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Non Technical summary

A number of factors have been identified as increasingly important for growth in a knowledge based economy. Assuming that these factors can partly be expressed in firms, regions or a country's capacity to generate new ideas and to implement these new ideas into new innovations and flow of new products to the market, we would then expect a close relationship between innovation and growth.

This paper investigates whether variations in the return on research and development (R&D) and other innovation investments at the firm level can explain variations in productivity growth at the aggregate level. Empirical analysis is based on a comparison of three Nordic countries of Norway, Finland and Sweden. While the Finnish and Swedish growth rates in the manufacturing sector are highest among the OECD-countries during the last decade, Norway is at the bottom level.

Based on firm level data from the second Community Innovation Survey (CIS), this study does not find any close link between firms' innovation performance and manufacturing sector productivity growth. We further highlight whether this reflects the true situation or rather a limitation linked to the cross-country comparability of firm-level data. The later were partly imposed by the national statistical agencies for the reasons of confidentiality. Both factors are found to play an important role in the explanation of a possible relationship

The Link between Firm-Level Innovation and Aggregate Productivity Growth

A Cross-Country Examination*

Hans Lööf [1] and Almas Heshmati

February 2003

Abstract

This paper investigates whether failure in innovation at the firm level can account for cross-country heterogeneity in manufacturing productivity growth. There is no strong evidence in the literature on the existence of such link. Our work, however, differs in a number of ways from much of the previous cross-country comparisons on the relationship between innovation and productivity using firm-level data. First, a broader definition of innovation input is used in which research and development is one of several sources of innovation. Second, a quantitative innovation output measure is used in the analysis. Third, the analysis is based on larger and more representative samples of firms including small firms. Finally, an econometric framework based on the knowledge production function accounting for both selectivity and simultaneity bias is employed. The results from Nordic countries show that given difficulties in pooling the data, it is important to specify country-specific models accounting for country-specific effects and differences in the countries national innovation systems.

Keywords: community innovation, cross-country comparisons, manufacturing, productivity

JEL classification: C51, D24, L60, O31, O32

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The result using Finnish and Norwegian data has partially been used in a joint work with Svein-Olav Nås and Rita Asplund entitled 'Innovation and Performance in Manufacturing Industries: A Comparison of the Nordic Countries', published as SSE/EFI Working Paper Series in Economics and Finance 2001:457.

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[1] Hans Lööf, visiting research fellow at the Center for European Economic Research (ZEW) 2002/2003.

1. Introduction

Two general sources contribute to productivity growth at the manufacturing level. The first source affects productivity through reallocation of resources among plants and firms of different efficiencies through creative destruction. The second source has impacts through productivity improvement at existing firms and plants. This paper deals with the latter effect in a cross-country framework.

Although the Nordic countries have a high degree of political, social, and cultural similarity, they have differed during recent years largely from one another concerning manufacturing productivity performance. While the Finnish and Swedish growth rates are the highest among the OECD-countries, Denmark is in the middle and Norway is at the lowest levels. During the 1990s – a period sometimes described as the introduction of the New Economy – the annual growth rate in labour productivity in Finland and Sweden was about twice higher than in Denmark and five to seven times higher than Norway.

A number of factors have been identified as increasingly important for economic growth in the 'new' or 'knowledge based' economy. Assuming that they can partly be expressed in capacity to generate new ideas and the rate of flow of new products introduced to the market, we would expect a close relationship between innovation and growth.

This paper investigates if cross-country variation in productivity growth can be explained by differences in the innovation performance at the firm level. There is, however, no strong evidence in the literature for a close link between the *level* of research and development (R&D) and the *growth rate* of productivity at any level of aggregation. Therefore lack of a relationship calls for further research to establish the nature of such relationship.

In analysing the data for French and US manufacturing Griliches and Mairesse (1983) found that differences in firm-level R&D effort do not account for much of the observed differences in the productivity growth across firms or industries within and between the two countries. Replicating their methodology and studying differences in the firm-level R&D in Japan and US, Griliches and Mairesse (1990) concluded that the large difference in manufacturing productivity between these countries must be looked for elsewhere. In a recent survey, Klette and Kortum (2002) report that while the level of productivity and the level of R&D across firms are positively associated, the growth rate of productivity is not strongly related to the firm-level R&D.

Our work differs from much of the previous, and still rare, by studying cross-country comparisons on R&D and productivity growth using firm-level data. The main features are summarized as follows. First, a broader definition on innovation input in which R&D is one of several sources used. Second, we incorporate a quantitative innovation output in the analysis. Third, a larger and more representative sample of firms including small firms is used. Finally, an econometric framework based on the knowledge production function which also accounts for both selectivity bias and simultaneity is employed.

A central issue in the analysis and the choice of our methodological approach is whether there are some identifiable sets of characteristics that make the firm a successful innovator. Some authors express scepticism in this regard and argue that the innovation process is incredibly complex and that the requirements for profitable outcome vary greatly from one case to another (see Kline and Rosenberg 1986). While other researchers, partly based on branches of theoretical endogenous models, suggest that factors such as entrepreneurship, human capital, knowledge capital, the firm's R&D history and previous successful innovations (Hall and Mairesse 1995, Geroski et al. 1993, Aghion and Howitt 1998, Haltiwanger 2000) characterize firms as successful innovators.

An interesting step towards a more extensive empirical base for this disagreement was recently taken by the OECD, Eurostat and other national and international organizations, through their effort to develop and standardize the methodology and information used in innovation surveys. Consensus on this prolonged work was reported in the Oslo Manual (OECD, 1992 and OECD and Eurostat, 1997), and today it serves as a theoretical foundation for the Community Innovation Survey (CIS) data collected in the European OECD and in some other industrialized countries.

The basic approach we follow in this paper is to use the CIS-data and estimate a knowledge production function in the spirit of Pakes and Griliches (1984) and Crépon Duguet and Mairesse (1998) that gives the causal relationship between innovation input, innovation output and productivity.

Due to restrictions imposed by the national statistical agencies for the reasons of confidentiality of firm-level data, a direct cross-country comparison by pooling individual CIS firm-level data sets from the three countries (Finland, Sweden and Norway) unfortunately has not been possible. The method of aggregating micro-data adopted by Eurostat offers an opportunity to get around some of the confidentiality problems. Mohnen et al. (2001) found that the procedure proposed by Eurostat – where each observation is replaced by an average of itself and the two adjacent observations in a ranked order of observations for each variable – does not really affect the results.[2] Unfortunately some countries, including Sweden and Finland, do not allow their CIS-data to be used in similar micro averaging procedures, while Norway and Finland apply a restrictive policy concerning access to their CIS-data sets. This paper therefore employs an alternative method for conducting cross-country comparisons.

An identical model describing the relationship between innovation and productivity are estimated separately in the countries investigated using different original data sets based on more or less identical innovation surveys. National registers in all the Nordic countries studied in this report facilitate the merging of national data for the firms studied with the CIS data. However, only differences with respect to human capital, measured as the proportion of employees with a university degree and value-added have been used here.

Initially we aimed to include Denmark as well. However, an unsolved problem with the Danish sample found to be related to the sample size. The data has too few observations

2 It should be noted that a limitation with this method of merging data is that complementary data from other sources concerning the individual firms' production, value added, employment, physical capital, human capital and financial capital structure cannot be added to common regressions, unless it is added prior to application of the averaging procedure.

to be considered as statistically representative sample of the Danish manufacturing industry, and is therefore not included in the analysis.

The rest of the paper is organized as follows. Section 2 of the paper provides a brief overview of economic data and performance indicators used in comparing the Nordic countries. Section 3 describes statistical evidence from the Community Innovation Survey. The data, model specification and estimation issues, are presented in Section 4, followed by a cross-country comparison of the empirical regression results in Section 5. Summary and conclusions based on simple numerical data and regression results are presented in Section 6.

2. A country comparison based on macro indicators

Before looking at the firm-level data we will present a brief overview of comparative statistics on productivity growth within the OECD and the innovation activities in the three countries studied. This simple comparison based on a number of key indicators is an important complement to the better and more systematic comparison based on modelling and regression analysis. As indicators of cross-country performance heterogeneity we use two classes of indicators. The first consists of non-CIS indicators and include labour productivity, manufacturing share of GDP, research and development expenditures, competitiveness, openness, trade balance, taxes, and education. It is to be noted that these sets of information will not be included in the subsequent regression analysis.

The second class of indicators, presented in Section 3, are based on the CIS data and include sales, employment, factor intensity, human capital, innovativeness, obstacles to innovation, strategy on innovation, sources of information for innovation, and cooperation on innovation.

Table 1. Average annual rate of labour productivity measured as value-added per employed person and per hour worked in manufacturing in 12 OECD countries, 1990–2000.

	Per employed person	Per hours worked
Finland	*6.4*	*6.4*
Sweden	*5.7*	*4.7*
USA	4.1	4.0
Canada	4.1	2.1
France	3.6	4.2
Belgium	3.4	3.3
Denmark	*3.0*	*NA*
The Netherlands	3.0	3.1
United Kingdom	2.9	2.8
Japan	2.8	3.6
Italy	2.3	2.1
Norway	*0.7*	*0.8*

Source: Statistics Finland, for Finland. US Department of Labour (2000), Bureau of Labour Statistics for all other countries.

It is to be noted that regardless of whether the Finnish and Swedish growth rates are measured per employee or per hours of work, Table 1 shows that countries with annual growth rates between 4–6 per cent hold a top position on the list of the 12 most developed OECD countries ranked by productivity growth during 1990 to 2000. The rate of productivity growth in Norway was only about 1 per cent. The growth rate in Denmark is about the OECD average, 3.0 per cent.

An important issue to be explored here is to what extent the weak Norwegian performance reflects structural characteristics of the country. In Table 2, the manufacturing performance is disaggregated by nine different industries. Between 1990 and 1997 the manufacturing growth rate was 6.1 per cent in Finland, 5.2 per cent in Sweden and only 1.1 per cent in Norway. Using the information on composition of the manufacturing sectors in the right hand side of Table 2 we find that the annual growth rate for Norway would have only increased from 1.1 per cent to 1.2 per cent if we assume the same structure of the manufacturing industry as in Sweden. Imposing the same structure as in Finland it would have remained at 1.1 per cent. Hence, the main explanation for the weak productivity growth in Norway is essentially not the structure of manufacturing when two-digit NACE codes are considered.[3]

Table 2. Annual growth in labour productivity in 1990–97 and manufacturing share of GDP.

	Labour productivity			Share of manufacturing		
	Sweden	Finland	Norway	Sweden	Finland	Norway
Food, drink and tobacco	4.4	4.3	1.1	8	12	16
Textiles, apparel & leather	5.0	7.3	2.4	3	7	3
Wood, cork and furniture	3.4	8.2	1.8	8	7	7
Paper & printing	2.9	6.2	0.0	16	22	14
Chemical products	5.7	3.3	0.0	11	11	11
Stone, clay and glass	-0.1	6.2	3.2	3	4	4
Basic metal industries	6.8	7.3	0.7	6	4	13
Fabricated metal & machinery	6.4	9.3	1.7	46	32	32
Other manufacturing	0.0	0.0	0.0	0	1	1
Total manufacturing	5.2	6.1	1.1	100	100	100

Source: Statistics Finland, for Finland and US Department of Labour (2000), Bureau of Labour Statistics for other countries.

Table 3 shows that gross expenditures on R&D (GERD) relative to GDP is very high in Sweden (3.7) and Finland (2.7), but relatively low in Norway (1.7) in an international perspective. Gross expenditures on R&D in per capita terms is most sizeable in Sweden, while the R&D intensity, expressed in terms of R&D personnel as a proportion of the labour force is greatest in Finland. Norway has the lowest figures in both cases.

Patents are used widely as indicators of firm innovativeness, though they do not necessarily reflect innovations. Bearing in mind this limitation in the residential patent applications in relation to the size of the population of firms, the results shows that the number of patents in Norway is about 40 per cent lower than those of Sweden and Finland.

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3 It should, however, be noted that industries are heterogenous in terms of technological opportunities and prospects for growth. Industry composition and large innovative payers play an important role. Therefore a deeper analysis of the differences in the industry structure must be based on more disaggregated data than 2 digit NACE-codes. In addition one must also take into account factors such as differences in firms size and presence of large innovative companies (e.g. Nokia, Ericsson, Pharmacia, ABB, SAAB, etc). Lack of possibilities to identify major players make such exercise out of the scope of this study.

Table 3. Comparisons of countries by gross research and development expenditure.

	Sweden	Finland	Norway
R&D/GDP	3.7	2.7	1.7
GERD per capita population (current PPP $)	774	556	443
R&D personnel per thousand labour force	15.4	16.4	10.9
Residential patent applications/10 000 population	4.7	4.6	2.7
GERD financed by the industry, %	67.7	62.9	49.4
GERD financed by the government, %	25.2	30.9	42.9
GERD performed by the business sector, %	74.8	66.0	56.9
GERD performed by the higher education sector, %	21.5	20.0	26.6

Source: OECD (2000), Main Science and Technology Indicators.

Some 68 per cent of the gross expenditure on R&D is financed by government in Sweden, compared with 63 per cent in Finland and only 50 per cent in Norway. About 75 per cent of GERD is performed within the business sector in Sweden, 66 per cent in Finland and 57 per cent in Norway. The main conclusion drawn from Table 3 is that the Norwegian economy is considerably less R&D intensive compared to the economies in Sweden and Finland. Moreover, a relatively large part of the R&D investment activities in Norqay is found financed and performed outside or with weak links to the business sector.

R&D is perhaps the most important but not the only input in the innovation process. Recent research has emphasized the role of broad concepts such as 'national systems of innovation' and their differences across OECD countries in terms of national institutions, their internal and external relationships, human and natural resources and specialization. Hall and Jones (1999) discuss the importance of institutions and governments in creating environments that encourage capital accumulation, skill acquisition, invention and technology transfers. Putnam (1993) argues that certain aspects of relationships between individuals, such as trust, values in common, norms, informal networks and levels, and social interactions are favourable for competitiveness. However, entities such as institutions, social capital and cultural factors are not readily measurable, and the formal empirical investigations of their statistical relationship with growth in cross-country regressions have not yet produced any unambiguous results. This pattern has previously been observed by several researchers (Helliwell (1996) and Keefer and Knack (1997)).

World values surveys and world competitiveness executive opinion surveys represent two attempts to capture hard-to-measure conditions for competitiveness. Keefer and Knack (1997) constructed a trust index based on the World Values Survey question, 'Generally speaking, would you say that most people can be trusted, or that you can't be too careful in dealing with people?'. The average index value using a scale of 0 to 100 was found to be 39 for the 23 OECD countries involved. Norway tops the list with 61, followed by Finland and Sweden with 57. This can be compared with 45 for the USA, 41 for Japan and only 25 for France.

Table 4 contains selected descriptive statistics on some parameters including macroeconomic conditions and human capital in the manufacturing industry in the three northern European countries. The import and export intensities are about the same for all three countries, while using the export/import ratio for four different high-technology sectors indicate the existence of some differences. Sweden specializes foremost in pharmaceutical production, electronics and aerospace technologies; Finland specializes in high technology in the electronics industry, and Norway specializes in manufacturing and areas not traditionally defined as high technology production activties. Norway is currently the world's third-largest oil exporter and in an effective way used the oil revenues to develope major competitive advantages within various branches and sub-sectors of the oil-cluster.

Table 4. A comparison of Nordic countries by various economic indicators.

	Sweden	Finland	Norway
Global openness			
Export/GDP	41.5	43.2	40.0
Import/GDP	34.3	34.2	33.0
Trade balance in knowledge intensive industries			
Export/Import ratio aerospace industry	1.39	0.21	0.41
Export/Import ratio electronics industry	1.93	1.97	0.46
Export/import ratio office machinery and computer industry	0.30	0.75	0.26
Export/import ratio drug industry	2.59	0.30	0.21
Taxes			
Total taxes and fees as proportion of GDP (1999)	52.1	46.5	41.8
Employers' social security contribution, % of the payroll	33	26	13
Corporate tax, %	28	28	28
Capital tax, %	30	28	--
Education			
Proportion of population (25–64) with higher tertiary education, %	13	13	24
Proportion of population (25–64) with lower tertiary education, %	28	29	26

Source: OECD (2000) Human capital, Education at a Glance, Export and value-added.

The design of the tax systems in all three countries is similar. Northern Europe is a high-tax area, particularly when it comes to taxes on labour. Marginal tax on personal income is above the 50 per cent level, while the employers' social security contribution as a percentage of the payroll varies from just over 10 per cent of the gross wage in Norway to 33 per cent in Sweden. The corporate tax and capital tax rates are about 30 per cent in all three countries, which is similar to many other OECD countries in Europe. Sweden has the world's largest ratio of total taxes and fees as a proportion of GDP, 52 per cent. The corresponding figures for Finland and Norway are 47 per cent and 42 per cent, respectively.

The percentage of the working age population with higher tertiary level of education is highest by a substantial margin in Norway at 25 per cent, compared with only 15 per cent in both Finland and Sweden. However, considering the percentage of population with lower tertiary level of education, the figures are about the same for all three countries.

To sum one major difference between the high productivity growth of Sweden and Finland and the low productivity of Norway is to be found in the differences in level of R&D-investment in relation to GDP and the way the sample countries R&D activities are organized. The countries' ways of organising their R&D activities is influenced by the R&D investment traditions and access to production resources. Sweden enjoyed a comparative advantage in this respect and experienced a continous higly developed industrial sector with excellent research potential.

3. A country comparison based on micro indicators

We look now at the CIS data for all three countries[4]. Starting with the samples used, Table 5 Panel A, shows that the number of manufacturing firms included is 1,062 in Finland, 1,315 in Norway and 743 in Sweden. Comparing the mean and median values for sales and employment as expected indicates a large degree of asymmetry in the size distribution, with the mean values being 2–4 times larger than the medium values. The analysis is limited to firms with a minimum of 20 and a maximum of 5,000 employees in 1996 in Norway and Sweden, while the corresponding limits in Finland for the same year are 10 and 10,000. This leads to different medians of 50 employees per firm in Sweden, 44 in Norway and 27 in Finland.

Table 5. Summary statistics of sales, employment, factor intensity and human capital by innovativeness.

Panel A: All firms

	Finland	Norway	Sweden
Number of observations	1,062	1315	743
Sales in 1,000s and in local currency			
Mean	92,000	154,000	244,000
Median	15,000	47,000	62,000
Minimum	700	2,000	6,000
Maximum	1.19e+07	8.71e+06	2.19e+07
Employment			
Mean	95	105	148
Median	27	44	50
Minimum	10	20	20
Maximum	9,600	4,900	5,000
Sample composition			
Labour-intensive firms, %[a]	0.636	0.678	0.565
Knowledge-intensive firms, %[a]	0.303	0.258	0.314
Capital-intensive firms, %[a]	0.053	0.063	0.073
Human capital			
Engineers, %[b]	0.053	0.050	0.083
Administrators, %[b]	0.029	0.044	0.020

Notes: (a) percentage of firms, (b) percentage of sales. All values are weighted.

A comparison of the factor intensities[5] shows that the proportion of labour-intensive firms is largest in Norway, which also has the smallest proportion of knowledge-

4 For detailed information on the quality and the nature of the CIS-data used in this paper, please see Statistics on Science and Technology in Europa (2001), European Commission and Eurostat, Theme 9, Science and Technology. In the present study all the data used have been weighted. This means that the difference between the number of firms in given strata and the number of respondents in the survey are taken into account to make the observations representing the whole population of firms.

5 The following definitions and classifications of factor intensity have been used: (i) capital-intensive manufacturing consists of a two-digit international system for industrial classifications, ISIC 10-14, 16, 21, 24 and 27 excluding 24.4-24.5, (ii) knowledge-intensive manufacturing includes ISIC 24.4-24.5, 28, 29, 30-33, 34-35, and (iii) labour-intensive manufacturing consists of ISIC 15, 17-19, 20, 22, 25, 26 and 36-37.

intensive firms. The proportion of capital intensive firms is about the same in all three countries.

The human capital variable defined as the proportion of employees classified as engineers and others (labelled here as 'administrators') with a university degree, or a post-secondary education for engineers, is about the same in all three countries. However, there are larger proportions of engineers in Finland and Sweden. The possible double counting of R&D expenditures were adjusted for in the subsequent regression analysis by subtracting R&D personnel from the skilled labour variable defined as engineers.

Panel B: Innovative firms

	Finland	Norway	Sweden
Number of observations	323	485	405
Sales in 1,000s and in local currency, mean			
Mean	259,000	292,000	351,000
Median		81,000	90,000
Minimum	2,200	3,200	12,000
Maximum	1.19e+07	8.71e+06	2.19e+07
Employment			
Mean	233	184	209
Median	-	70	65
Minimum	10	20	20
Maximum	9,602	4,912	5,000
Sample composition			
Labour-intensive firms, %[a]	0.447	0.506	0.457
Knowledge-intensive firms, %[a]	0.450	0.422	0.451
Capital-intensive firms, %[a]	0.094	0.071	0.084
Human capital			
Engineers, %[b]	0.065	0.102	0.110
Administrators, %[b]	0.038	0.048	0.021

Notes: (a) percentage of firms, (b) percentage of sales. All values are weighted.

Panel B presents the same statistics as in Panel A but only for the innovative sample. In order to be innovative according to the definition used here, the firms must invest in innovation activities and introduce new products and processes to the market. This results in 485 innovative firms in Norway, 405 in Sweden and 323 in Finland.[6] The innovative firms are generally of larger size than the non-innovative firms in all of the three sample countries. This is valid irrespective of whether size is measured in terms of sales or employment. The typical innovative firm has a larger proportion of highly educated personnel compared with the non-innovative firms.

Considering various indicators on the degree of innovativeness, Table 7 shows that 46 per cent of the Swedish firms introduced at least one technologically new or essentially improved product on the market during 1994–96.[7] The corresponding figures for

6 It should be noted that the innovative sample is not weighted here resulting in an over-representation of the innovative sample in comparison with a case where the sample is weighted by the size of firms.

7 Unger (2000) reports that the average level of product innovativeness among EU members is 48 per cent in the CIS-II data set.

Norway (1995–97) and Finland are 35 per cent and 24 per cent, respectively. Four out of ten Norwegian firms launched one or more process innovations compared with 36 per cent of the Swedish firms and 20 per cent of the Finnish firms. The proportion of firms that applied for a patent during the period considered was considerably lower in comparison with the two indicators on innovativeness presented above, being 19 per cent in Sweden, 12 per cent in Finland and 8 per cent in Norway.

Perhaps the most interesting piece of information contained in the CIS-surveys are innovation investments as a proportion of total sales, and the percentage of sales associated with innovative products. The total expenditures on innovative activities corresponded to 3.3 per cent of the total sales for the average manufacturing firm in Sweden, 2.5 per cent for the average Norwegian firm and a surprisingly low level of 1.9 per cent for manufacturing firms in Finland. When the total sample is considered, innovation sales, or innovation output, expressed as a percentage of total sales are 15.1 per cent in Sweden, 11.4 per cent in Norway and 8.0 per cent in Finland.

Table 6, Panel B, shows that the subsamples 'innovative firms' are rather similar in all three countries when innovation input and innovation output are considered. However, there are considerable differences in the percentage of innovative firms between the three countries. Innovation input corresponds to 7.6 per cent of sales in Norway, 7.1 per cent in Finland and 6.1 per cent in Sweden. The proportion of innovative sales to total sales for innovative firms is 36 per cent in Norway, 34 per cent in Finland and 33 per cent in Sweden.[8]

Table 6. Summary statistics by type of innovation

Panel A: Total sample

	Sweden	Finland	Norway
Number of observations	763	1062	1315
Innovativeness			
Product innovation, %[a]	0.463 (0.499)	0.240 (0.427)	0.348 (0.476)
Process innovation, %[a]	0.365 (0.481)	0.203 (0.402)	0.402 (0.490)
Patent, %[a]	0.192 (0.394)	0.117 (0.322)	0.076 (0.266)
Innovation input, %[b]	0.033 (0.078)	0.019 (0.100)	0.025 (0.078)
Innovation output, %[b]	0.153 (0.255)	0.080 (0.191)	0.114 (0.228)

Panel B: Innovation sample

	Sweden	Finland	Norway
Number of observations	423	323	485
Sales in 1,000s and in local currency			
Product innovation, %[a]	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
Process innovation, %[a]	0.656 (0.475)	0.607 (0.488)	0.795 (0.403)
Patent, %[a]	0.389 (0.488)	0.433 (0.496)	0.214 (0.411)
Innovation input, %[b]	0.062 (0.097)	0.071 (0.198)	0.065 (0.124)
Innovation output, %[b]	0.331 (0.285)	0.336 (0.262)	0.334 (0.284)

Notes: (a) percentage of firms, (b) percentage of sales. All values are weighted.

8 These figures are somewhat lower than those reported by Mohnen et al. (2001). Based on CIS I data from seven European countries, Belgium, Denmark, Germany, Ireland, Italy, the Netherlands and Norway, they found an average proportion of observed innovative sales of 47 per cent in high-R&D sectors and 39 per cent in low-R&D sectors (48 per cent and 33 per cent respectively for Norway).

Source: Authors' own calculation.

The Tables 7, 8 and 9 report information concerning the important CIS indicator variables. The degree of importance for each variable is indicated in a three level scale as: low, medium or high. Here we use the frequencies of firms reporting the degree of "high" in relation with the factors of: obstacles to innovation and strategy of innovation in Tables 7 and 8. The cooperation variables in Table 9 do not differentiate between various degrees of importance.

When considering the total samples, it can be seen in Table 7 that risks (14 per cent of the firms) and costs (15 per cent) are the two dominating factors highly hampering innovation in Finland, while organizational rigidity (14 per cent) and lack of qualified labour (12 per cent) are the most important hampering factors found in Norway. Lack of qualified labour (20 per cent) and over-perception of risks (20 per cent) are amongst the factors having a negative impact on innovation activities in Sweden.

Table 7. CIS indicators, obstacles to innovation, based on total sample, percentage of the firms.

	Sweden	Finland	Norway
Number of observations	743	1062	1315
Excessively perceived risk	0.20	0.14	0.09
Innovation cost too high	0.16	0.15	0.07
Lack of appropriate sources of finance	0.10	0.09	0.05
Organizational rigidities	0.17	0.06	0.14
Lack of qualified personnel	0.20	0.09	0.12
Lack of information on technology	0.09	0.10	0.06
Lack of information on markets	0.09	0.06	0.05
Problem fulfilling regulations or standards	0.06	0.04	0.02
Lack of consumer responsiveness	0.10	0.08	0.04

Source: Authors' own calculation.

Table 8 limits the comparison only to the innovative firms. Table 8, Panel A shows a list of factors of crucial importance to the firms' innovation strategies. The opening-up of new markets, increasing market share and improved product quality are among the most frequently given reasons for innovation in Finland, Norway and Sweden. However these strategies are most noticeable in Norway and least in Finland.

Table 8. CIS indicators and innovation strategy, based on innovative sample, percentage of the firms.

	Sweden	Finland	Norway
Number of observations	405	323	485
Panel A: Strategy on innovation, factors of crucial importance			
Improving product quality	0.59	0.31	0.69
Opening up new markets/increasing market share	0.56	0.34	0.68
Extending product range	0.35	0.28	0.52
Reducing labour costs	0.37	0.20	0.47
Improving production flexibility	0.24	0.23	0.33
Reducing materials consumption	0.32	0.17	0.30
Replacing products being phased out	0.43	0.27	0.23
Fulfilling regulations, standards	0.31	0.13	0.23
Reducing environmental damage	0.27	0.08	0.18
Reducing energy consumption	0.19	0.07	0.14

Panel B: Sources of information for innovation, factors of crucial importance			
Clients or customers	0.69	0.44	0.60
Sources within the firms	0.57	0.39	0.58
Suppliers of equipment, materials, components or software	0.12	0.08	0.23
Competitors	0.17	0.09	0.21
Fairs, exhibitions	0.16	0.13	0.19
Other firms within the group	0.11	0.09	0.18
Professional conferences, meetings, journals	0.04	0.05	0.09
Universities or higher education institutions	0.04	0.09	0.06
Consultant enterprises	0.02	0.04	0.05
Computer-based information networks	0.02	0.02	0.05
Patent disclosures	0.02	0.02	0.01

Customers and internal knowledge within the firm itself dominate as crucial sources of information for innovation foremost in Norway and Sweden and to a lesser degree in Finland. Only a small proportion of Nordic firms considers knowledge received from patent disclosures, universities, computer-based information networks and consultants as very important for developing their products and processes. Panel B shows that the Norwegian firms exchange knowledge with suppliers, competitors and other firms more often within the same group of firms than their Finnish and Swedish counterparts.

Table 9 indicates that innovative cooperation with national universities is much more common in Finland than in Norway and Sweden. This table also shows that innovative Finnish firms have a higher propensity to co-operate with government and non-profit research institutes than innovative firms in Norway and those in Sweden. Finally, national cooperation appears to be more common than international cooperation in innovation, with the exception of other enterprises within the same group and competitors. In the two latter cases, no differences were found between the propensities to co-operate with national or international partners.

Table 9. CIS indicators, cooperation on innovation, based on innovative sample, percentage of the firms.

	Sweden		Finland		Norway	
Number of observations	405		323		485	
	(D)	(F)	(D)	(F)	(D)	(F)
Customers	0.35	0.25	0.41	0.31	0.29	0.19
Government/private non-profit research institution	0.14	0.06	0.36	0.09	0.27	0.04
Suppliers of equipment, materials, or software	0.27	0.17	0.36	0.28	0.25	0.23
Universities or higher education institutions	0.26	0.09	0.46	0.12	0.22	0.05
Other enterprises within the enterprise group	0.17	0.19	0.17	0.16	0.17	0.15
Consultant enterprises	0.23	0.07	0.23	0.08	0.17	0.06
Competitors	0.03	0.05	0.11	0.11	0.06	0.05

Note: Cooperation with Domestic (D) and Foreign (F) sources.

Bearing in mind that the CIS-indicators represents the hard-to-measure and difficult to interpret class of variables. These together with the quantitative descriptive statistics they do not, however, support any view that we *a priori* can expect a different innovation performance among the innovative Norwegian firms compared to those from Sweden and Finland.

4. The model

The model we consider is a modified version of the standard Cobb-Douglas production function. The approach used can be simplified by the following relationship:

(1) $\log Y = \alpha + \beta \log \mathrm{X} + \gamma \log K + \varepsilon$

where Y is productivity at the firm level, $\boldsymbol{X}$ is a vector of standard inputs, and K is knowledge capital capturing the transformation process from innovation input to innovation output, and α and ε represent systematic and random fluctuations, respectively, in productivity. Here, the focus is on estimation of γ, the elasticity of productivity with respect to knowledge capital. Evidence based on firm and industry level data and using traditional model points to the presence of a positive and strong relationship between innovation input (R&D), and productivity. In the between-firm dimension Mairesse and Cuneo (1985) found that the estimated elasticity of performance with respect to R&D capital in France, was in the interval of 0.09–0.26. The corresponding elasticities produced by Griliches and Mairesse (1990) for the US was 0.27–0.41, respectively. However, on the contrary, no stable correlation between the level of R&D and growth rate of productivity has been established in the within-firm dimension.

As many researchers have pointed out, it is not innovation input, but rather innovation output that increases productivity. Moreover, R&D identified as just one and often a minor part of firms' expenditure on innovation. In the CIS survey, innovation investment is broken down into seven different investment categories. For example, the Swedish data used in this study shows that internal R&D corresponds to 1.5 per cent of total sales, while all seven categories together correspond to 3.3 per cent of total sales. It has been shown in Section 3, CIS data also provides a direct measure of innovation output, defined as the innovation product's share of sales.[9]

The challenge of this work is to incorporate the new data on innovation input as well as innovation output into the analysis and use an econometric framework that can handle the peculiarities of the data. The empirical model used here is a modified version of the model introduced by Pakes and Griliches (1984) and further developed by Crépon et al. (1998). The model, referred to as the CDM model, includes four equations and three established relationships including the innovation input linked to its determinants, the knowledge production function relating innovation input to innovation output, and the productivity equation relating innovation output to productivity.

Our measure on productivity is the level of labour productivity. Labour productivity is normally defined as value-added per hours worked or per employee. Due to limitations in the existing data sets, we do not have access to the same output measure in all three countries. While the Finnish observations contain information on net output (value-added), the Norwegian output measure is nominal output (total sales). For Sweden we

9 It should be noted that the two CIS measures of innovation input and innovation output exhibit several shortcomings. For example, they are based on the subjective opinion of respondents to the survey. Furthermore, innovation is a heterogeneous phenomenon showing large variations between industries and firm sizes. These measures are new and rather unknown for many firms. Despite the limitations encountered above, experience from working with CIS data indicates that these measures provide reasonable estimates, and to a high degree comparable across countries over time.

use both gross and net outputs. Moreover, the data sets for Finland and Norway do not include information on the firms' physical capital. In addition, the firm size coverage differs between the three countries. While the Finnish firms have between 10 and 10,000 employees, the Norwegian firms have between 20 and 5,000 employees.

Since the original Swedish data set is more extensive than the other two countries' we can make some sensitivity analysis on the issue of sizes, the importance on physical capital, and various productivity measures.

4.1 Formulation of the model

The basic econometric problems that the empirical model aims to solve are selectivity and simultaneity biases. When only the innovation sample is used, which is the most common case in R&D studies, a selection bias may arise. And when several links in the process of transforming innovation investment to productivity is considered in a simultaneous framework, one possible problem emerging is that some explanatory variables often are determined jointly with the dependent variable, i.e. they are not exogenously given and there will be simultaneity.[10]

The model used here is a multi-step structural model consisting of four equations. The first two equations are estimated separately as a generalized tobit model where observations on both innovative and non-innovative firms are included. The last two equations are estimated in a simultaneous equation system where the endogenous innovation output variable is limited only to strictly positive values in the last step. More specifically, we have the following equations:

(2) $$g^* = \beta_0^0 + \sum_n \beta_n^0 x_n^0 + \varepsilon^0$$

(3) $$k^* = \beta_0^1 + \sum_m \beta_m^1 x_m^1 + \varepsilon^1$$

(4) $$t = \beta_0^2 + \beta_k k + \beta_{MR} MR + \sum_l \beta_l^2 x_l^2 + \varepsilon^2$$

(5) $$q = \beta_0^3 + \beta_t t + \sum_j \beta_j^3 x_j^3 + \varepsilon^3$$

where g^* is a latent innovation decision variable, k^* represents latent innovation input, t is innovation output, q is productivity, MR is the inverted Mill's ratio introduced to correct for possible selection bias, x^0, x^1, x^2 and x^3 are N, M, L and J vectors of variables explaining investment decision, innovation input, innovation output and productivity including employment, human capital and various innovation indicators variables. The β^0 and β^1 are vectors of unknown parameters to be estimated reflecting the impact of certain factors on the probability of being engaged in R&D and other innovation investments and on the actual level on these investments, the β^2 is parameters associated with the level of innovation output while β^3 is associated with the level of productivity. The $\varepsilon^0, \varepsilon^1, \varepsilon^2$ and ε^3 are random error terms. We assume the following assumptions regarding the error terms:

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10 For a detailed discussion on the issues of identification related to the estimation of production functions, see Griliches and Mairesse (1997).

(6) $E(\varepsilon^0\varepsilon^1) \neq 0, E(\varepsilon^2\varepsilon^3) \neq 0, E(\varepsilon^1\varepsilon^2) \neq 0, \text{else } E(\varepsilon^i\varepsilon^j) = 0$.

In this paper, an innovation investor is defined as an enterprise that claims to have invested in innovation activities in 1996. Equation 3 expresses the amount of innovation investment per employee. Equation 4 expresses variations in the amount of innovation output (innovation sales) per employee among the innovative firms. This measure is obtained by multiplying innovative products share of sales of innovative products, defined as technologically new or improved products introduced between 1994–96, by total sales. The sum is then divided by the number of employees. Finally, Equation 5 shows variations in productivity where productivity is defined as either sales or value-added per employee.

4.2 Specification and estimation of the model

The explanatory variables introduced to explain the firms' propensity to innovate (Equation 2) are numerous and include the following variables: industry dummies, firm size measured as the logarithm of the number of employees, export as a share of gross output, recent innovations indicated by a dummy variable for patent applications during 1994–96, the proportion of administrators and non-R&D engineers in the workforce, the factor intensity (knowledge, labour and capital) dummy variables, and finally a set of control variables indicating whether turnover in 1996 increased or decreased by 10 per cent or more due to new establishments, mergers with another enterprise or part of it, or sales or closures of part of the enterprise taking place during 1994–96. In explaining the level of innovation, additional indicators are added to the list of explanatory variables listed above. These included a number of indicators very important as sources of information for innovation, perceived obstacles to innovation, and firms' national and international cooperation on innovation.

The measure of innovation output (Equation 3) has been classified into two distinct groups: all innovations and radical innovations. Radical innovation is a subset of innovations, defined as innovations new to both the market and to the firm. Estimations are done separately for the two categories of innovation. The underlying assumption is that radical innovations differ from other innovations. The difference is in the presence of a weaker correlation of radical innovation with recent R&D investment and returns to R&D.

Innovation output (Equation 4) is explained using predicted innovation investments, feedback effects from predicted productivity, Mill's ratio predicted from the propensity to invest equation, 17 industry dummies, three factor-intensity dummies, a dummy for process innovation, and additional indicator variables representing reasons for innovation through a number of strategy variables. These strategy variables include product strategies that are offensive (proactive) and defensive, a strategy for reducing the costs of labour, material or energy consumption and a strategy for increasing flexibility in the production process.

The additional variables include a number of composite dummy variables indicating moderate and very important sources of information for innovation, cooperation in innovation, firm size, and control variables for recent establishments, mergers, acquisitions and plant closures.

Variations in the productivity variable (Equation 5) are explained by the logarithm of predicted innovation sales per employee, human capital, industry and factor-intensity dummies, a dummy for process innovation, important sources of knowledge for innovation, composite effects, factors hampering innovation, dummy variables for establishments, mergers and closures and finally the firm size.

In estimating the structural model, Equations 2 and 3 in a generalized tobit model are estimated by maximum likelihood method, while Equations 4 and 5 are estimated jointly in a simultaneous equation system by using two-stage least squares (2SLS) and a three-stage least squares (3SLS) estimation methods. Two different innovation measures are used in the estimation process. These are distinguishable from one another by the degree of novelty, namely all (radical and incremental) innovations and only radical innovations.

In order to derive a consistent estimator, our model accounts for simultaneity bias by relying on the instrumental variable approach. The instruments consist of variables not correlated with the model error terms but correlated with the endogenous variables appearing in the right hand side.

Although, Equations 4 and 5 are estimated separately from 2 and 3, we still allow for limited correlation between the error terms of the equations in the system. We believe that by splitting the model into two (0 and 1) and (2 and 3) parts, we avoid allowing for full correlation structure of the error terms and thereby work with tractable estimation procedure and easier interpretable results. We are aware of the necessity of modelling correlation among the residuals within the two parts separately and also between the two parts. It is important to note that we still account for limited but necessary degree of correlation by linking the two parts using the Mill's ratio (*MR*) variable. Our approach is thus an intermediate approach compared to the Pakes and Griliches (1984) model which neglects any form of correlation and the Crépon et al. (1998) approach allowing for full correlation between the four residuals. The variance covariance matrix in our model is a block diagonal where the elements in the off-block-diagonal consist of a scalar linking Equations 2 and 3 (Lööf and Heshmati (2002)).

5. Main results

Table 10 summarizes our main results concerning the elasticity of productivity growth with respect to innovation output for the three Nordic countries studied. The summary of the elasticity of innovation output with respect to innovation input is given in Table 11. The parameter estimates associated with various steps of the four equation models are presented in Appendices A1–A4.

The results are generally in agreement with our expectations. Recent studies using different versions of the CDM knowledge production function give rise to innovation output estimates in the range of 0.1–0.3. The estimated innovation output coefficients in the productivity equations are 0.26 and 0.16 for Norway and Sweden when controlling for firm size, human capital, industry and factor intensity, and using the 3SLS estimation method and assuming gross (sales) output per employee. The corresponding results 0.09 and 0.19 for Finland and Sweden using net (value-added) output. The corresponding results from the 2SLS model are 0.26 for Norway and 0.16 for Sweden using gross output, and 0.07 and 0.18 for Finland and Sweden, respectively with value-added per employee as performance measure. The estimates are highly significant in cases of Norway and Sweden, while the Finnish estimates are statistically insignificant in both estimation methods. In comparison between the 2SLS and 3SLS methods, the latter is preferred. The 3SLS accounts for cross correlation between the two equations and consequently being more efficient.

Table 10. Estimated elasticity of productivity growth with respect to innovation output.

Model	Norway[a]	Finland[b]	Sweden[a]	Sweden[b]	Sweden[c]
1	0.257***	0.090	0.163***	0.194***	0.155***
	(0.062)	(0.058)	(0.044)	(0.047)	(0.036)
2	0.255***	0.072	0.162***	0.177***	0.139***
	(0.060)	(0.066)	(0.058)	(0.061)	(0.050)
3	0.169**	0.082	0.061	0.105**	0.177***
	(0.085)	(0.080)	(0.039)	(0.044)	(0.038)
4	0.211***	0.104*	0.069	0.098**	0.147***
	(0.065)	(0.060)	(0.046)	(0.038)	(0.048)

Notes Coefficients, and standard errors in parenthesis. Significant at the 1% (***), 5% (**) and 10% (*) levels of significance.
a: log sales per employee;
b: log value-added per employee;
c: log value-added per employee and the productivity equation includes log physical capital.
Model 1: 3SLS including all innovations.
Model 2: 2SLS including all innovations.
Model 3: 3SLS including only radical innovations.
Model 4: 2SLS including only radical innovations.

The estimates drop substantially when only radical innovations are considered. The result from Equations 3 and 4 show that the contribution from innovation output is higher in Norway than in Sweden when sales productivity is considered, and higher in Norway than in Finland when sales productivity is used compared with value-added productivity. The estimates in the right hand side of the table are based on the standard Schumpeterian specification, which uses value-added per employee as performance measure and including physical capital intensity among the control variables.

Table 11. The estimated elasticity of innovation output (innovation sales per employee) with respect to innovation input.

Model	Norway[a]	Finland[b]	Sweden[a]	Sweden[b]	Sweden[c]
1	-0.013	-0.050	0.372***	0.285***	0.266***
	(0.172)	(0.088)	(0.109)	(0.086)	(0.081)
3	0.018	0.294*	-0.164	0.023	0.038
	(0.040)	(0.160)	(0.144)	(0.142	(0.086)

Notes: Coefficients, and standard errors in parenthesis. Significant at the less than 1% (***), 5% (**) and 10% (*) levels of significance.
a: log sales per employee;
b: log value-added per employee;
c: log value-added per employee and the productivity equation includes log physical capital.
Model 1: 3SLS including all innovations.
Model 3: 3SLS including only radical innovations.

What is most striking in our results is the high estimated contribution of innovation output to the level of productivity in the case of Norway and the weak impact of innovation output on productivity in Finland. Looking the link between innovation input and output, however, indicates a weak estimated contribution of innovation investments in both Norway and Finland, and a rather strong contribution in Sweden.

A variety of problems can emerge from the data and methodology used in the study. The important issue here is whether the regression results between the three countries are affected by data error, model specifications, the estimation technique, unobservable firm-specific or country-specific effects, or other ignored effects. We shall elaborate on these issues in the following.

Starting with the data, the harmonized survey satisfies the conditions for a collection of unified endogenous and exogenous variables. However, satisfying the conditions does not necessarily guarantee a high level of confidence in the quality of the data. For instance only 24 per cent of the Finnish firms are product innovative according to the CIS criteria, compared to 35 per cent of the Norwegian firms and 46 per cent of the Swedish firms. Particularly the low level of innovative firms according to the CIS-data in the highly productive Finnish economy can be questioned. Moreover, the results are sensitive to the representativeness of the total sample as well as the selected innovative sample. While the Finnish firms have between 10 and 10,000 employees, their counterparts in Norway and Sweden have between 20 and about 5,000. The main concentration in all cases is, however, at the lower limits.

In Norway the CIS survey was compulsory, which guaranteed that nearly all responding firms with 20 or more employees were included in the data. In Finland and Sweden only minority of firms in the selected sample responded to the questionnaire. The rate of response was biased towards large firms particularly in the case of Finland. This means that large – and probably relatively more process oriented firms – are over-represented in the total sample.

The problem mentioned above can to some extent be eliminated by attaching different weights to different observations. However, the measure does not entirely eliminate the selection problem raised. In a small experiment adjusting the firm sizes upward in the Swedish data set by including a few large firms with more than 5,000 employees had very little effect on our regression estimates.

Another possible explanation for the unexpected divergence between the Finnish and Norwegian innovation output estimates, which can be associated with data problem, is that the former case the analysis is based on value-added, while the latter is based on sales productivity. Comparing these both measures in regressions on the more extensive Swedish data set, however, the results do not indicate any significant differences between gross and net outputs.[11] Moreover, estimation of the Swedish and Norwegian samples with identical output definitions produces higher estimates for the average Norwegian firm.

An additional possible problem associated with the data sets is that the Swedish and Finnish data sets were collected in 1997 and refer to the period 1994–96, while the Norwegian data were collected in 1998 and concern the period 1995–97. The difference in the period observed and the fact that countries differ might reflect the impacts of business-cycle factors.

11 Using a sample consisting of about 50 per cent of the Swedish manufacturing firms Lööf and Heshmati (2003) found that the sales measure tends to overestimate the elasticity of productivity with respect to innovation output.

Turning now to the model specifications. The common specification of the model was results of a comprehensive sensitivity analysis concerning variable definitions, variable selection, and estimation procedures from the Swedish data found in Lööf and Heshmati (2003). Identical model specification has then been applied to the Finnish and Norwegian data sets. Although we control for a large number of factors, there are difficulties in applying such technique across countries, since it is unlikely that different countries have the same production technology. Ideally one should use statistical techniques (e.g. factor analysis) to identify sets of factors which are soecfically important in each country. The opportunities for modifying the basic model to account for the unique country and firm-specific characteristics and peculiarities in all three different country data sets have been strongly limited by the Finnish and Norwegian Statistical agencies. Lack of possibilities to pool the data rendered to test statistically the differences among the three countries for each factor. Hence, it is reasonable to assume that the model is biased towards the Swedish data and production technology.[12]

In the analysis of the link between firm level innovation and aggregate productivity growth it is desirable that the model is extended to a dynamic specification to include issues like the process of creative destruction. This implies that we do not only focus on the population of firms existing in a year, but also on the impact of entry and exit. In their study of the link between aggregate and micro productivity growth, using US retail trade data, Foster et al. (2002), for instance, suggest that a large part of the productivity growth at the sector level can be explained by the entry of a more productive establishment. The entrants replace much less productive establishment exiting the market.

A closely related set of possible causes for the different and unexpected results might be found in the method of estimation. Here a single model specification is estimated at an individual country level without pooling the data. When the data is estimated in separate regressions, the specifications should ideally be country specific and incorporate some testing procedure. In the absence of confidentiality problems, the use of firm-level CIS data in a pooled country regression of the relationship between productivity growth and innovation could be a preferable research method. Of course, this is meaningful only when complementary information on country-specific effects is accounted for.

A number of factors in addition to those discussed above might individually or jointly contribute to explaining the puzzling results, in particular concerning the Norwegian and the Finnish firms. One factor might be that the analysis is based on the level of productivity while the weak Norwegian productivity reflects the growth rate point of views. From the firms' perspective, however, it is generally necessary to be competitive in both the level and the rate of growth. Therefore highly productive firms today are very likely to be highly productive firms tomorrow as well.

Some of the main issues ignored is the fact that the firms' productivity performance represents the outcome of returns generated by knowledge production and its diffusion

12 The Zentrum für Europeishe Wirtschaftsforshnung in Mannheim, Germany, offers an opportunity to avoid the confidentiality problem characterizing most of other OECD countries databases. This is done by creation of a firm-level data where firm identity numbers are decoded. The decoded data containing information about anonymous firms is available for purely scientific and non-commercial purposes.

not only associated with new products but also with factors such as new techniques embodied in equipment and production processes,[13] new methods of organization, and the quality of management and entrepreneurship. Moreover, in our analysis we only account for spillover effects by the inclusion of 17 industry dummies and some hard to measure indicators on cooperation on innovation and external sources of knowledge for innovations.[14]

Finally, simple correlation matrices and regression of each explanatory variables on remaining variables show relatively low degree of collinearity among the variables. However, we are aware of possible collinearity problem resulting in difficulties in separation of the factor specific effects and that the results should be interpreted with cautious.

We cannot draw any concrete conclusions about whether the estimation results are affected by data error, model specifications, the estimation technique, unobservable effects or other ignored effects. However, given that problems and issues discussed above do not cause introduction of serious disturbances in the estimation results, the tentative conclusion from this study suggest the following. A better data, more representative samples and the use of knowledge production function model do not deviate much from previous findings. Cross-country differences in productivity growth cannot be explained by the relationship between innovation and productivity at the firm level, simply by controlling for firm size, industry, factor intensity (capital, labour and knowledge) and human capital.

6. Summary and conclusions

One of the major differences between the three northern European countries Finland, Norway and Sweden has been in the growth rates of productivity. When aggregated labour productivity growth in manufacturing is considered, Finland and Sweden show the highest growth rates amongst the OECD countries during recent years, while Norway has shown a very low growth performance. At the same time Finland and Sweden are highly ranked internationally as R&D investors and have a high ratio of residential patent applications per capita, while Norway's ranking is very low in both cases. This suggests that the R&D and innovation performances might be key factors causing the differences in productivity growth amongst the Nordic countries.

An initial issue of interest investigated here was whether the observed difference in growth at the aggregate manufacturing level is also apparent at the disaggregated two-digit NACE-level and is not just an artefact of the composition of the industry structure.

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13 The accumulation of physical capital is one of the main sources of economic growth. Jorgenson (1990) found that the contribution of physical capital accounts for more than 40 per cent of the growth in the US during 1947–85. In allowing for quality differences in capital equipment, Hulten (1992) found that the best practice technology is about 20 per cent above the average level of efficiency in the US.

14 Recent studies indicate that the knowledge externalities have significant contribution to the firm-level productivity (see for example Klette 1996). A basic assumption in many of these studies is that technological change is transmitted to other industries and firms in the form of quality improvements in the inputs they buy from other R&D performing industries. The prices of such inputs do not fully reflect their quality improvement.

Between 1990 and 1997 the manufacturing growth rate was 5–6 per cent in Finland and Sweden and only 1 per cent in Norway. Imposing the same structure as in Finland or Sweden the Norwegian growth rate would have remained at the same low level.

Simple statistical analysis reveals that the proportion of innovative firms, the amount of innovation investment or innovation output is not low in Norway. The econometric analyses also show that the size of estimated elasticity of productivity, with respect to innovation output at the firm level, is significantly lower in the high productivity Finnish economy compared to the Norwegian economy. The link between innovation and productivity is also stronger in the average innovative manufacturing firm in Norway compared to its counterpart in Sweden.

Our findings indicate that results from a broadening of the definition of innovation input from only formal R&D to all expenditures on investment in innovative activities, an inclusion of innovation output into the analysis, using a larger and more representative samples of firms compared to previous studies, an inclusion of small firms and finally an econometric framework based on the knowledge production function which accounts for both selectivity and simultaneity biases do not deviate much from the findings in the literature. These findings are in agreement with the proposition that the link between innovation and productivity at the firm level cannot account for much of the observed differences in productivity growth across countries.

In analysing the role of innovation in productivity performance at the firm level, one has to control for the impacts of internal factors such as the size and quality of capital equipment. It is important to use time series of productivity measured in value-added terms and to use reliable lagged innovation investments. Other control variables are measures of knowledge externalities, information on the relationship between innovate firm and the market for financial market as well as various information on the industrial or national systems of innovation.

Future cross-country innovation analyses do not only require access to better data sets but also better possibilities to compare the nationally collected data over time and across countries without excluding information about individual firms. One method to solve the confidentiality problem is by releasing variance-covariance matrices for recoded data from the national surveys. A remaining problem is how to complete this decoded data with other firm-specific, industry-specific and country-specific information from register data sets.

An extension of the analysis by accounting for creative destruction as well as for externalities is desirable. The former would account for entry and exit of firms but the latter is more problematic. One method of testing for externalities to R&D and innovation is to compare results obtained from firm and industry levels data. If there are significant externalities to innovation activities within an industry, than the computed returns should be higher at the industry than at the firm level.

References

Aghion, P. and P. Howitt (1998), *Endogenous Growth Theory*, MIT Press, Cambridge MA.

Crépon, B., E. Duguet and J. Mairesse (1998), Research, Innovation, and Productivity: An Econometric Analysis at the Firm Level, NBER Working Paper No. 6696.

European Commission and Eurostat (2001), Statistics on Science and Technology in Europe, 2000 edition, Theme 9 Science and Technology.

Foster, L., J. Haltiwanger and C. J. Krizan (2002), The Link between Aggregate and Micro Productivity Growth: Evidence from Retail Trade, NBER Working Paper No. 9120.

Geroski, P., S. Machin and J. van Renen (1993), The Profitability of Innovating Firms, *RAND Journal of Economics*, Vol. 24, No. 2, pp. 198–211.

Griliches, Z. and J. Mairesse (1983), Comparing Productivity Growth: An Exploration of French and US Industrial and Firms Data, *European Economic Review*, Vol. 21, No. 1–2, pp. 89–119.

Griliches, Z. and J. Mairesse (1990), R&D and Productivity Growth: Comparing Japanese and US Manufacturing Firms, NBER Working Paper No. 1778.

Griliches, Z. and J. Mairesse (1997), Production Functions: The Search for Identification, Document de Travail CREST 9730.

Hall, B. and J. Mairesse (1995), Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms, *Journal of Econometrics*, Vol. 65, pp. 263–93.

Hall, R. E. and C. I. Jones (1999), Why do some Countries Produce so much more Output per Worker than Others?, NBER Working Paper No. 6564.

Haltiwanger, J. (2000), Aggregate Growth: What have we Learned from Microeconomic Evidence?, Economic Department Working Papers No. 267, OECD, Paris.

Helliwell, J. (1996), Economic Growth and Social Capital in Asia, NBER Working Paper No. 5470.

Hulten, C. R. (1992), Growth Accounting when Technical Change is Embodied in Capital, *American Economic Review*, Vol. 82, No. 4, pp. 57–71.

Jorgenson, D. W. (1990), Productivity and Economic Growth, in: E. Berndt and J. Triplett (eds), *Fifty Years of Economic Measurement*, University of Chicago Press, Chicago.

Keefer, P. and S. Knack (1997), Why Don't Poor Countries Catch Up? A Cross-Country Tests of an Institutional Explanation, *Economic Inquiry*, Vol. 35, No. 3, pp. 590–602.

Klette, T. J. (1996), R&D, Scope Economies and Plant Performance, *RAND Journal of Economics*, Vol. 27, pp. 502–22.

Klette, J. and S. Kortum (2002), Innovating Firms and Aggregate Innovation, NBER Working Paper No. 8819.

Kline, S. J. and N. Rosenberg (1986), An Overview of Innovation, in R. Lindau and N. Rosenberg (eds), *The Positive Sum Strategy*, Harnessing Technology for Economic Growth, National Academy Press, Washington DC, pp. 275–305.

Lööf, H. and A. Heshmati (2003), On the Relationship between Innovation and Performance: A Sensitivity Analysis, *Economics of Innovation and New Technology*, forthcoming.

Lööf H. and A. Heshmati (2002), Knowledge Capital and Performance Heterogeneity: A Firm Level Innovation Study, *International Journal of Production Economics* Vol. 76, No. 1, pp. 61-85.

Mairesse, J. and P. Cuneo (1985), Recherche-Développement et Performances des Enterprises; Une Etude Économetricque sur Données Individuelles, *Revenue Economique*, Vol. 36, pp. 1001–52.

Mohnen, P., J. Mairesse and M. Dagenais (2001), The Importance of Being Innovative: A Comparison across Seven European Countries, Mimeo.

OECD (1992), Guidelines for Collecting and Interpreting Technological Innovation Data – Oslo Manual, OECD, Paris.

OECD (2000), Main Science and Technology Indicators, OECD, Paris.

OECD and Eurostat (1997), *Olso Manual Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, Paris.

Pakes, A. and Z. Griliches (1984), Patents and the R&D at Firm Level: A First Look, in Z. Griliches (ed.), *R&D, Patents and Productivity*, University of Chicago Press, Chicago, pp. 390–409.

Putnam, R. D. (1993), *Making Democracy Work: Civic Traditions in Modern Italy*, Princeton University Press, Princeton.

Unger, B. (2000) Innovation Systems and Innovative Performance: Voice Systems, Organization Studies 21(5), Special Issue on The Institutional Dynamics of Innovation Systems, Berlin/New York.

United States Department of Labor (2000), International Comparisons of Manufacturing Productivity and Unit Labor Cost Trends, http://stats.bls.gov.

Appendix A1. Probit model of innovation decision (Equation 2) using total samples.

	Finland	Norway	Sweden
Sample size	1,062	1,315	743
Firm size	0.171*** (0.043)	0.223*** (0.061)	0.141*** (0.045)
Export intensity	0.104*** (0.021)	0.006 (0.007)	0.070*** (0.023)
Patent applications 1994–96	1.572*** (0.142)	0.555*** (0.211)	1.455*** (0.165)
Non R&D-engineers	-1.432** (0.622)	0.107 (0.869)	0.820 (0.892)
Administrators	0.310 (0.971)	2.405** (0.996)	-0.354 (1.626)
During the period 1994–96 production was changed by at least 10% due to:			
- the firm was established	0.010 (0.226)	0.107 (0.280)	-0.716* (0.372)
- merger with another firm or part of it	0.267 (0.168)	-0.100 (0.194)	0.117 (0.175)
- sale or closure of part of the firm	-0.028 (0.205)	0.306 (0.282)	-0.031 (0.237)

Notes: Significant at 1% (***), 5% (**) and 10% (*), standard errors in parentheses.

Appendix A2. Tobit model of innovation investment (Equation 3) using total samples

	Finland	Norway	Sweden
Sample size	1 062	1 315	743
Firm size	-0.483*** (0.099)	0.951*** (0.323)	0.108 (0.106)
Export intensity	0.181*** (0.042)	0.081** (0.038)	0.055 (0.045)
Factor intensity: Knowledge	-0.849 (1.878)	-1.822* (0.985)	1.376* (0.776)
Factor intensity: Capital	-0.115 (1.101)	-1.747* (0.946)	2.490* (1.40)
Previous research proxied by patents	1.630*** (0.267)	2.678*** (0.943)	0.727*** (0.274)
Human capital: Non-R&D-engineers	-3.179*** (1.173)	-0.450 (4.112)	0.640 (1.508)
Human capital: Administrators	0.573 (2.107)	13.775** (5.506)	2.227 (2.623)
During the period 1994–96 production was changed by at least 10% due to:			
- the firm was established	-0.478 (0.444)	1.578 (1.410)	-2.597*** (0.966)
- merger with another firm or part of it	0.323 (0.328)	0.227 (1.084)	-0.139 (0.302)
- sale or closure of part of the firm	0.530 (0.429)	0.199 (1.417)	-0.398 (0.437)
Obstacles to innovation			
Excessively perceived economic risk	0.522 (0.343)	1.335 (0.950)	-0.207 (0.333)
Innovation costs too high	0.207 (0.341)	0.577 (1.006)	0.399 (0.320)
Lack of appropriate sources of finance	0.175 (0.322)	-0.983 (0.173)	1.003*** (0.338)
Organizational rigidities	0.386 (0.351)	2.171*** (0.817)	-0.217 (0.279)
Lack of qualified personnel	0.535* (0.312)	-0.411 (0.877)	0.686** (0.283)
Lack of information on technology	0.726** (0.309)	1.311 (1.010)	-0.776** (0.341)
Fulfilling regulations or standards	-0.456 (0.374)	-0.447 (1.122)	0.066 (0.360)
Lack of consumer responsiveness	-0.219 (0.362)	-1.986 (1.236)	0.541* (0.322)
Strategy on innovation (very important factors)			
Improving products	0.179 (0.258)	3.798*** (0.682)	1.294*** (0.231)
Opening up new markets	-0.042 (0.259)	3.212*** (0.700)	0.566** (0.243)
Extending product range	1.005*** (0.284)	4.013*** (0.670)	0.619** (0.261)
Fulfilling regulations or standards	0.086 (0.338)	0.228 (0.777)	0.412 (0.258)
Replacing products being phased out	0.005 (0.281)	1.481* (0.779)	0.405* (0.235)
Reducing labour costs	-0.342 (0.338)	1.597** (0.738)	0.190 (0.269)
Reducing material consumption	0.282 (0.410)	-0.891 (0.836)	-0.234 (0.301)
Improving production flexibility	0.940*** (0.291)	0.111 (0.740)	-0.164 (0.275)
Reducing environmental damage	1.165** (0.499)	-2.612*** (0.993)	0.306 (0.348)
Crucial sources of information for innovation			
Sources within the enterprise	0.983*** (0.248)	3.041*** (0.641)	0.979*** (0.244)
Clients or customers	0.596** (0.240)	2.758*** (0.689)	1.471*** (0.254)
Other firms within the group	0.331 (0.463)	2.193** (0.907)	-0.677* (0.381)
Competitors	-0.388 (0.438)	-0.423 (0.810)	-0.155 (0.311)
Consultancies	0.195 (0.632)	-1.259 (1.400)	0.554 (0.723)
Supply of equip., materials, software	-0.654 (0.419)	-0.809 (0.778)	0.511 (0.360)
Universities or higher education institute	-0.143 (0.466)	1.897 (1.499)	-0.417 (0.562)
Patent disclosures	0.493 (0.896)	3.060 (3.993)	0.207 (0.636)
Prof. Conferences, meetings, journals, IT	0.156 (0.535)	-1.902 (1.203)	0.035 (0.671)
Computer-based information networks	-0.784 (0.832)	0.811 (1.700)	-2.434*** (0.761)
Fairs, exhibitions	0.742** (0.366)	2.939*** (0.861)	0.186 (0.339)
Domestic cooperation in innovation			
Customers	0.986*** (0.281)	3.327*** (0.875)	0.660** (0.278)
Suppliers	0.148 (0.291)	0.719 (0.874)	0.496 (0.326)
Competitors	0.864** (0.412)	1.716 (1.450)	-1.577** (0.660)
Other firms within the group	0.128 (0.363)	-0.830 (0.958)	0.254 (0.357)
Consultancies	-0.224 (0.329)	-0.067 (0.992)	0.263 (0.328)
Universities	1.185*** (0.310)	0.850 (1.003)	0.149 (0.328)
Government	0.418 (0.290)	1.159 (0.897)	0.180 (0.373)

Notes: Significant at 1% (***), 5% (**) and 10% (*), standard errors in parentheses.

Appendix A3. 3SLS estimation results from innovation output (Equation 4) based on innovative samples. Dependent variable is log innovation output per employee.

	Finland	Norway	Sweden
Panel A: All innovations	353	485	405
Innovation input	-0.050 (0.088)	-0.013 (0.172)	0.372*** (0.109)
Productivity	0.390 (0.219)	1.333*** (0.329)	0.095 (0.443)
Firm size	-0.074 (0.063)	-0.098* (0.527)	-0.050 (0.058)
Knowledge-intensive industries	0.478 (1.037)	0.720 (1.388)	2.642*** (0.803)
Capital-intensive industries	1.401 (0.696)	0.301 (1.332)	2.068** (1.028)
During the period 1994-96 production was changed by at least 10% due to:			
- the firms was established	0.274 (0.258)	0.322 (0.262)	1.251** (0.548)
- merger with another firm or part of it	0.076 (0.178)	0.216 (0.188)	-0.185 (0.168)
- sale or closure of part of the firm	0.615** (0.276)	0.243 (0.248)	0.191 (0.254)
Strategy on innovation			
- offensive (proactive)	0.326 (0.547)	0.377 (0.958)	-1.103** (0.431)
- defensive	0.844*** (0.181)	0.096 (0.074)	0.144 (0.132)
- reduce cost	0.168 (0.137)	0.305*** (0.113)	-0.398** (0.175)
- improve production flexibility	0.327** (0.133)	-0.102 (0.094)	0.212 (0.140
Important (moderate) sources of information for innovation			
- other firms within the group	-0.239 (0.171)	-0.305** (0.146)	0.158 (0.166)
- the market	0.015 (0.142)	0.247** (0.126)	0.404** (0.179)
- non-market network	-0.198 (0.130)	0.173 (0.165)	0.277** (0.125)
- prof. Conferences, meetings, journals, IT	0.005 (0.126)	0.021 (0.119)	-0.341*** (0.124)
Domestic innovation cooperation			
- customers	-0.094 (0.137)	0.101 (0.099)	-0.318** (0.142)
- consultancies	0.138 (0.151)	0.023 (0.104)	-0.396** (0.163)
- universities	0.020 (0.158)	0.182 (0.109)	0.172 (0.161)
Mill's ratio	-0.115 (0.153)	0.145 (0.125)	0.225 (0.236)

Notes: Significant at 1% (***), 5% (**) and 10% (*), standard errors in parentheses.

Appendix A4. 3SLS estimation results from productivity growth (Equation 5) based on innovative samples. Dependent variable is measured as log value-added per employee in Finland and log sales per employee in Norway and Sweden.

	Finland	Norway	Sweden
Panel A: All innovations	323	485	407
Innovation output	0.090 (0.058)	0.257** (0.062)	0.163*** 0.044)
Firm size	0.062*** (0.021)	0.031 (0.021)	0.067***(0.016)
Non-R&D-engineers	0.851*** (0.164)	1.269** (0.317)	0.638** (0.304)
Administrators	2.758*** (0.719)	0.617* (0.358)	3.392*** 0.597)
Process innovation	-0.029 (0.060)	0.008 (0.044)	-0.148**(0.043)
Knowledge-intensive industries	-0.546 (0.516)	-0.424 (0.604)	-1.132**(0.245)
Capital-intensive industries	0.110 (0.356)	-0.285 (0.578)	-1.360**(0.304)
During the period 1994–96 production was changed by at least 10% due to:			
- the firms was established	0.184 (0.131)	-0.106 (0.114)	-0.382* (0.200)
- merger with another firm or part of it	-0.078 (0.084)	0.010 (0.083)	0.070 (0.056)
- sale or closure of part of the firm	-0.296 (0.139)	-0.078 (0.109)	-0.135* (0.081)
Obstacles to innovation			
Excessively perceived economic risk	0.033 (0.089)	-0.038 (0.047)	-0.032 (0.056)
Innovation costs too high	-0.125 (0.090)	-0.076 (0.047)	-0.007 (0.056)
Lack of appropriate sources of finance	-0.113 (0.088)	-0.031 (0.053)	-0.051 (0.053)
Organizational rigidities	0.240*** (0.087)	-0.030 (0.040)	-0.076* (0.046)
Lack of qualified personnel	-0.035 (0.079)	0.024 (0.042)	-0.021 (0.045)
Lack of information on technology	0.073 (0.077)	0.054 (0.048)	-0.034 (0.058)
Lack of information on the market	-0.111 (0.087)	0.000 (0.051)	-0.086 (0.058)
Lack of consumer responsiveness	0.166* (0.089)	0.082 (0.059)	0.150*** (0.056)
Crucial sources of information for innovation			
Within the firm	0.072 (0.058)	-0.055 (0.045)	0.007 (0.043)
Other firms within the group	0.233** (0.096)	0.101* (0.056)	0.151** (0.058)
The market	-0.002 (0.058)	-0.025 (0.052)	-0.015 (0.042)
Non-market network	-0.071 (0.087)	-0.058 (0.070)	0.029 (0.074)
Professional conferences, meetings, journals, IT	-0.224 (0.074)	-0.004 (0.051)	0.012 (0.047)

Notes: Significant at 1% (***), 5% (**) and 10% (*), standard errors in parentheses.