could be necessary to reach certain critical levels for the smaller companies. Knowledge is of course also essential, both university educated staff and the level of the firm's ICT use made significant contributions to the innovation intensity.

The innovation output, the proportion of new products and services in sales, is not only explained by product innovation activities but is also dependant on process innovation. The latter is even more important for the medium sized and large companies. For those companies the output that a firm produces, given the innovation input, is also significantly increased for the firms who had access to fast broadband in the beginning of the period. For all firms the efficiency of the innovation process, more output for a given input, increased with scale.

Finally the productivity of the innovative firms was dependent on the innovation output irrespectively the size of the firm. The quality of staff, as the market values it, was also an important factor for the productivity of the firm. Both these factors were major contributors to the productivity growth.

Introduction

This paper is partly based on a bachelor thesis[1] made by Adrian Adermon and Emma Nilsson at Uppsala University in cooperation with Hans-Olof Hagén and Martin Daniels at Statistics Sweden. These analyses have been further developed by Caroline Ahlstrand, Martin Daniels and Hans-Olof Hagén, the project manager. This work has been done in contact with an ongoing innovation project run by the Organisation for Economic Co-operation and Development (OECD) which Statistics Sweden is participating in. We want to thank Hans Lööf at the Royal Institute for Technology for being our inspiration for this work and also for his valuable comments. We also want to thank Mariagrazia Squicciarini, VTT Technical Research Centre of Finland and KUL Leuven *and Pierre Mohnen from Merit at the Maastricht University for many important comments and suggestions.*

Innovation is a strategy to improve the firm's performance

There are several reasons why a firm chooses to innovate, but primarily a firm is innovative because it can potentially improve its performance. This can for example be by increasing demand or reducing costs. As a result of innovation activity; new products or processes can evolve that will enhance the competitive advantage of the innovative firm creating higher prices, increased market share and thus increased profits. Innovation also has the potential of improving a firm's performance due to the fact that it increases the ability to innovate. By process innovation the production creates a higher capability for the development of new products, organisational skills and knowledge that can be used to innovate even further. Innovation can thus be seen as an aspect of business strategy or part of an

1 *"Innovation and Productivity amongst Swedish Firms 2002-2004, An Empirical Analysis" by Authors:Adrian Adermon and Emma Nilsson http://www.dis.uu.se/Statistik/essays/c/Innovation_and_Productivity_rev%5B1%5D.pdf*

investment decision undertaken to create competence for product development or improved efficiency. (Oslo Manual 2005, p.29f)

Surveys and models

Innovation as an engine for growth in output and productivity has been widely acknowledged in the last decades and several studies have been conducted in the field trying to achieve a better understanding of the economic impact of innovation activities. In 1979 Griliches introduced a framework for the analysis of innovation and productivity illustrating how investments in research generate knowledge, innovation output and finally growth in production. Using a production function, Griliches estimated the partial contribution of R&D to growth and found significant problems concerning simultaneity, the measurement of output in R&D intensive industries, and the stock of R&D capital (Griliches 1979 p.2). With the Crepón, Duguet & Mairesse (CDM) paper in 1998, three important contributions were made in order to further understand the proposed link between innovation and productivity.

Firstly the CDM-paper introduced a structural model which explained productivity by innovation output[2], and innovation output by research investment and by doing so the authors brought together important parts of the empirical research conducted after Griliches (1979).

Secondly the CDM-paper made use of new data provided by the European Community Innovation Survey (CIS) which included important information on patents and innovative sales as well as qualitative indicators on demand pull and technological push indicators.

Thirdly the paper presented a significant contribution to the econometric method of innovation research by developing a modelling framework that accounted for sample selectivity (which originates from the firms' choice of undertaking R&D), simultaneity biases (productivity, innovation and research are determined endogenously), and the different statistical features of the data. (Crepón et al 1998 p.2).

Models similar to the CDM have become widely used amongst innovation researchers[3] and so also in Sweden. In Lööf & Heshmati (2006) a version of the CDM model was applied to Swedish CIS-data examining the sensitivity between innovation and firm performance amongst both manufacturing and service firms. Using the same framework for both groups of firms the authors examined the

2 *Previous research had concentrated on innovation input (R&D) and its effects on productivity.*

3 *See for example Klomp & van Leeuwen (2001), Criscuolo & Haskell (2003), Janz et al (2004) Benavente (2006), Jefferson, Huamao & Xiaojing (2006), Van Leeuwen & Klomp (2006), Mohen, Mairesse & Dagenais (2006)*

effect of innovation investment on innovation output as well as the effects of innovation output on firm performance. Matching the information from the CIS survey with business register data allowed the authors to widen the analysis and explore the sensitivity of their results even further. Whilst the understanding of the economic effects of innovation has grown it is still considered to be incomplete. Globalization and changes in the world economy have continuously changed the process of innovation as well as widened markets and access to information for firms. It is therefore important to continue to examine and improve the measures of innovation in order to develop efficient tools for analysis and design better policies for further economic growth. (Oslo Manual 2005, p.10) The CIS surveys have shown us that it is possible to collect information on the complex and differentiated process of innovation. With new Swedish data on innovation activities, we are presented with an excellent opportunity for further research on innovation amongst Swedish enterprises.

Our model

We have used a model developed by Lööf & Heshmati (2006) which allowed us to compare our results with theirs. While Lööf & Heshmati used data for their analysis from an enlarged survey we are presented with a much more narrow range of information by the CIS4. An exact comparison with the Lööf & Heshmati study will therefore not be possible since the CIS4 lacks information on variables included in their analysis.

However, in addition to using labour productivity to measure productivity as Lööf & Heshmati did, we also used multifactor productivity and the increase in multifactor productivity between 2002 and 2004. The multifactor productivity is generally a better measure of productivity since it takes account of more production factors. This is also true for innovation research purposes. Furthermore, it is an advantage to study the effect of innovation on the development in productivity for the same period and be able to use variables from different years.

Our data

The innovation data that was used is from the most recent Community Innovation Survey (CIS4), covering innovation activities in Swedish enterprises from 2002 to 2004, and as in Lööf & Heshmati this was complemented with business register data on the firms in CIS4. Some data on individuals was also taken from the LISA database to get some information on the quality of the staff of the individual firms. Finally a small proportion of the CIS4 firms, around 450, had also answered the questions in the E-business surveys for 2003 and 2004. These surveys actually cover the activities under 2002 and 2004 respectively, and the firms that have answered all the questions mainly have over 250 employees.

Definitions

Due to the complexity of innovation and the innovation process it is important to develop a basic definition of innovation and the innovative firm before we continue. According to the Oslo Manual (2005) which stakes out the guidelines for collecting and interpreting innovation data, innovation can occur in four main areas: product (good or service)[4], process[5], organisational[6] and marketing[7]. While the first two areas of innovation have been focused in previous manuals, organisational and marketing innovations are quite new and still not fully developed. The data in CIS4 contains information solely on product and process innovations our analysis will therefore be narrowed down to examining these two areas only.

When using the definition provided in the Oslo Manual it is not required that the firm implementing the product or process is the first firm on the market to do so (the definition allows imitators).[8] Instead the minimum requirement of innovation is that the product or process implemented needs to be new or significantly improved to the firm.

Our definition of innovation therefore becomes: *"a product (goods or service) or process new or significantly improved to the market or to the firm"*.

We use this definition when categorizing our sample into innovative and non-innovative firms. A firm is defined as innovative if it reports positive innovation investment (input) and has positive innovative sales (output). Non-innovative firms hence became those that during the same time period show; neither positive innovation investment nor positive innovative sales, firms with positive innovation input but no positive innovation output, and finally firms with positive innovation output but no innovation input.

4 *A product innovation is in the Oslo Manual (2005) defined as: ìthe introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.î (Oslo Manual (2005) p.48)*

5 *A process innovation is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.î (Oslo manual 2005 p.49)*

6 *An organisational innovation is the implementation of a new organisational method in the firmís business practices, workplace organisation or external relations.î (Oslo Manual 2005, p.51)*

7 *A marketing innovation is the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricingî (Oslo Manual 2005, p.49)*

8 *This originates from the fact that imitators often become innovators when they unintentionally or by design do things differently in the imitation process and therefore become innovators themselves.*

Like Lööf & Heshmati (2006) we define innovative sales (innovation output) as the sales revenue of a firm that originates from products introduced on the commercial market in the three most recent years (here 2002-2004). Innovation input is defined as the total sum of expenditures in four different areas of innovation involvement including: (i) R&D based products, services or process innovations within the firm, (ii) purchase of R&D undertaken by other firms, public or private research organisations (external R&D), (iii) acquisition of machinery and equipment related to products, services and process innovations, (iv) the acquisition or licensing of patents or non-patented inventions, know-how, or other knowledge from firms or organisations outside the firm (external knowledge). In Lööf & Heshmati the definition of innovation input is extended to eight innovation expenditures, covering areas such as education, industrial design and introduction of innovations to the market. Unfortunately the CIS-data covering our period of interest do not provide us with information on these expenditures.

Treatment of extreme values

Very few restrictions were imposed on the data in order to make it more suitable for analysis. All observations were removed for which the number of employees was missing or less than 10. Firms which according to questions in CIS4 had an ongoing or an abandoned innovation activity had to have spent money on innovation or else they were deleted from the dataset. Firms which produce innovation need to have a market to sell it on. The markets must be either local, national, European or in any other non-European country or else the firms were excluded. One question in the CIS4 innovation survey all firms hade to answer whether they innovated or not: had they introduced new or significantly improved methods of production, logistic, delivery or distribution system or introduced new improved supporting activity to the market? Otherwise they were dropped.

Theoretical framework

Previous research has shown that estimation of innovation models requires special care in choosing methods that correctly take into account the characteristics of the relationships and data material. Crépon et al (1998) have constructed a model (the CDM model) that takes account of both selectivity and simultaneity problems, which are known to arise when studying innovation and productivity. Failure to account for selectivity and simultaneity will cause biased results. A modified version of this model, presented by Lööf & Heshmati (2006), will be used in this thesis. But we are more true to the CDM model in the sense that we use lagged variables.

Hall & Mairesse (2006) pointed out that different researchers have tended to use slightly different specifications and methods when studying innovation, which makes comparisons between different studies harder. Therefore we will stay fairly close to the model used by Lööf & Heshmati (2006).

Model

In the Lööf & Heshmati (L & H) model as well as in ours only the sub-sample of innovative firms is used in the second half of the model. The sub-sample of innovative firms consists of those firms that have had both positive innovation input and positive innovation output during the period.

The model consists of three relationships, represented by four equations. The first is the determination of innovation input modelled as two equations:

$$(1)\quad g^* = \beta_{10} + \sum \beta_{1i} x_{1i} + \varepsilon_1$$

$$(2)\quad k^* = \beta_{20} + \sum \beta_{2i} x_{2i} + \varepsilon_2$$

Equation (1) is a selection equation that models the decision of individual firms whether to innovate or not. The dependent variable g^* is a latent (unobservable) variable representing the decision to innovate or not, and has an observable counterpart g = 1 when $g^* > c$, and g = 0 otherwise. The explanatory variables x_{1i} are the determinants of whether a firm innovates or not. In this study we have followed L & H and set c = 0, and thus assume that firms that report no innovation input actually do not innovate at all.

Equation (2) models the amount of innovation effort done by firms, where k^* is a latent variable representing innovation input. Its observable counterpart k = k^* when g = 1 and k = 0 when g = 0. The explanatory variables x_{2i} are the determinants of the amount of innovation effort done by innovating firms.

Equations (1) and (2) are estimated for the full sample of firms, using a Heckman sample selection model[9].

The second relationship in the model is the one between innovation input and innovation output, which is estimated on the sub-sample of innovative firms:

$$(3)\quad t = \beta_{30} + \beta_{31} k + \beta_{32} \lambda + \sum \beta_{3i} x_{3i} + \varepsilon_3$$

where t represents innovation output (or knowledge production), k is predicted innovation input, x_{4i} is the inverted Mill's ratio estimated from Equation

9 *This model is also sometimes called generalized tobit, or heckit.*

(1), which is used to correct for sample selection bias, and the remaining explanatory variables x_{3i} are other determinants of innovation output. We use innovation sales as a proxy for innovation output.

The fourth relationship is a production function, relating the firm's production to its innovation output and other determinants:

$$(4) \quad q = \beta_{40} + \beta_{41} t + \sum \beta_{4i} x_{4i} + \varepsilon_4$$

where q is productivity, t is innovation output, and the remaining explanatory variables x_{4i} are other determinants of productivity. In the L&H model, equations (3) and (4) are estimated as a system using three-stage least squares, to correct for simultaneity bias, using sub-sample of innovating firms only. This last equation in the system is based on an augmented Cobb-Douglas production function (Crépon et al 1998).

Model specification

In Lööf & Heshmati (2006), the model was estimated separately for manufacturing and service firms. We have mainly limited us to work with the total sample, for which the results will be presented. However in addition we have also estimated the equations separating manufacturing and service firms, but we will only comment on some of these results.

In the selection equation (1), the dependent variable is a dummy variable (g*) set to 1 if the firm has reported innovation input, and 0 otherwise. The continuous explanatory variable, the indicator of size is the logarithm of employment while the other continuous variable is the percentage of the staff which has at least a three-year university education. In addition, we have used a dummy variable specifying if the firm is part of a business group and four dummies for which geographic market(s) the firm sells to. The possible nine dummy variables representing strongly important obstacles to innovation, three dummies for cancelled or delayed innovation activities, have been tried and skipped. They all seem to have been answered to a much larger extent by the firms which actually do innovate, and are thus meaningless to use in this context. The two dummies representing strongly important reasons why the firm is not innovative are instead only answered by those who do not innovate and are equally meaningless.

In the innovation input equation (2), the dependent variable (k*) is the natural logarithm of innovation input per employee. The explanatory variables are the same as in equation (1), with the addition of seven dummies representing the firm's most valuable cooperation partner for innovation and less the group variable.

For the innovation output equation (3), the dependent variable (t) is innovation output per employee, measured as log innovation sales per employee. The continuous explanatory variables are again the size variable and the proportion with a university degree. Parallel to equation (1) we have a dummy for the firms belonging to a business group. Equation (3) also has the estimated inverted Mill's ratio from equation (1) as an explanatory variable to correct for selection bias, as well as a variable measuring productivity, used to catch any feedback effects from Equation (4). The productivity measurement which is used is the logarithm of the multifactor productivity year 2002, since this could give an indication of the economic opportunities for innovation activities during the period 2002-2004.

The productivity equation (4) is specified with three alternative measures of productivity (q) as the dependent variable. The alternative specifications are: log value added per employee (labour productivity), the log of gross production multifactor productivity and the difference between the log for the multifactor productivity years 2002 and 2004. The continuous explanatory variables, all as logs, are innovation output, employment, physical capital per employee and average human capital per employee. In the L&H model, simultaneity is taken care of by the 3SLS method. Several dummy variables are included in the analysis, one controlling for whether or not the firm belongs to a business group, and three dummies representing new or markedly improved process innovations for the firm. We have also tested with the Mills ratio in equation (4) but this did not change the result very much. The differences were not on the positive side, since it did not improve the estimation result for the other variables so we decided to only use it in equation (3).

Additionally, all equations contain 8 dummy variables controlling for differences between the industries. Since we have dummies for all industries, the intercept term in each equation would be a linear combination of the industry dummies, making estimation impossible. Thus the intercept term has been dropped.

Results

Using the L&H model we estimated a four equation model measuring three main relationships: determining innovation input using our full sample and a Heckman sample selection model (equations 1 & 2, the first relationship), the relationship between innovation input and innovation output (Equation 3), and the relationship between innovation output and productivity (Equation 4). The last two equations were estimated simultaneously with 3SLS, using a sub-sample of only innovative firms.

After removing or correcting observations with missing values, we have 2 728 firms in our full sample, of which 1695 are manufacturing firms and 1033 service firms. The innovative sample used consists of 1374 firms, but due to missing variables around 960 observations were used in the last two equations, of which roughly 670 were manufacturing firms and 290 service firms.

Equation 1 – selection equation

The first equation is a selection equation, constructed as a dependent dummy variable, and models the probability to engage in innovation activities with an outcome of 1 if the firm has reported innovation input, and 0 otherwise. Because this equation is modelled with a so-called probit method we cannot interpret the coefficients directly as marginal effects, but rather we use the estimate's relative size and statistical significance. Table 1 presents the most important coefficients for equation (1).

Variable definitions

Size = Number of employee 2004

University degree = Share of employment with a post-secondary education 3 years or more 2002

Group = Enterprise is part of a group, 0/1 dummy

Market Local = Enterprise has sold goods or services on the local market during 2002-2004, 0/1 dummy

Market National = Enterprise has sold goods or services on the national market during 2002-2004, 0/1 dummy

Market EU = Enterprise has sold goods or services on the European market during 2002-2004, 0/1 dummy

Market other (foreign) = Enterprise has sold goods or services on other foreign markets 2002-2004, 0/1 dummy

Industry 1 = Capital intensive manufacturing, 0/1 dummy

Industry 2 = Labour intensive manufacturing, 0/1 dummy

Industry 3 = High tech intensive, 0/1 dummy

Industry 4 = Utilities, 0/1 dummy

Industry 5 = Trade, 0/1 dummy

Industry 6 = Transport, 0/1 dummy

Industry 7 = Communication, 0/1 dummy

Industry 8 = Knowledge intensive services, 0/1 dummy

The result from the first equation in table 1 gives a significant estimate for all included variables on a one percent level. The size of the company measured as the number of employees has together with the employee level of qualification (university degree) a great positive effect on the probability (or choice) to become innovative. But also the indicator that measures if the enterprise belongs to a group has a positive, significant effect. This is in consensus with economic theory.

Table 1 Sample selection equation (1)

Parameter	Estimate: Full sample
Size	0.102a
University degree	0.967a
Group	0.102a
Market Local	-0.222a
Market National	0.277a
Market EU	0.194a
Market other foreign	0.323a
a significant at the 1 percent level	
b significant at the 5 percent level	
c significant at the 10 percent level	

The geographical market the firm is operating on affects the choice of whether or not to conduct innovation activities. Firms operating on the local market are less likely to innovate than firms operating on the national or the European market. Most likely to innovate are firms operating on foreign markets outside Europe.

The industry dummies are only for strengthening the model and are not interpreted.

If the innovation selection equation is estimated separately for manufacturing services one finds that the differences are rather small, but being a part of a group does not matter for service firms. Furthermore, size and the percent of the staff that have a university degree is a little less important for the decision to become innovative.

Equation 2 – Innovation input

The first and the second equation in the model is a simultaneous determination of innovation input into the firm. The first equation was a Heckman selection equation that models the decision of individual firms on whether to innovate or not. The second is the outcome equation of Heckman called innovation input equation that models the amount of innovation input done by innovating firms. Table 2 presents the most important coefficients for equation (2).

Variable definitions

Own group = Cooperation with other enterprises within enterprise group, 0/1 dummy

Suppliers = Cooperation with suppliers of equipment, materials, components, or software, 0/1 dummy

Clients = Cooperation with clients or customers, 0/1 dummy

Competitors = Cooperation with competitors or other enterprises in your sector, 0/1 dummy

Consultants = Cooperation with consultants, commercial labs, or private R&D institutes, 0/1 dummy

Universities = Cooperation with universities or other higher education institutions, 0/1 dummy

Government = Cooperation with government or public research institutes, 0/1 dummy

Table 2 Innovation input equation (2)

Variable	Estimate: Full sample
Size (employment)	-0.104a
University degree	3.721a
Own group	0,254c
Suppliers	0.411a
Customers	0.888a
Competitors	0.921a
Consultants	0.939a
Universities	0.537a
Government	0.391
Market Local	-0.297a
Market National	0.199c
Market EU	0.558a
Market other foreign	0.574a
a significant at the 1 percent level	
b significant at the 5 percent level	
c significant at the 10 percent level	
In all equations industry is controlled for	

The result from the second equation in table 2 gives a negative significant relationship between employment and the amount of innovation input per employee. Notice that this means that large firms innovate less per employee, not less in total amount of money spent on innovation input.

The human capital variable has a large significant positive effect on the amount of innovation input. A significant positive effect on the amount of innovation input is also the case for enterprises being part of a group.

Cooperation with other partners had a positive effect on innovation input. In other words, those firms spend on average more on innovation input. A significant positive effect on innovation input is the case for cooperation with suppliers, clients, competitors, consultants and universities. Competitors, clients and consultants are most important cooperation partners as can be seen from the size of the coefficients. One kind of cooperation partner did not have a significant effect on the innovation activity: government or public research institutes, probably due to too few observations. These kinds of organisations have a very small role in the Swedish context since almost all government money goes to the universities.

The estimates for the geographic market show that firms selling to local markets do less innovation than firms selling to national or global markets.

A separate estimation of the innovation input equation for manufacturing and service firms give quite similar results but the diminishing investment per head does not appear for the manufacturing firms. One the other hand staff education and innovation cooperation is even more important for these than for the service firms.

Equation 3 – Innovation output

The purpose of Equation 3 is to explain what affects firm's innovation output. Equation 3 contains only one model, but different results are achieved as the model is simultaneously estimated with the productivity Equation (Equation 4) presented in table 4. Equation 4 is estimated with three different models. The dependent variables differ between the models. The dependent variables used in Equation 4 are: Value added labour productivity 2004, gross production multifactor productivity 2004, and gross production multifactor productivity 2002-2004. Innovation output is used both as an endogenous variable (table 3) as well as an exogenous variable in the productivity model (table 4).

Variable definitions:

Innovation output = Log innovation output per employee

Improved production methods = Dummy variable where 1 = Introduced onto the market a new or significantly improved methods of production, 0 otherwise

Improved distribution methods = Dummy variable where 1 = Introduced onto the market a new or significantly improved logistic, delivery or distribution system, 0 otherwise

Improved support methods = Dummy variable where 1 = Introduced onto the market a new or significantly improved supporting activities, 0 otherwise

To explain innovation output, variable size and business-group is included, as in model 1 and model 2. Three improved methods within the business, namely for production, distribution and support, as well as gross production multifactor productivity for 2002 (not presented in table 3) are also used in order to explain innovation output. How much the companies spend on innovation input is predicted in equation 2 and included to this model. Finally the inverted Mill's ratio is included to correct for selection bias as only innovating firm is used in equation 3 and equation 4. Human capital and cooperation with others was tested for in this model but did not give any effect and is not included in equation 3. But they are indirectly included since they are major explanatory variables for the innovation input so the predicted value of innovation input might provide the equation with that information.

Table 3. Results of the different specifications of the innovation output

	Innovation output measurement:		
Variable	Value added labour productivity 2004	Gross production multifactor productivity 2004	Gross production multifactor productivity 2002-2004
Size	0.654a	0.637a	0.691a
Group	0.279a	0.278a	0.279a
Improved production methods	0.191b	0.210b	0.1355c
Improved distribution methods	0.267b	0.241b	0.188c
Improved support methods	0.138	0.129	0.141
Predicted value of innovation input	0.225a	0.233a	0.262a
Inverted Mill's ratio	-0.130	-0.139	-0.024
a significant at the 1 percent level			
b significant at the 5 percent level			
c significant at the 10 percent level			
In all equations industry and gross production multifactor productivity is controlled for			

The number of people employed, (size) has a huge positive effect on innovation output in all models in table 3. According to the results large companies produce more innovation output per employee, controlled for other factors in the model, then small firms. If the innovation output equation is estimated separately for manufacturing services one finds that being a part of a group is important for service firms. Otherwise the results are almost identical.

Companies who improved both production and distribution methods during 2002-2004 generated more innovation output in 2004. The improvements for distribution are generally more effective to innovation output for service firms and the production for the manufacturing firms. Improved support methods had on the contrary no significant effect on innovation output.

More money spent per employee on innovation input results in more innovation output. According to the coefficient in the value added labour productivity model a 50 percent increase in innovation input raises innovation output by 10 percent points.

Equation 4 – Productivity

The productivity equations are an attempt to explain the productivity differences, respectively the changes in productivity, with the estimated innovation output and other relevant factors. In the first equation the productivity measurement is the value added labour productivity. This productivity measurement is the natural logarithm of value added in constant prices divided by the number employed persons in the respective firm. In the second equation gross production multifactor productivity is used instead as productivity measurement and in the third it is the change in the multifactor productivity. The multifactor concept means that both the input of intermediates, labour and capital is taken into account.

Variable definitions:

Gross production = total production sold to other firms or consumers in fixed prices

Intermediate inputs = the input of goods and services bought from other firms

Value added = gross production – intermediate inputs in fixed terms

Labour= number of people working in the firm

Capital=Book value of physical capital

Share of intermediate inputs in gross production = value of intermediate inputs/ gross production in current prices

Share of labour inputs in gross production = value of labour inputs/gross production in current prices

Share of capital inputs in gross production = value of capital inputs/gross production in current prices

Value added labour productivity = value added/ employment

Gross production multifactor productivity=gross production – industry median of value share of intermediates * Intermediates input –industry median of labour value share* Labour inputs – industry median of capital value share* Capital inputs

In this equation we will use some of the factors that are included in all the first three equations with just one exception, namely the size variable and an indication of the firm is part of a group. Beside the innovation output the new variables are the capital intensity (=logarithm for (physical capital per employed year 2004)) and the human capital variable. When it comes to explaining the productivity, it is not only the percentage of staff with an academic degree which is of relevance, as in the innovation process; it is the quality of the whole staff that matters. Therefore such an indicator that measures the quality of the whole staff has been used in the production function. It is also the level from the same year (2004) as the productivity measurement that is relevant since it is the people working that year that had created the productivity level which is to be explained.

Human capital

The method to calculate the human capital indicator that has been used is very much a market oriented one. The working population has been split into many subgroups according to four different characteristics. For each of the subgroups we calculated the average incomes from both the employed and the self-employed.

If the labour market functions well, the average income for each subgroup is the market's valuation of the different categories as labour inputs. This is in accordance with a long tradition represented by Jorgensen (1987) and Bureau of Labour Statistics (1993) both of which have somewhat different approaches for the US labour market. This has been further developed in US and Canadian data by Gu and Maynard (2001). The income means are then treated as the market valuation of different categories of labour in respective workplaces. In most workplaces there are of course only a small number of these categories represented. But with the help of the average income or prices on the labour input for each group it is possible to calculate a synthetic labour cost, or labour composition indicator for the whole workplace. This is a measurement that gives the labour quality as the market values it for each firm.

The characteristics that have been used are the traditional ones: age, education and ethnicity. However, gender is not included. The choice of the different categories for each variable is based on how they are valued on the market. The education variable is split into two dimensions: orientation, and levels. There are five different levels but only two fields: 1) the technical and natural science orientation and 2) all other orientations together. The levels starts with primary (level 1 and 2) and lower secondary, and ends with post graduate education (level 6). Concerning age, the workforce is split in as many as six categories, but of these the first and the sixth are very infrequent on the Swedish labour market. These categories are namely those who are 16-20 years of age, and those who have reached the age of 67. The ethnicity variable is based on the countries where they were born. Those with an origin outside of Sweden are divided in four groups.[10]

In the third specification of productivity which is used is the change in multifactor productivity between 2002 and 2004. In consequence with this choice the change in human capital between the same years are used instead of their 2004 levels. In all these specification it is controlled for industry.

Value added labour productivity

The hypothesis behind the specification of the productivity equation is that the innovation activity 2002-2004 that has created new products and services in 2004 should increase the firm's productivity level. The first alternative measurement of productivity is value added labour productivity. As can be seen from table 5 the coefficient is very high and significant, actually as high as 0.4. The capital intensity is as expected to be positive and significant. More machinery per worker should of course increase the value added per worker. However the coefficient is only 0.12 which is rather low compared with standard results. This could be because the size and group variable captures some of its effect.

There seems to be an increasing return to scale since the size coefficient comes out significant and positive. The advantage in the innovation process of being part of a group gives an additional boost to the firm's labour productivity with as much as 10 percent, given the innovation output and other factors. But more interesting is the very high coefficient for the human capital variable. A 10 percent higher level of this measurement leads to 7 percent higher value added labour productivity. But perhaps it is not so surprising since the cost of hiring more qualified staff increases the wage bill in proportion to value added just as much.

10 *The reason why the gender variable is excluded is because the human capital indicator that is used in this context was constructed for growth accounting purposes. Most of the differences of yearly earnings between men and women are more of an indicator of the differences of working hours than of anything else. In Sweden there are many more women than men who are working shorter hours. Since the quantitative labour input is measured in hours, the sector difference is already incorporated in that variable, and if the gender is included it is measured twice. The rest of the differences between the two sexes are considered to be a reflection of discrimination and not a difference in labour quality. Regional differences in wage levels also exist on the Swedish labour market, but these differences are not mainly due to differences in competence but rather to the size and character of the local labour market. The same is true for industries. In general there could be a tendency for an expanding sector to pay more for the same skill since it needs to attract more people. Sector differences can also be a reflection of regional differences. However, this is not only due to chance but also to conscious choices. Industries that are maturing are driven out from growth areas due to high wages and high rents. These factors are the reason for not including regions and sectors among our variables.*

Table 4 Results of the different specifications of the productivity equation

	Productivity measurement:		
Variable	Value added labour productivity 2004	Gross production multifactor productivity 2004	Gross production multifactor productivity 2002–2004
Group	0.099c	-0.024	-0.043
Size	0.425a	0.029	-0.137a
Capital intensity	0.115a	-0.106a	-0.046a
Human capital (2004 level respectively the change 2002–04)	0.734a	0.471a	Change variable 0.685a
Innovation output (estimated)	0.442a	0.075a	0.217a
a significant at the 1 percent level			
b significant at the 5 percent level			
c significant at the 10 percent level			
In all equations industry is controlled for			

There are also some other factors which have been tested for but found not significant, and thus are excluded from the final estimation. Among these variables is process innovation, but it should be remembered that this comes out significant in the estimation of the innovation output. That means that if process innovation is included in the productivity equation it is only to test if it gives some extra to the explanation of the labour productivity besides its effect on the innovation output. And since it is a measurement of process innovation input and not innovation output it is a very logic result. To get an similar output measure as for product innovation it is necessary to include a question like "What percentage of the production is made in a new or significantly improved process" and so on…in the CIS surveys. Furthermore, if the group indicator and the size variable become significant this is in addition to their effects on the innovation process.

Gross production multifactor productivity

A more interesting productivity measurement is the gross production multifactor productivity which measures how efficient the firm uses not only its labour input, but also its intermediates and its capital. All the coefficients should be smaller in this equation since their effect is measured on the gross production instead of value added which on average is more than twice as large. No indication of additional advantage of being part of a group is found here, nor any return to scale. On the contrary the large firms have improved their productivity to a lesser degree.

The significant and negative coefficient for the capital intensity must be interpreted as the capital intensive firms are less efficient in our data set. However it must be remembered that since industry is controlled for in the equations, capital intensive firms are those firms which are more capital intensive than the average firm in their industry. This result could perhaps been influenced by the fact that there is a high correlation between the increase in capital intensity between 2002 and 2004 and the level 2004.

Even in this equation the human capital indicator comes out very significant and with a very large coefficient. Here the effect should be higher than the increased cost of the wage bill. The overall competence, as valued by the market, is very important for the firm's productivity beyond the effect of the innovation output and thus not only via the innovation process. Finally the innovation process also seems to be very important, not only for value added labour productivity but also for the gross production multifactor productivity, now with a much smaller coefficient. Still it is very significant. This means that a 13 percent higher proportion of new services and products in the firm's sales give a one percent higher level of sales given all inputs. This is something when 5 percent is a rather normal figure for net profit rate on sales. The growth in the gross production multifactor productivity

The innovation process that has taken place between 2002 and 2004 should not only be able to explain the differences in gross production multifactor productivity between firms 2004, but even more interesting the development during these years. Generally the results are very similar to those in the previous equation. This means that the innovative activities during these years have had a large impact on the multifactor productivity growth. A 10 percent higher proportion of new products and services in sales of 2004 should increase sales between 2002 and 2004 by almost 2 percent. This is as always when all inputs in form of labour, capital and intermediates have been taken into account. There has not been any additional value of being a part of a group in this development process other than via the innovation process. But given the earlier results, it is not surprising than an increased quality in firm's staff has a very large impact on their increase in efficiency. This effect is also far beyond its effect on the cost side. Neither the capital intensive firms nor the large firms have been very successful in increasing their multifactor productivity during these years.

If the dataset is split into manufacturing and service firms, similar results are found for manufacturing while for service firms the innovation output does not give a significant effect in the multifactor level specification but in the change specification. It must be remembered that the service set is a rather small data set.

General observation for some variables

The size variable is included in all the equations and this gives some general results. Large firms are more inclined to innovate but they invest less per employee. However, in total they get out more of their investments in the form of new products and services given this investment and since they are more efficient in the innovation process. This effect is much larger, 0.7 compared with -0.1 which means that large firms have much more innovative sales per employee, especially since the -0.1 is scaled down by 0.2 which was effect of innovation input on output. Given their innovative sales their labour productivity is also higher, but this is explained by their higher capital input, since the sign is switched for the multifactor specification. But this can not offset the fact that the large firms get a higher productivity boost from their efficiency in the innovation process.

Another variable that is used in three of the four equations is the variable that indicates that a firm belongs to a group. This apparently increases the probability of the firm to decide to innovate. From a separate test we also know that these firms do not invest more per employed persons. However they got out much more in the form of innovative sales given the investments and their labour productivity are somewhat higher and the multifactor productivity is not significantly lower given the innovative output. This means that both size and group are major contributors to innovation and especially to the efficiency in the innovation process, and finally to the productivity.

Another import variable is human capital. In the first two equations it is the percent of the staff that have at least a 3 year university degree which is introduced as an explanatory variable, while in the production function it is a measurement of quality of the total labour input that is used. From this it is very evident that labour quality both increases the probability to innovate and also the invested amount. Finally it increases productivity via the innovation output as well as directly.

Equations with ICT variables

An important aspect of innovative firms and something that probably influences their performance is of course their ICT level and ICT use. This could make a difference in all the steps in the innovation process; the decision to become innovative, how much to spend on innovation, the efficiency in the innovation process and finally the productivity outcome.

The only possible source of information about the firm's ICT standard and use is the Eurostat E-business survey. Unfortunately the samples for the E-business survey and the CIS4 are drawn independently; this means that there is a very small probability for a small or medium sized firm to be selected for both surveys. But all larger firms get both questionnaires. Since the response rate is around

70 percent in both surveys there are even less firms that have answered the questionnaire for both surveys. Actually there are only 452 observations available, and the majority of these are innovative as could be expected, since larger firms are more innovative than smaller ones. But with the criteria for excluding some observations and missing values already mentioned there are finally just 209 innovative firms left to study. This means that the results will be rather uncertain and it will be quite hard to get significant results in the regressions for many variables. Still it is worthwhile to make a try, since the ICT and innovation should be rather interlinked.

ICT use is a complex process with many links between the different uses. If a single activity is picked out and put in a regression and found significant, the result will most likely be exaggerated. The firms that use ICT in this way are probably also using it in other ways, so the regression results reflect the effect of these combinations and not of just the single variable. The only alternative to avoid this is to realize that ICT use comes in bundles and create measurements that capture this phenomenon and use these instead. This is of course not easy and will be highly questioned, since there is no apparent way to make such bundles.

These kinds of composite indicators are created by adding activities that are measured in quite different ways. It is like composing fruit baskets with different fruits and trying to decide which fruit basket is most attractive. To one person who does not like oranges, it does not matter how many oranges you put into the baskets; it will not become more attractive to that person, but to many others it will make a difference. Weighing together different indicators of ICT use is even more challenging; the only comfort is that most broad composite indicators will rank firms in similar order.

The ICT level

In this context a broad composite indicator has been created based on the Eurostat E-business survey 2003, which actually measures the situation year 2002. The choice of the year 2002 is based on the perception that it is the ICT use in the beginning of the innovation period that influences the process during this period. The broad indicator is based on four different aspects of the firm's ICT use: internet use, business system integration, purchase and sales on electronic channels, mainly the Internet.

Variable definitions:

Internet use = Number of business activities

Business system integration level = types of activities integrated with orders and purchase systems

Online purchasing in percent of total purchase

Online sales in percent of total sales

ICT level = Internet use + business system integration level+0.1* (online purchasing in percent + online sales in percent)

Internet use. The different Internet activities are the following in 2003 E-business survey: general information, analysis of competitors, financial transactions, provide service and support, download digital content and finally staff education.

Business system integration level. The business system integration activities that are integrated with the firm's order and purchase system which are specified in 2003 E-business survey are: internal system for reordering, pay system, production, logistics, marketing, customers and suppliers.

Fast broadband

The importance of the Internet could not be exaggerated in today's business, but it was already critical five years ago which has been proven in some studies. This means that a high standard of Internet connection could also be of importance in itself or as an indication of the value the firm puts on the Internet. In 2002 an Internet connection with at least 2 MB was really a high speed connection. This variable, if the firm has access to an Internet connection of at least 2MB, has been used together with the ICT level composite indicator in the estimations, bearing in mind the problems with single variables.

The innovation selection

In table 5 the difference between the estimates for two samples on the selection equation is highlighted. As could be expected it is hard to get significant results in the small ICT sample. But probably the advantage of being part of a group and being rather big is not relevant for the choice of being innovative or not for these rather big firms.

Table 5 **The Innovation selection equation, the full sample and ICT-sample compared**

Variable	Estimate	
	Full sample	ICT sample
Group	0.10a	0.03
Size	0.10a	0.07
University degree	1.10a	0.54
Geographic markets		
Local	-0.22a	-0.58a
National	0.28a	0.33c
EU, EFTA	0.19a	-0.06
Other countries	0.32a	0.67a
ITC-level 2002	---	0.04c
a significant at the 1 percent level		
b significant at the 5 percent level		
c significant at the 10 percent level		
In all equations industry is controlled for		

What caused the education variable, the percent of the staff with at least a 3 year university education leading to a degree to become non significant is probably more the sample size than anything else, since the coefficient is not that much lower than in the equation with the full sample. However, the geographical markets the firm is working on do have a significant effect on the probability for firms to innovate, also for this sample. The firms which just are local seem to have low incentive to innovate irrespectively of their size. It is even more necessary for the larger firms to innovate if they are selling on the world market. The firm's ICT level becomes significant, but on a rather low level, and adding the broadband indicator did not give any result.

The innovation input

The difference in estimation results for the innovation input between the two groups is not that large for the firms which actually spend resources on innovation. The importance of being a part of a group regarding the amount the firm spends on innovation per employed has vanished for the ICT group with only larger firms. One the other hand the diminishing investment per employed is much stronger for the ICT sample. It is also much more important for these firms with all forms of cooperation; even cooperation within their group becomes significant.

Table 6 The Innovation input equation, the full sample and ICT sample compared

Variable	Estimate	
	Full sample	ICT sample
Size	-0.10a	-0.58a
Academies	3.72a	2.76a
Geographic markets		
Local	-0.30a	-0.14
National	0.20	0.58b
EU, EFTA	0.56a	1.05a
Other countries	0.57a	0.48c
Within the Group	0.25	0.56b
Suppliers	0.41a	1.16a
Customers	0.89a	1.66a
Competitors	0.92a	1.72a
Consultants	0.94a	1.49a
Universities	0.54a	1.26a
Government	0.39	1.29
IT-level 2002	---	0.16a
a significant at the 1 percent level		
b significant at the 5 percent level		
c significant at the 10 percent level		
In all equations industry is controlled for		

Finally, even if the ICT use had some effect on the probability of being innovative, the effect of how much the firms spends on innovation per employee is much higher. In this equation the broadband indicator has also been tested and found insignificant.

The innovation output

The estimation of the efficiency of the innovation process, how much output is produced given the innovation input, gives a rather similar picture even if there are some substantial differences for single coefficients. The coefficient that differs most is the process innovation which is of much more importance to the larger firms in the ICT sample. Innovation inputs and size on the other hand matter almost as much for both samples. For the firm to get something out of the innovation process, it seems to be an advantage to be a large company. And of course if a firm adds some innovation input it gets more innovation output. Fast broadband with a speed over 2 megabits per second seems to be of significant importance, but not the ICT level.

For the multifactor alternatives the similarities and differences are the same between the two samples. The third specification of the productivity variable, the change in gross production multifactor productivity, gives a mirror result of the level specification. The only difference is a tendency for the impact of the innovation input on the innovation output to be slightly higher. Looking at these results together the obvious reflection is on the similarities of the results. This means that the results are quite robust.

Table 7 The innovation output equation, the full sample and ICT sample compared

	Productivity measurement					
Sample	Labour		Multifactor		Change in Multifactor	
	Full sample	ICT sample	Full sample	ICT sample	Full sample	ICT sample
Size	0.65a	0.58a	0.63a	0.56a	0.69a	0.65a
Innovation input (estimated)	0.22a	0.17c	0.23a	0.16c	0.26a	0.21b
Improved production methods	0.19b	0.55a	0.21b	0.54a	0.15c	0.52c
Fast Broadband 2002	---	0.65a	---	0.69a	---	0.66a
Inverted Mill's ratio	-0.13	-1.54b	-0.13	1.64a	-0.07	1.81a
a significant at the 1 percent level						
b significant at the 5 percent level						
c significant at the 10 percent level						
In all equations industry is controlled for						

The productivity equation

In the production function all the different specifications of productivity seem to work almost as well as for the ICT sample as for the full sample; even the degree of significance is almost the same even if a somewhat lower level should have been expected as the number of observations has been reduced substantially.

Table 8. The Productivity equation, the full sample and ICT-sample compared

	Productivity measurement					
Sample	Labour		Multifactor		Change in Multifactor	
	Full sample	ICT sample	Full sample	ICT sample	Full sample	ICT sample
Size	0.42a	0.30a	0.03	0.06	-0.14a	-0.07b
Capital intensity	0.12a	0.22a	-0.11a	-0.12a	-0.05a	-0.03
Human capital (2004 level respectively the change 2002-04)	0.73a	0.75a	0.47a	0.37a	0.68a	1.96a
Innovation output (estimated)	0.44a	0.36a	0.08a	0.10c	0.22a	0.15a

a significant at the 1 percent level
b significant at the 5 percent level
c significant at the 10 percent level
In all equations industry is controlled for

Given the innovation output there is no extra advantage of being a part of a group or being big for the larger firms in the ICT sample. However, in the value added labour productivity specification the size is significant but the coefficient is just half of the full sample level. Actually it seems to be a disadvantage for the large firms when it comes to productivity growth between 2002 and 2004, as it was in the full sample. The same is true for the firms which were capital intensive relatively to their industry means. However, the human capital specification is very significant with large coefficients in all the specifications. A change in the relative human capital level with a given percent gave on average an increase in the production that was twice as large.

Overview of the estimation results

The elasticity between innovation input and innovation output for the labour productivity that was found in this study was lower than the estimates from Lööf & Heshmati. However Both Lööf & Heshmati and Crépon et al find elasticises for innovation output on productivity of around 0.1, while our results for the value added labour productivity are as shown much higher. This gives roughly the same relation between innovation investments and productivity. For the multifactor specification the results were little lower than the estimates found in the literature. Using multifactor productivity the effect of innovation output ranging from 0.15

to 0.17 which is twice as much as our findings. Van Leeuwen & Klomp (2006) find an elasticity of around 0.13, using a multi-factor productivity specification. Griffith et al (2006), using a different model, find elasticities of 0.13 for France, 0.11 for Germany and 0.06 for Spain and the UK, using CIS3 data. On the other hand our result for the change in multifactor productivity is high 0.2, which is higher than all these.

We had also access to a sub sample with ICT variables from E-business 2003 and E-business 2005 (actually describing the situation the years before: 2002 and 2004) where all firms had at least 250 employees.

The results obtained in this thesis support the links between innovations and firm performance, and the estimated strengths of these links are in line with previous innovation literature. The CDM model has proven to be robust across different data sets and specifications. Our main contribution to the innovation literature is that we test the model by Lööf & Heshmati by applying it to a new data set, as well as introducing multifactor productivity and change in multifactor productivity in addition to labour productivity to measure firm performance. We have also developed an advanced measurement of the labour quality which is used in the productivity equation. Finally, an introduction of the ICT variables in a small sub sample is also new.

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Appendix

Tables

Table 1 Summary statistics for the continuous variables, full sample

Variable	Mean	Maximum	Minimum	Std Dev
Innovations input	109 086	11 904 762	0	583 862
Innovations output	3 955	651 297	0	25 196
Gross Production	27	351	2.6	24
Multifactor productivity 2004				
Gross Production	1.2	148	0.1	3.0
Multifactor productivity 2002–2004				
Value added labour productivity	37 000	2 874 820	35	136 656
Value added in fixed prices	141 929	15 288 845	104	605 200
Capital in fixed prices	137 010	18 101 676	3.3	842 999
Employment	194	19213	10	677

Table 2 Summary statistics for the continuous variables, ICT sample

Variable	Mean	Maximum	Minimum	Std Dev
Innovations input	346 421	9 836 065	0	1 223 135
Innovations output	15 081	574 964	0	45 800
Gross Production	28	163	3.9	27
Multifactor productivity 2004				
Gross Production	1.2	9.9	0.1	0.8
Multifactor productivity 2002–2004				
Value added labour productivity	132 471	2 874 820	2 237	279 384
Value added in fixed prices	565 852	10 180 766	3 685	1 242 924
Capital in fixed prices	590 522	18 101 676	100	1 864 164
Employment	714	8754	11	1 071

Table 3 Summary statistics for all variables

Variable	Min	Max	Mean	N
Innovation dummy	0	1.00	0.50	2728
Innovation input	-5.1	12.7	1.91	2728
Innovation output	0	15.1	3.11	2681
Productivity	3.54	15.3	9.19	2654
Multifactor productivity	-2.2	6.40	3.01	2623
Gross production multi factor productivity 2002–2004	-4.3	5.00	0.05	2604
Employed persons	2.30	9.86	3.90	2728
Part of a group	0	1.00	0.64	2728
Physical capital intensity 2004	-1.8	12.5	4.86	2666
Humacd02	0	1.00	0.12	2728
Humcap04	6.73	7.92	7.37	2702
Improved production methods	0	1.00	0.25	2728
Improved distribution methods	0	1.00	0.14	2728
Improved support methods	0	1.00	0.24	2728
Capital intensive manufacturing industry	0	1.00	0.11	2728
Labour intensive manufacturing industry	0	1.00	0.23	2728
High tech intensive industry	0	1.00	0.24	2728
Utilities industry	0	1.00	0.03	2728
Trade industry	0	1.00	0.08	2728
Transport industry	0	1.00	0.11	2728
Communication industry	0	1.00	0.02	2728
Knowledge intensive services	0	1.00	0.17	2728
Local market	0	1.00	0.81	2728
National market	0	1.00	0.60	2728
European market	0	1.00	0.56	2728
All other countries	0	1.00	0.36	2728
It Level 2002	0	15.5	7.16	457
Fast Broadband	0	1.00	0.71	457
Within the group	0	1.00	0.06	2728
Suppliers	0	1.00	0.09	2728
Customers	0	1.00	0.09	2728
Competitors	0	1.00	0.01	2728
Consultants	0	1.00	0.03	2728
University	0	1.00	0.02	2728
Government	0	1.00	0.00	2728