IGNORed
Innovation and Growth in the Nordic Economies

Innovation indicators and performance – An analysis for Danish firms

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April 24, 2008

Abstract
This paper analyses the impact of innovation on growth for Danish firms, and how innovation indicators can be used to aid in this analysis. Drawing on other recent international studies, we examine classifications of innovative firms based on a number of factors that can impact innovation performance, among these the roles of novelty and in-house development, formal or creative innovation activity and collaboration with others, non-technological innovation and innovation drivers. Thereafter we analyse the impact of these factors on innovation performance and productivity, drawing on recent versions of the Crepon, Duguet and Mairesse (CDM) model which examine the relation between innovation, knowledge production and productivity.

Paper prepared for the PRIME Indicators conference, May 28-30, Oslo

This paper is part of the IGNORed project on innovation and productivity. Funding from the Nordic Innovation Centre (NICe) is gratefully acknowledged.

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1 Introduction

Knowledge, research and innovation are of crucial importance for the competitiveness of the modern economy, as well as for the high standard of living and welfare. Policy documents, reports and analyses show that there is a need to develop a more accurate and detailed understanding of the role and dynamics of different types of innovation for companies' performance and economic growth. Here, systematic and comparable analysis can result in a better understanding which is fundamental for sound, evidence-based support to policy making.

Taking the stand point that innovation increases productivity, as shown in Crépon et al (1998) among others, it is obviously clear to ask whether there are characteristics such as education (absorption capacity), innovation type (strategic innovation, user driven innovation, open innovation, imitating innovation etc.), innovative output (innovative sales), or other characteristics such as use of ICT or new technology etc. that augment the effect of innovation, i.e. increase the effect of innovation on productivity.

Innovation surveys based on the Oslo Manual (OECD/Eurostat, 2005) were introduced in many OECD countries in the early 1990s. The original purpose of these surveys was to obtain data on innovation outputs plus on a range of innovation inputs and activities that were not based on formal R&D. However, examinations of the usefulness or impact of innovation indicators for policy give the impression that the impact of innovation surveys has so far been fairly minor (see eg. Arundel, 2006). R&D indicators are still the most widely used indicators of innovative activity. One important factor here is that in order for innovation indicators to be useful, they must be widely known and accepted as measures of innovation activity. This requires extensive analysis, both econometric and otherwise to examine the properties of the indicators.

An additional factor that may have reduced policy use is an under exploitation of innovation survey data. Many potentially useful indicators of direct relevance to policy concerns have not been developed. Almost all publicly available indicators from innovation surveys are simple indicators based on a single question, such as the share of enterprises that applied for one or more patents, or the percentage of firms that have engaged in innovation cooperation. Although these indicators can be highly useful, they fail to incorporate key factors that are linked to innovation outcomes.

In short, there is a need for a greater quantitative basis both in improving our understanding of the impact of innovation and in forming innovation policy strategies. Innovation indicators can be a valuable tool in this regard, though they may be insufficient on their own. On their own, they will still lack quantitative analysis of impacts on productivity.

The objective of this paper is to analyze the impact of innovation on growth for Danish firms, and how innovation indicators can be used to aid in this analysis. In order to enhance the applicability of this analysis, we will examine a number of innovation indicators that have recently been developed in other international work, including the Nordic NIND project[1] (funded by the Nordic Innovation Centre), the OECD Innovation Microdata Project[2], and work by Anthony Arundel and Hugo Hollanders for the European Innovation Trendchart. In particular, we examine classifications of innovative firms based on a number of factors that can impact innovation performance, among these the roles of novelty and in-house development, formal or creative innovation activity and collaboration with others, non-technological innovation and innovation drivers. The paper discusses these indicators and examines results across industries for Danish firms.

Thereafter, we analyse the impact of these factors on innovation performance and productivity. The econometric analysis will draw on recent versions of the Crepon, Duguet and Mairesse (CDM) model which examine the relation between innovation, knowledge production and productivity. We will follow the basic modeling approach used in Lööf and Heshmati (2006), the OECD microdata project and in other IGNORed project work and estimate the model in stages. The strength of this approach is that it allows us to analyse impacts on the innovation process at several different stages: the decision to innovate, determinants of innovation intensity, impacts on innovation performance and on overall productivity.

The next section shows composite indicators of innovation and illustrates them across industries for Danish firms. Section 3 discusses approaches for the estimation of the relation between innovation and productivity and main issues that have been discussed in the literature. Section 4 presents the model used in the analysis and results. Section 5 concludes.

2 Indicators of innovativeness

Classification of innovators

This section examines innovation for Danish firms across industries using a variety of indicators. In particular, we will look at the roles of novelty, non-technological innovation and innovation drivers utilizing innovation indicators recently developed in other projects.

Simple indicators of the share of innovative firms are often used as general indicators of innovativeness. For example, one of the most widely used innovation indicators is the share of firms that has implemented a product or process innovation. However, as Arundel and Hollanders (2005) argue, these broad indicators fail to uncover the wide variation if innovative firms, giving an incomplete picture of how innovative firms are in a sector or country, and may potentially be misleading in international comparison.

The ability to classify and distinguish different types of innovative firms may be of great value for innovation policy design and for further analysis. There is a need for a clear and detailed view of firm innovation that aids in identifying policy needs and characteristics that may help in properly targeting innovation policies.

[1] See Bloch et al. (2007).
[2] The results of projects implemented in 2007 are expected to be published by 2008.

However, what is equally important in this regard is the performance of different types of innovative firms. It is of central relevance for policy not just identifying the different ways in which firms innovate, but also the impacts of different innovation strategies on firm productivity. The next section will conduct an econometric analysis of the impact of innovation on productivity for Danish firm.

2.1 Output-based innovation modes

Firms can innovate in a large number of ways. For example, some firms may be at the cutting edge for their market, developing products and technologies that are truly novel. Other firms may invest little in in-house development activities and instead adopt new technologies from others. For some firms, organizational practices or marketing methods may form the core of their innovation activities. The identification of each of these groups could be of interest for policy. For example, in terms of novelty, there is interest in identifying the most novel firms that are active in creating new knowledge, and also in promoting their development. However, in order to fully capitalize on this knowledge creation, it is important that a large share of firms adopt and implement this new knowledge in their own goods and services.

Box 1. Output-based innovation modes

- **New to market international innovators**
  These enterprises have introduced a product innovation that is new to international markets and have developed new products or processes in-house. Innovations for these enterprises have the highest degree of novelty and at the same time in-house development (product or process innovation developed by enterprise itself or together with others) indicates that these enterprises possess (at least some of) the capability to create novel products.
- **New to market domestic innovators**
  These enterprises have introduced product innovations that are novel for domestic markets, but not necessarily new for international markets. These enterprises only operate on domestic markets. As with new to market international innovators, innovations are at least partially developed in-house.
- **International innovators**
  These enterprises have some in-house development activities, but product and/or process innovations already exist on international markets (new to enterprise product or process innovators). Innovations may or may not be new to domestic markets.
- **Domestic modifiers**
  These enterprises only operate on domestic markets. Product and/or process innovations already exist on domestic markets (new to enterprise domestic product or process innovators). These enterprises are thus adopters, but are able to adopt and implement the new technologies themselves.
- **Adopters**
  These enterprises have not developed product or process innovations in-house, but have had them developed by others. This group thus includes all product and process innovators that have had all their product-process innovations developed externally, regardless of novelty.

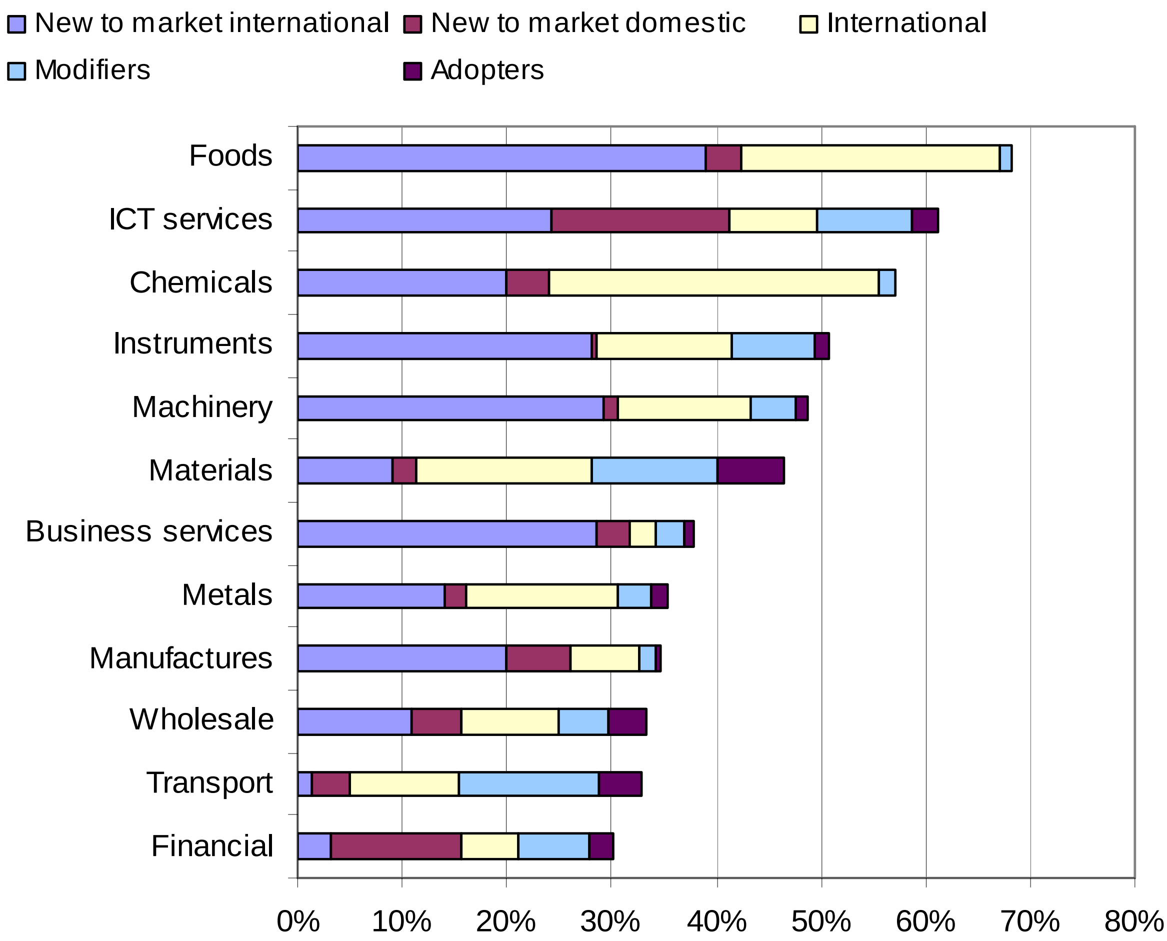
Source: Bloch et al. (2007).

Output based innovation modes classify innovative firms according to the novelty of their innovations and whether innovation development was conducted in house or mainly by others (see box 1). We examine marketing and organizational innovation, and its combination with product-process innovation, later in this chapter.

Figure 1 shows output based modes across Danish industries[3]. As can be seen, there is a high degree of variation, with high shares of novel innovators in some industries whereas in other industries innovation is mainly concentrated on the use and modification of existing products and processes. Perhaps surprisingly, Food and Beverages has the highest share of innovative firms, with close to 40 percent having introduced product innovations new to international markets. Among the other top performing industries are Chemicals, Machinery, Instruments and ICT services.

The overall share of innovative firms in Business Services is somewhat lower, however, among those that innovate a high share are new to market international innovators. And in sectors such as Materials, Metals, Transport and Financial intermediates, innovators are predominantly process innovators or have introduced innovations that are new to the firm only.

Figure 1. Output based innovation modes



Source: CIS4 data for Denmark. Based on shares of product-process innovative enterprises.

[3] See the annex for a list of industries (NACE 2- digit) included in each group.

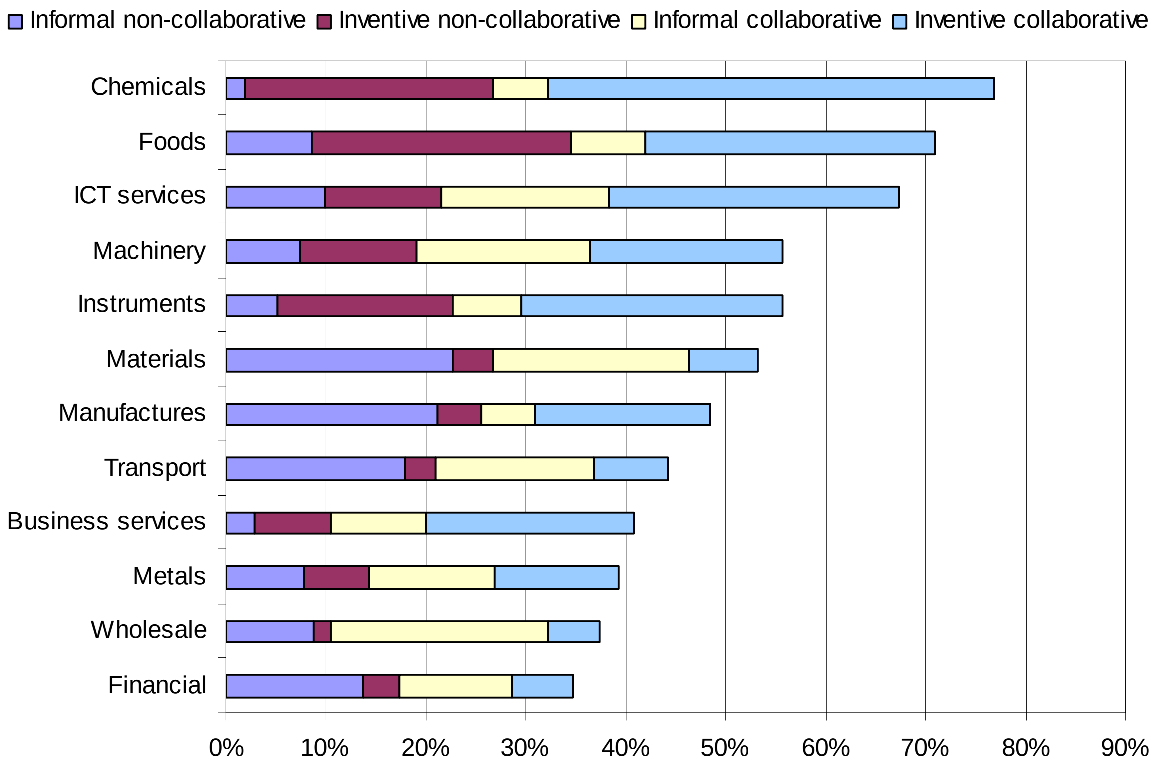
2.2 Innovation status

Two important dimensions of enterprise innovation are inventive or creative activities and diffusion. Arundel and Hollanders (2006), as part of work on the European Innovation Trendchart, develop an indicator of innovative enterprises classified along these two dimensions. Inventive in-house activities are measured by in-house R&D or the application for a patent, while reliance of diffused technology is indicated either if enterprises' innovations were developed with or solely by others, or if the enterprise engaged in active innovation cooperation. This indicator also draws on insights from European policy interviews (Arundel and Hollanders, 2006), where in particular formal innovation and collaboration were cited as important aspects of relevance for innovation policy.

Inventive collaborative innovators both carry out in-house creative activities and rely on diffusion in its innovation activities. **Inventive non-collaborative innovators** carry out creative in-house activities, but do not actively access external knowledge. **Informal collaborative innovators** do not carry out creative in-house activities but actively access external knowledge. Finally, **informal non-collaborators** do not have inventive in-house activities, nor do they actively access external knowledge.

Innovation policy is concerned with promoting both formal innovation and collaboration. Formal innovation activities, such as R&D are an important element in developing novel products and processes, new competences and new knowledge that can diffuse to other firms.

Figure 2. Innovation status



Source: CIS4 data for Denmark. Based on shares of innovation active enterprises.

In looking at figure 2, we can see some different patterns compared to that for output based modes. Food and Beverages stands out in having a high share of innovative[4] firms with formal innovation but no collaboration on their innovation activities. On the other hand, there are a number of industries that have relatively high shares of firms with collaboration but no formal innovation, such as Metals, Wholesale, Transports and Financial intermediates. In particular Chemicals, but also to a lesser extent in Instruments, ICT services and Business services, the majority of innovative firms both conduct formal innovation and are engaged in innovation collaboration.

2.3 Technological and non-technological innovation

The Oslo Manual innovation concept includes four different subtypes: product, process, organizational and marketing innovations. An examination of simple combinations of innovation types may be useful to investigate a number of issues, particularly the prevalence of marketing and organizational innovation among product and process innovators. Product and process innovations are often considered technological innovations while marketing and organizational are thought of as non-technological. This simplification, however, is not always fully correct. For example, many product and process innovations, particularly within services, may not involve the use of technologies, while marketing or organizational innovations can include a technological component. Nevertheless, in order to ease the discussion, we will use this simplification to characterize the different types of innovations.

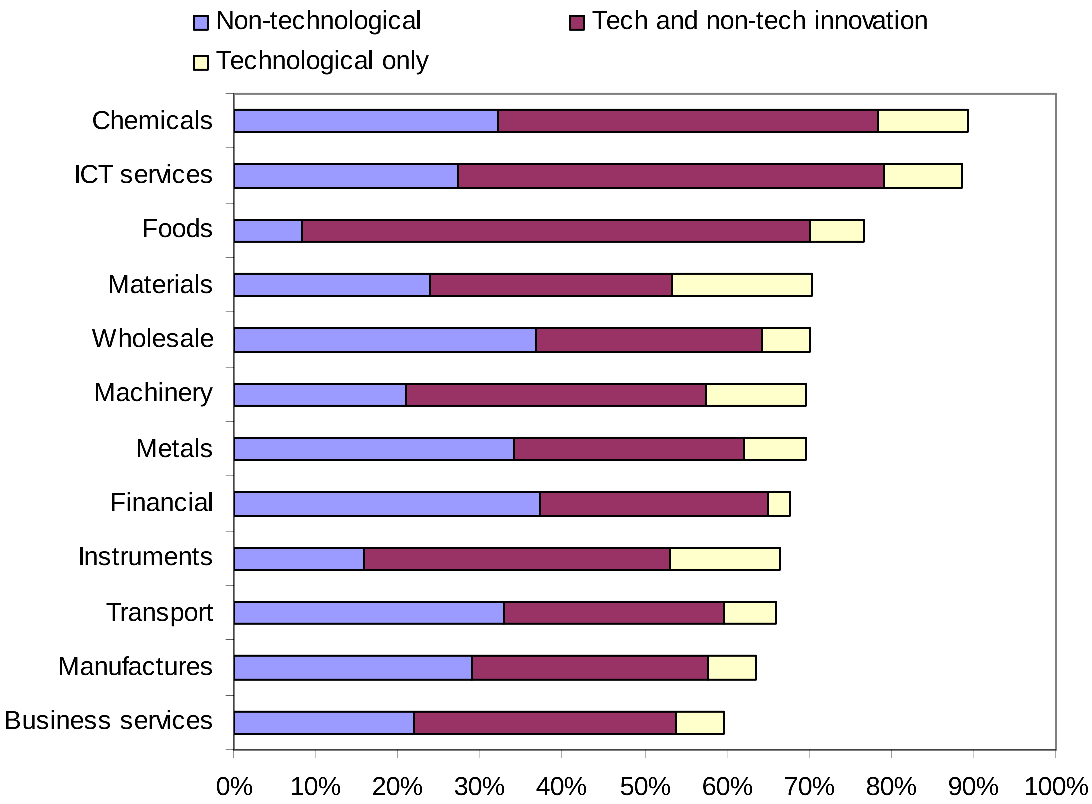
Enterprises are classified into four groups:

- Technological innovators (product and/or process innovation only)
- Non-tech innovators (marketing and/or organizational innovation only)
- Tech and non-tech innovators
- No innovations implemented

Figure 3 shows the results. Using a broader definition of innovation that includes non-technological innovation, we find that by far the highest shares of innovative firms are in Chemicals and ICT services. Shares of innovative firms are surprisingly constant across the other sectors. We can also note that shares of firms that have only implemented technological innovations are quite small, generally between 5 and 10 percent. Shares of firms with non-technological innovation only are slightly higher in services sectors such as Wholesale trade, Transport and Financial intermediates, than for most manufacturing sectors. However, the difference is in many cases very small, suggesting that non-technological innovation is important both for manufacturing and service firms.

[4] To be more precise, innovation status shows shares of innovation active firms, i.e firms with either a product or process innovation or with uncompleted innovation activities. For simplicity here, however, we will also refer to innovation active firm as innovative firms.

Figure 3. Technological and non-technological innovative firms



Source: CIS4 data for Denmark.

2.4 Innovation drivers

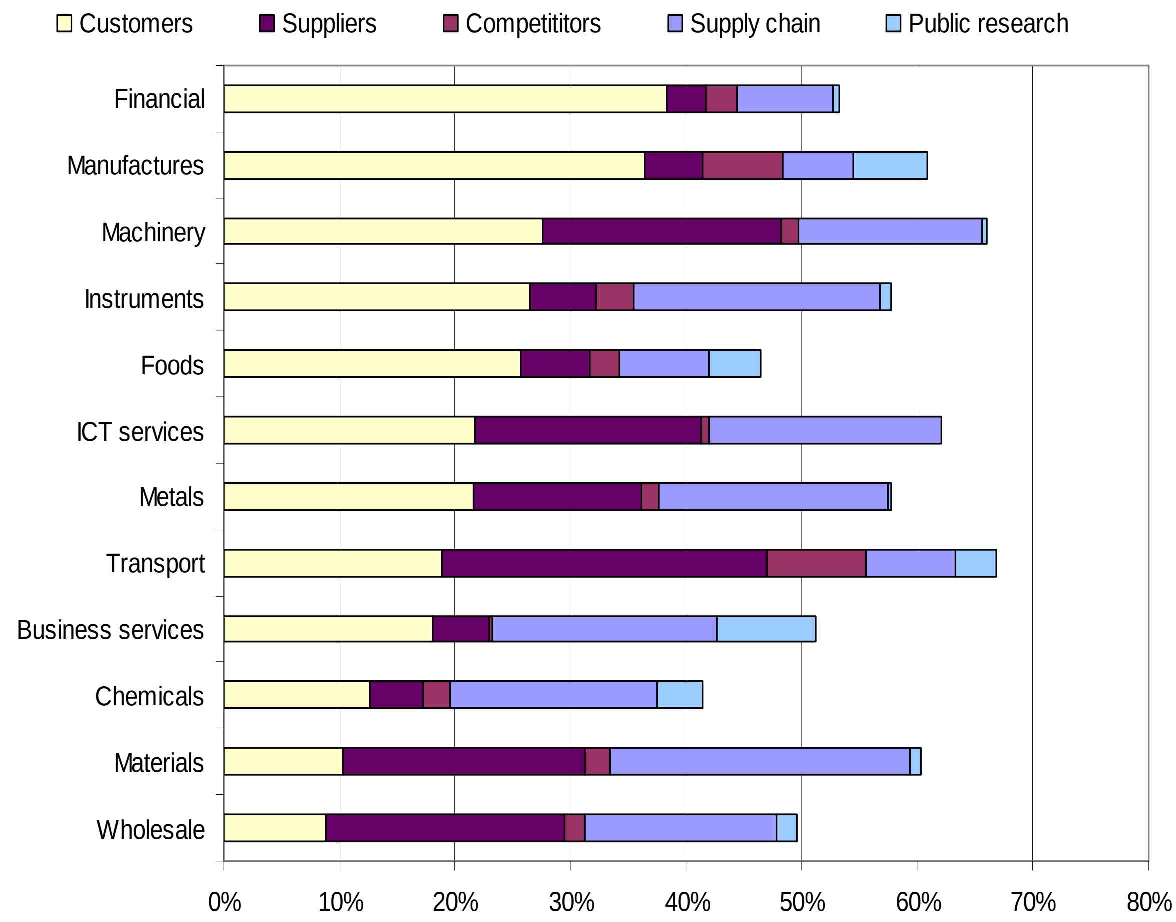
The capture and use of knowledge are important factors in characterizing innovative enterprises. The role of linkages has been emphasized in a number of strands of innovation theory, among them innovation systems (eg. Lundvall, 1992; Nelson, 1993), open innovation (eg. Chesbrough, 2003) and user-driven innovation (eg. Nordic Council of Ministers, 2006; von Hippel, 2005). There is also increasing focus on the role of consumers in product development (eg. Nordic Council of Ministers, 2006; Commission of European Communities, 2006). User driven innovation involves the systematic use of knowledge of customer needs in the enterprise's innovation activities. It also implies a greater focus on the latter stages of product development and on market introduction. Furthermore, interaction with customers may not only concern identifying user needs, but also seeking solutions for the development of new products. This attributes users a greater role as a linkage source, potentially also as a source of new technological knowledge. For policy purposes, it is thus valuable to have indicators of the role of customers as a driver of product development.

This subsection develops composite indicators of innovation drivers. Innovation drivers are relevant for policy in a number of ways. For example, much innovation policy consists of R&D support, however the overall impact of these policies will depend greatly on how new knowledge and technology is diffused throughout the economy and implemented in new products and processes. Indicators of technology as a driver of innovation can be useful in this context.

Looking ahead to the econometric analysis of the impact of innovation, it is useful to be able to isolate different types of drivers. Generally, innovation in a high share of firms will be driven to some extent by their customers and suppliers. Where possible, the classification we use here attempts to identify the single most important driver of a firm's innovation activities. An external source is considered a driver if it is cited as a very important source of information for an enterprise's innovation activities. Firms that cite more than one source as very important are classified as 'supply-chain driven'. See the annex for the simple shares of firms that have cited each external source as highly important for their innovation activities.

Figure 4 shows shares of innovation drivers by external source and sector. The figure in total shows the share of innovative firms that cite at least one external source as highly important for the innovation activities, and thus provides a measure of the relative impotance of external knowledge in each sector. The highest overall shares are within Transport and Machinery.

Figure 4. Innovation drivers



Source: CIS4 data for Denmark. Shares of product-process innovative firms with external drivers.

Generally around 20 to 25 percent of innovative firms are supply chain driven, ie. they draw heavily on a number of different external sources in their innovation activities. In Manufactures and Financial intermediates, under 10 percent are supply chain driven. Here customers are by far the main innovation driver, with over 35 percent citing customers as very important information sources.

Customer driven innovation is also important in Food and Beverages, Machinery and Instruments, while supplier driven innovation is most important in Materials, Wholesale trade and Transport. In a number of industries, public research does not appear to play a dominant role in firm innovation. However, in Chemicals, Manufactures, and Business services, public research driven innovation accounts for close to 10 percent of innovative firms.

3 Innovation and productivity – literature

Econometric analyses of the relation between innovation and productivity build to a large extent on work by Griliches (1979) and Pakes and Griliches (1984). Griliches (1979) noted that investments in R&D and innovation are not directly factors in production; research and other innovative activity generate 'economically valuable knowledge' [5] which can then be used in the production of goods and services.

This concept of a knowledge production function has since been implemented in a number of empirical analyses (see eg. Jaffe, 1986). Pakes and Griliches (1984) were the first to develop and estimate a full model of both the knowledge production function and the final output production function. As an indicator of economically valuable knowledge they used patent counts, where investments in knowledge creation were modeled using R&D expenditures.

While patent data is useful in many respects, it also has a number of shortcomings as a measure of innovative output. First, patents differ greatly in their economic impact, with many patents not being used at all. Second, the majority of innovations are not based on patents. Third, while patents can be considered an output of research, they are generally still inputs in the sense that much development work needs to be undertaken before the new technology can be implemented in new products or processes.

For these reasons, and with the advent of innovation surveys such as the Community Innovation Survey (CIS), researchers have sought alternative measures of innovative output. Pioneering work on this was done by Crepon et al (1998, CDM), who were the first to model the relation between innovation input, innovation output and productivity. In their approach, they take steps to correct both for selection and simultaneity biases, and estimate the full model as a system, using asymptotic least squares. Their model includes four equations for: the decision to invest in innovation, the determination of R&D investments, an equation for innovation output and a productivity equation. By estimating the model as a system, the CDM model allows for correlation among the disturbances in the four equations.

[5] Pakes and Griliches (1984).

Loof and Heshmati (2006) adopt a somewhat simpler approach to estimate the CDM model. They estimate the model in two stages with instrument variables methods, using a generalized tobit model to estimate the equations for innovation investment and three stage least squares to estimate the equations for innovation output and productivity.

A somewhat similar framework to that in Lööf and Heshmati (2006) has been employed in the OECD innovation microdata project and the IGNORed project. In general, the choice of estimation method has to weigh the trade off between the benefits of estimating as a full system and dealing appropriately with simultaneity and selection bias against drawbacks due to complexity, and problems with finding good instruments.

As will be illustrated in the analysis to follow, the strength of this model is the ability to analyze innovation processes at different stages:

- Determinants of the decision to innovate
- Determination of amount of innovation investment
- Impact of innovation activities in terms of knowledge production, innovation performance
- Ultimate impact of innovation outputs on productivity

In the analysis here, we choose a simple, pragmatic structure that follows closely the main models used in the OECD innovation microdata project and the IGNORed project, which attempts to deal with biases, but estimates model in stages, not as a full system. Our main rationale for using a simple framework is to allow greater flexibility to examine a number of different aspects of each stage of the innovation process that may be relevant for policy.

The basic equations of the model are specified as follows:

$$Innovation: \quad g_i^* = x_{0i}b_0 + u_{0i} \qquad (1)$$

$$Inputs: \quad k_i^* = x_{1i}b_1 + u_{1i}; \quad k_i^* = k_i \quad if \quad g_i^* > 0 \qquad (2)$$

$$Outputs: \quad t_i^* = \alpha_k k_i^* + u_{2i}; \quad t_i^* = t_i, k_i^* = k_i \quad if \quad g_i^* > 0 \qquad (3)$$

$$\Pr oductivity: \quad q_i = \alpha_t t_i^* + x_{3i}b_3 + +u_{3i} \qquad (4)$$

g* is the underlying decision variable for innovation, k* is the latent innovation investment intensity while k is the actual innovation expenditures per employee for innovative firms. t* is latent innovation output and t is the actual innovative sales per employee for innovative firms, while q is productivity (sales per employee). x_0, x_1, x_2 and x_3 are vectors of exogenous variables while u_0, u_1, u_2 and u_3 are disturbances for the 4 equations. In principle there are two decision equations in this model: the decision to invest in innovation and the decision to implement a product innovation given innovation investments. However, for practical purposes, we model these two together, so that g* represents the latent decision variable for being innovative (having both engaged in innovation activities and implemented a product innovation).

Equations 1 and 2 are estimated using a Heckman's two step model. In order to control for selection bias, the Mill's ratio from the estimation of equations 1 and 2 is included in all estimations of equations 3 and 4.

We use more than one approach to estimate the innovation output and productivity equations. The innovation output equation is estimated both with actual values for innovation expenditures and predicted values from the Heckman model. The productivity equation is estimated both on its own using OLS (though with the inclusion of the Mills ratio to control for selection bias) and using an instrument variables approach to control for endogeneity of innovation output.

There are a number of issues that should be considered or kept in mind when conducting an analysis of this nature. First, there are some measurement issues: often we have only sales and not value added or material inputs (coefficients tend to be inflated because material inputs are constant). Other problems include double counting of R&D, deflators, and depreciation.

An identification problem also appears because inputs and outputs occur simultaneously (innovation improves productivity, while productivity growth encourages innovation). Identification can be achieved by finding a suitable instrumental variable, but choosing the wrong instrument can also cause additional problems.

Among the other shortcomings of the model is a lack of time series dimension: innovation is a dynamic process yet we are using data for both inputs and outputs from the same time period. A few recent studies have tried to get around this problem by constructing a panel of innovation data (eg. Wladimir, 2007). This problem is, however, not new and has be encountered often in studies of R&D and productivity. A general interpretation of cross sectional analyses (Mairesse and Hall, 1995) of innovation and productivity is that we are mainly capturing the effects of permanent or medium term innovation activities, whereas panel data approaches capture the effects of changes in the level of innovation activities.

In addition, we are only able to examine the impact of product innovations, as we do not have a quantitative output measure for process innovations, nor for marketing or organizational innovations.

4 Econometric analysis

4.1 The model

The main model is specified in the following way:

1) **Innovation Equation**: To model the propensity to innovate (INNOV), we use: a dummy indicating whether the firm is part of a multinational enterprise (MNE); a dummy indicating whether the firm is serving the foreign market (FOR_MKT), indicators of knowledge (HAKNOW), cost (HACOST) and market (HAMARKET) barriers, log employment (log(EMP)), the (2-digit) industry share of product innovators (IND_PDT) and of firms with patent applications (IND_PAT); and industry dummies.

2) **Innovation Expenditure equation**: regresses log innovation expenditure per employee log(RTOT) on: MNE; FOR_MKT; a dummy for cooperation (COOP) and a dummy for receipt of public financial support for innovation activities (FINSUP), IND_PDT, IND_PAT; and industry dummies.

Firms are considered innovative (INNOV=1) if they have both positive innovation expenditures and positive innovation sales. The indicators for barriers are calculated as the average scores (normalized to be within zero and one) of the following variables:

- HAKNOW: lack of qualified personnel, lack of information on technologies, lack of relevant partners for innovation projects
- HACOST: high innovation costs, lack of internal financing, lack of external financing
- HAMKT: market dominated by established firms, uncertain demand and lack of information on markets.

Innovation expenditures include intra and extramural R&D, purchases of other external knowledge, purchases of machinery, equipment and software, and other intramural innovation expenditures. Innovative sales are the share of turnover that are due to product innovations.

3) **Innovation Output equation:** regresses log innovative sales per employee (LISPE) on: log(EMP); log physical capital per employee (log(CAP)), MNE; FOR_MKT , COOP, HAKNOW, HACOST, HAMARKET, [predicted or actual] log(RTOT); industry dummies; the Mills ratio.

4) **Productivity equation:** regresses log turnover per employee (LLPPE) on: log(EMP), log(CAP), MNE; FOR_MKT , COOP, HAKNOW, HACOST, HAMARKET, [predicted or actual] LISPE; industry dummies; the Mills ratio.

We also consider a number of extensions to this main model in order to examine the impacts of the innovation indicators shown and discussed above: novelty, innovation status, non-technological innovation, and innovation drivers. In examining the role of novelty, we use two additional variables: a dummy for product innovations that are new to the firms' market (NEWMKT) and a dummy for whether product innovations are developed mainly by others (ADOPT). For innovation status we use a dummy variable for collaboration (COL, cooperation or product-process innovations at least partly developed by others) and for formal innovation (FORMAL, intramural R&D or applied for a patent). For non-technological innovation we define NT as a dummy variable that equals one if the firm has implemented a marketing or organisational innovation. Innovation drivers are defined in order to isolate the effects of individual drivers. An external source is considered a 'driver' if it is cited as a very important information source:

- Customer driven – only customers cited as driver
- Supplier driven – only suppliers cited as driver
- Competitor driven – only competitor or consultant cited as driver
- Research driven – university or govt research cited as driver (where here others may also be cited)
- Chain driven – more than one driver cited

4.2 Data and variables

The analysis here is based mainly on data from the CIS4 survey in Denmark, which covers innovation activities in Danish firms over the period 2002 to 2004. Data for physical capital is taken from a business register, while data on whether firms are part of a MNE are based both on CIS4 and business register data. All firms from the CIS4 survey are included in the analysis. The Danish CIS4 includes the standard Eurostat core group of industries plus retail trade and all business services. Furthermore, for selected industries, firms with less than 10 employees are also included in the survey. The sample used in the analysis here includes 1961 observations, 608 of which are innovative (ie have both positive innovation expenditures and innovative sales).

Tables 1a, 1b and 1c show the descriptive statistics for the sample. The largest shares of firms are within Machinery, ICT services and Business services. A high share of firms operate on foreign markets in most industries, with the exception of Financial intermediates, Transport and, surprisingly, ICT services. Among innovative firms, there is also little variation across industries for a number of variables, such as non-technological innovation, new to market product innovations, cooperation and collaboration, and barriers.

Table 1a. Descriptive statistics

	Share firms in sample*	Share on international markets*	MNE*	Sales per employee*	Employees*	Share innovative sales	Innovation expenditutres (share sales)	Share receiving innovation funding	Share with patent applications
Foods	0.08	0.96	0.63	5315	653	0.23	0.04	0.44	0.44
Materials	0.05	0.83	0.55	1611	249	0.16	0.05	0.10	0.35
Chemicals	0.05	0.87	0.83	2276	692	0.18	0.09	0.37	0.53
Metals	0.07	0.89	0.57	1330	219	0.22	0.03	0.25	0.45
Machinery	0.14	0.95	0.70	1353	328	0.26	0.06	0.20	0.58
Instruments	0.10	0.94	0.83	1579	287	0.29	0.13	0.32	0.62
Manufactures	0.05	0.94	0.53	1711	376	0.27	0.05	0.15	0.47
Wholesale	0.11	0.75	0.60	3364	285	0.21	0.02	0.10	0.22
Transport	0.02	0.40	0.60	2712	1045	0.09	0.02	0.10	0.20
Financial	0.04	0.48	0.33	4540	909	0.19	0.09	0.00	0.04
ICT services	0.15	0.59	0.56	1400	542	0.40	0.15	0.12	0.20
Business services	0.15	0.70	0.26	942	280	0.23	0.15	0.36	0.26
Total	1.00	0.79	0.57	2073	412	0.26	0.09	0.22	0.37

*: share of all firms in sample. Otherwise, shares based on innovative firms.

Table 1b.

	Share with product or process invoation	Organisational innovation	Marketing innovation	Marketing or organisational innovation	New to market product innovation	Product-process innovations developed by others	Formal innovation (Intramural R&D or patenting)	Innovation cooperation	Collaboration
Foods	0.57	0.79	0.31	0.88	0.79	0.02	0.83	0.63	0.79
Materials	0.21	0.72	0.41	0.90	0.79	0.03	0.59	0.59	0.72
Chemicals	0.44	0.73	0.27	0.80	0.70	0.03	0.90	0.70	0.83
Metals	0.28	0.75	0.27	0.82	0.70	0.02	0.82	0.75	0.86
Machinery	0.61	0.83	0.27	0.84	0.83	0.02	0.85	0.62	0.69
Instruments	0.57	0.79	0.26	0.82	0.83	0.00	0.92	0.74	0.85
Manufactures	0.47	0.76	0.32	0.85	0.76	0.09	0.76	0.53	0.76
Wholesale	0.17	0.92	0.47	0.94	0.76	0.15	0.40	0.63	0.82
Transport	0.11	0.60	0.30	0.70	0.70	0.00	0.50	0.60	0.80
Financial	0.32	0.85	0.63	0.93	0.74	0.00	0.63	0.59	0.67
ICT services	0.47	0.84	0.42	0.88	0.75	0.02	0.77	0.64	0.74
Business services	0.29	0.91	0.43	0.92	0.77	0.02	0.78	0.73	0.81
Total	0.41	0.82	0.37	0.87	0.77	0.04	0.75	0.66	0.78

Table 1c.

	Supply chain drriven	Customer driven	Public research driven	Supplier driven	Competitor driven	Cost barriers	Knowledge barrriers	Market barriers
Foods	0.13	0.33	0.10	0.08	0.04	0.73	0.76	0.75
Materials	0.28	0.14	0.03	0.14	0.00	0.61	0.70	0.58
Chemicals	0.27	0.20	0.07	0.10	0.03	0.70	0.69	0.67
Metals	0.25	0.23	0.05	0.09	0.02	0.79	0.75	0.76
Machinery	0.23	0.29	0.08	0.07	0.03	0.69	0.71	0.78
Instruments	0.29	0.23	0.18	0.11	0.08	0.63	0.75	0.73
Manufactures	0.12	0.26	0.12	0.15	0.03	0.68	0.73	0.65
Wholesale	0.19	0.13	0.07	0.15	0.03	0.56	0.58	0.64
Transport	0.30	0.40	0.10	0.00	0.00	0.80	0.77	0.80
Financial	0.11	0.30	0.04	0.11	0.07	0.54	0.67	0.74
ICT services	0.23	0.23	0.04	0.16	0.03	0.62	0.70	0.66
Business services	0.17	0.30	0.11	0.05	0.02	0.77	0.80	0.73
Total	0.21	0.25	0.09	0.10	0.03	0.67	0.72	0.71

4.3 Results

Table 2 shows the results for the main model. Columns 1 and 2 show the results for the Heckman two step estimation of the equation for innovation expenditures. Column 3 shows the estimation of the equation for innovation output using the actual value of innovation expenditures while column 4 shows the results using the predicted value of innovation expenditures from the Heckman two step. Finally, columns 5 and 6 show estimation results for the productivity equation, column 5 estimated using OLS and column 6 using instrument variables.

Looking first at the innovation expenditure equation, all three types of barriers have a positive and significant impact on the decision to innovate. The interpretation here would seem to be that firms with a greater focus on innovation are more likely to run into constraints on their innovation. Operation on a foreign market has strong positive effect on propensity to innovate. This effect dominates the variable for being part of a MNE.

Two industry level variables (2 digit NACE) are included in the innovation expenditure equation: the share of product-process innovative firms and the share of firms that has applied for a patent. The share innovative firms has a positive impact on the decision to innovate while the share of patenting firms has a positive impact on the size of innovation investment. One interpretation is that the share innovative firms captures the innovative possibilities in an industry (thereby making it more attractive to innovate) while the share patenting firms captures a competition effect that pushes firms to increase their investments in response to developments by other firms. Both the receipt of public innovation funding and engaging in innovation cooperation have a positive impact on the level of innovation investment.

Table 2. Results for the main model

Estimation method	Heckman	Two step	OLS	OLS	OLS	IV
Dependent variable	Log innovation exp. per employee	Dummy for innovativeness	Log innovation sales per employee	Log innovation sales per employee	Log sales per employee	Log sales per employee
Log(EMP)		0.205***	-0.227***	-0.255***	-0.0266	0.00658
		(0.027)	(0.069)	(0.073)	(0.034)	(0.042)
Log(CAP)			0.0999**	0.142***	0.113***	0.0943***
			(0.045)	(0.048)	(0.026)	(0.029)
Log(RTOT)			0.162***			
			(0.034)			
Log(RTOT)_pred.				0.105		
				(0.16)		
MNE	0.0600	0.102	0.367***	0.430***	0.162***	0.106
	(0.13)	(0.079)	(0.12)	(0.13)	(0.060)	(0.068)
COOP	0.257**		0.166	0.179	-0.0701	-0.0982*
	(0.12)		(0.10)	(0.12)	(0.047)	(0.052)
FINSUP	0.615***					
	(0.14)					
FOR_MKT	0.794***	0.574***	-0.101	-0.0445	-0.164	-0.170
	(0.17)	(0.075)	(0.22)	(0.26)	(0.11)	(0.12)
HAKNOW		0.574***	-0.249	-0.151	-0.0471	-0.0288
		(0.13)	(0.24)	(0.24)	(0.12)	(0.12)
HACOST		0.279**	0.0653	0.115	-0.200**	-0.215**
		(0.11)	(0.18)	(0.19)	(0.087)	(0.091)
HAMARKET		0.352***	-0.373*	-0.395*	-0.138	-0.0855
		(0.13)	(0.22)	(0.23)	(0.10)	(0.12)
IND_PDT	-0.657	1.772***				
	(0.73)	(0.55)				
IND_PAT	2.133**	-0.0530				
	(1.02)	(0.71)				
LISPE					0.256***	0.387***
					(0.026)	(0.10)
MILLS			-0.828*	-0.691	-0.263	-0.173
			(0.47)	(0.49)	(0.23)	(0.26)
Observations	1961	1961	608	608	608	608
R-squared	.	.	0.22	0.19	0.50	0.46
P-value LR test	0.0911					
Standard errors in parentheses		*** p<0.01, ** p<0.05, * p<0.1				

Examining next the innovation output equation, the elasticity of (actual) innovation expenditures is positive and significant at around 16%. However, the predicted value based on the Heckman is insignificant. The Mill's ratio is negative and significant, suggesting that there are unobserved characteristics that increase the probability of being innovative, with a negative impact on innovative sales per employee.

The barriers are also included in the innovation output equation. Interestingly, in contrast to the Heckman, the sign on 2 of the barriers is negative, though only one is significant. Market barriers have a negative impact on innovation output, hampering firms' ability to introduce new products on the market.

In contrast to the equation for innovation expenditures, MNE is positive and significant, while foreign markets is not. This suggests that while international exposure is important in both cases, being part of a multinational enterprise does not have an important impact on the propensity to innovative, but it does positively influence gains from product innovation. And, while we find that innovation cooperation has a positive impact on innovation expenditures, we find no evidence of an effect on innovation output.

The last two columns of table 2 show estimation results for the productivity equation. Innovation output is positive and significant, both in the OLS regression and using instrumental variables.

Being part of a MNE has a positive significant impact on productivity using OLS but not in IV. Innovation cooperation is negative in both equations though only significant in IV. All barriers have expected negative sign, though only cost barriers are significant. This suggests that both market barriers and cost barriers adversely affect the productivity of innovation, market barriers through their effect on innovation output and cost barriers through negative effects on the productivity of innovation output. We find no significant effect of knowledge barriers. Any negative impacts of knowledge barriers may perhaps run through restrictions on the level of innovation expenditures as opposed to affecting productivity of innovation activities actually undertaken.

The Mills ratio is insignificant in the productivity equation. It would appear that selection bias is only an issue for the innovation output estimation, and not for overall productivity. And, in comparing the results for OLS and IV, results are fairly similar, suggesting that simultaneity bias is not a major problem here.

Table 3 shows the results when looking at different types of innovative firms. Columns 1 to 4 examine the role of novelty and in-house development while columns 5 and 6 look at non-technological innovation. From column 1 we can see that NEWMKT has a strong positive effect on innovation output, indicating that firms that introduce product innovations that are novel to their markets tend to have higher innovation performance than those that adopt or modify existing technologies. The adoption variable is positive but not significant.

In the productivity equation we both included dummies for novelty and also interacted them with the log of innovative sales. Following the classification for output based modes, we interacted dummies for foreign markets, product innovations new to domestic markets and for those new to international markets. When only the dummy for newmkt is included (column 3), it is negative but insignificant. However, when including the interaction terms, newmkt becomes weakly significant. And, interestingly, the interactions for new to domestic markets are negative (and significant) while that for new to international markets is strongly positive. Hence the results here indicate that internationally novel innovators generate greater innovation output with a greater impact on productivity, while the opposite is the case for domestically novel firms.

Table 3. Novelty and non-technological innovation

	OLS	OLS	OLS	IV	OLS	OLS
Dependent variable	LISPE	LLPPE	LLPPE	LLPPE	LISPE	LLPPE
Log(EMP)	-0.236***	-0.0221	-0.0233	0.0206	-0.216***	-0.0308
	(0.070)	(0.033)	(0.034)	(0.046)	(0.069)	(0.034)
Log(CAP)	0.109**	0.113***	0.112***	0.0867***	0.102**	0.112***
	(0.045)	(0.026)	(0.026)	(0.032)	(0.045)	(0.026)
Log(RTOT)	0.150***				0.218**	
	(0.034)				(0.085)	
MNE	0.363***	0.161***	0.161***	0.0908	0.362***	0.165***
	(0.12)	(0.060)	(0.060)	(0.072)	(0.12)	(0.060)
COOP	0.143	-0.0545	-0.0656	-0.0957*		
	(0.10)	(0.046)	(0.047)	(0.053)		
FOR_MKT	-0.102	-0.128	-0.159	-0.163	-0.100	-0.169
	(0.22)	(0.13)	(0.11)	(0.12)	(0.22)	(0.11)
NEWMKT	0.323***	-0.190*	-0.0669	-0.135*		
	(0.12)	(0.12)	(0.057)	(0.082)		
ADOPT	0.383	-0.0380	-0.0108	-0.0567		
	(0.25)	(0.10)	(0.10)	(0.11)		
NT					-0.198	-0.0326
					(0.32)	(0.11)
HAKNOW	-0.290	-0.0410	-0.0332	0.00206	-0.211	-0.0677
	(0.24)	(0.12)	(0.12)	(0.13)	(0.24)	(0.12)
HACOST	0.0706	-0.202**	-0.198**	-0.216**	0.0638	-0.199**
	(0.19)	(0.086)	(0.088)	(0.092)	(0.19)	(0.088)
HAMARKET	-0.423*	-0.130	-0.127	-0.0516	-0.382*	-0.131
	(0.22)	(0.10)	(0.10)	(0.13)	(0.22)	(0.10)
LISPE		0.393***	0.260***	0.425***		0.246***
		(0.10)	(0.027)	(0.12)		(0.049)
LISPE*NT						0.00950
						(0.055)
Log(RTOT)*NT					-0.0588	
					(0.089)	
LISPE*FOR_MKT		-0.102				
		(0.094)				
LISPE*NEWMKT		-0.199**				
		(0.093)				
LISPE*NEWMKT_INTL		0.162**				
		(0.082)				
MILLS	-0.906*	-0.240	-0.237	-0.102	-0.814*	-0.279
	(0.48)	(0.23)	(0.23)	(0.28)	(0.48)	(0.23)
Observations	608	608	608	608	608	608
R-squared	0.23	0.52	0.50	0.44	0.22	0.50

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Concerning non-technological innovation, we are unable to check direct impacts of organisational or marketing innovations due to lack of data on innovation expenditures on non-technological innovation and a lack of any non-technological innovation output measure. Hence, our analysis here is restricted to analyzing the impact of non-technological innovations on the performance of product innovation. As can be seen in columns 5 and 6, we found no evidence of any effect on innovation output or productivity. We also examined a number of other variations, such as using individual types of organisational and marketing innovations, with the same results.

The composite indicator of innovative status builds on variables for collaboration and formal innovation. Policy interest for both these indicators goes beyond effects on the individual firm. Formal innovation for example represents the production of new knowledge in the economy that can be diffused to other firms, while collaboration is a channel for the exchange of knowledge to take place.

Nonetheless, it is still of interest to examine whether there are any direct impacts for the individual firm. Columns 1 to 3 in table 4 show estimates of the model with collaboration and formal innovation included. In comparison with regressions in the basic model using a variable for innovation cooperation, the coefficient for collaboration is slightly higher and, in contrast to innovation cooperation, is statistically significant in the equation for innovation output. This can suggest that cooperation has a positive impact on innovation output, but less active interaction (which is also included in the collaboration variable) may be equally effective as an exchange of knowledge. The collaboration variable is however, not significant in the productivity equations.

Formal innovation can be considered an input based measure of inventiveness, as opposed to NEWMKT, which is an output-based measure of novel innovative activity. However, we do not find here any evidence that firms engaging in formal innovation have higher performance than other innovative firms.

Columns 4 and 5 show results for the innovation drivers. As discussed above, we do not have detailed information on how firms access and use information, but we do have data on which are very important for a firm’s innovation activities. As can be seen in column 4, both customer driven and supplier driven innovation have a positive impact on innovation output. Close focus on value chain partners thus seems to lead to more successful development and implementation of product innovations. Both these drivers also have a positive impact on productivity, as do chain driven innovation (ie. firms that cite more than one source as very important for their innovation activities). We also examine whether these drivers augment the productivity of innovation output, and find that the interaction of customer driven innovation and innovation output has a positive significant impact on productivity. Hence, the general interpretation of these results is that a strong reliance on external sources has a positive impact on innovative performance and productivity, particularly concerning customer driven innovation.

Table 4. Innovation status and Innovation drivers

	OLS	OLS	OLS	OLS	OLS
Dependent variable	LISPE	LLPPE	LLPPE	LISPE	LLPPE
Log(EMP)	-0.218***	-0.0265	-0.0268	-0.229***	-0.0348
	(0.070)	(0.034)	(0.034)	(0.069)	(0.033)
Log(CAP)	0.100**	0.114***	0.114***	0.104**	0.109***
	(0.045)	(0.026)	(0.026)	(0.045)	(0.024)
Log(RTOT)	0.170***			0.168***	
	(0.035)			(0.034)	
MNE	0.350***	0.166***	0.168***	0.372***	0.159***
	(0.12)	(0.060)	(0.061)	(0.12)	(0.060)
FOR_MKT	-0.0957	-0.159	-0.158	-0.171	-0.194*
	(0.22)	(0.11)	(0.11)	(0.22)	(0.11)
HAKNOW	-0.243	-0.0486	-0.0484	-0.244	-0.0669
	(0.24)	(0.12)	(0.12)	(0.24)	(0.12)
HACOST	0.0769	-0.202**	-0.201**	0.0624	-0.189**
	(0.18)	(0.088)	(0.088)	(0.18)	(0.085)
HAMARKET	-0.377*	-0.137	-0.137	-0.421*	-0.141
	(0.22)	(0.10)	(0.10)	(0.22)	(0.10)
LISPE		0.257***	0.262***		0.191***
		(0.026)	(0.060)		(0.035)
SUPPLY_CHAIN_DRIVEN				0.138	0.161*
				(0.13)	(0.089)
CUSTOMER_DRIVEN				0.263**	0.250**
				(0.12)	(0.10)
RESEARCH_DRIVEN				-0.122	-0.0800
				(0.17)	(0.14)
SUPPLIER_DRIVEN				0.288*	0.327**
				(0.16)	(0.16)
COMPETITOR_DRIVEN				-0.313	0.117
				(0.33)	(0.19)
COL	0.207*	-0.0804	-0.102		
	(0.12)	(0.053)	(0.10)		
FORMAL	-0.135	-0.0230	-0.0114		
	(0.13)	(0.056)	(0.10)		
LISPE*CUSTOMER					0.144**
					(0.067)
LISPE_COMPETITOR					0.00968
					(0.078)
LISPE_SUPPLIER					0.146
					(0.093)
LISPE_RESEARCH					-0.0641
					(0.074)
LISPE_SUPPLYCHAIN					0.0529
					(0.048)
LISPE_FORMAL			0.00682		
			(0.051)		
LISPE_COL			-0.0130		
			(0.052)		
MILLS	-0.842*	-0.259	-0.256	-0.914*	-0.304
	(0.47)	(0.23)	(0.23)	(0.48)	(0.23)
Observations	608	608	608	608	608
R-squared	0.22	0.50	0.50	0.23	0.52
Standard errors in parentheses		*** p<0.01, ** p<0.05, * p<0.1			

5 Discussion and Conclusion

This paper has utilized composite innovation indicators both to examine innovation across industries for Danish firms and to analyse the relation between innovation and productivity. Four innovation indicators were examined: output based innovation modes, innovation status, technological and non-technological innovators, and innovation drivers.

There is a high degree of variation across sectors, with high shares of novel innovators in some industries whereas in other industries innovation is mainly concentrated on the use and modification of existing products and processes. Perhaps surprisingly, Food and Beverages has the highest share of innovative firms, with close to 40 percent having introduced product innovations new to international markets. Among the other top performing industries are Chemicals, Machinery, Instruments and ICT services.

Food and Beverages stands out in having a high share of innovative firms with formal innovation but no collaboration on their innovation activities. On the other hand, there are a number of industries that have relatively high shares of firms with collaboration but no formal innovation, such as Metals, Wholesale, Transports and Financial intermediates.

Using a broader definition of innovation that includes non-technological innovation, we find that by far the highest shares of innovative firms are in Chemicals and ICT services. Shares of innovative firms are surprisingly constant across the other sectors. We can also note that shares of firms that have only implemented technological innovations are quite small, generally between 5 and 10 percent.

Generally around 20 to 25 percent of innovative firms are supply chain driven, ie. they draw heavily on a number of different external sources in their innovation activities. In Manufactures and Financial intermediates, under 10 percent are supply chain driven. Here customers are by far the main innovation driver, with close to 40 percent citing customers as very important information sources.

Customer driven innovation is also important in Food and Beverages, Machinery and Instruments, while supplier driven innovation is most important in Materials, Wholesale trade and Transport. In a number of industries, public research does not appear to play a dominant role in firm innovation. However, in Chemicals, Manufactures, and Business services, public research driven innovation accounts for close to 10 percent of innovative firms.

The econometric analysis examines impacts on the innovation process at several different stages: the decision to innovate, determinants of innovation intensity, impacts on innovation performance and on overall productivity. We find a number of interesting results.

First, the impact of different barriers is greatest at different stages in the innovation process. Market barriers impact mainly innovation performance, reducing the innovation output of innovation investments. The impact of cost barriers, on the other hand, is mainly on the productivity of innovative output. These results underline the importance of both efforts to reduce barriers to competition and increase access to markets, particularly for services. They also provide support for efforts to promote increased orientation on customer needs in product development.

Second, we find that the impact of innovation output depends to a large degree on how ‘innovative’ firms are. For firms with product innovations that are new to international markets, impacts on innovation performance and productivity are greatest. This may indicate both that operating on international markets provides greater potential for innovations and that it may provide greater incentives to engage in novel innovation activities.

Third, we find no evidence of impacts of non-technological innovation. However, this may to some extent reflect the limitations of this analysis, that we are only able to examine the effects of non-technological innovations on the performance of product innovations.

Fourth, both customer driven and supplier driven innovation have a positive impact on innovation output. Close focus on value chain partners thus seems to lead to more successful development and implementation of product innovations. Both these drivers also have a positive impact on productivity, as do chain driven innovation (ie. firms that cite more than one source as very important for their innovation activities). We also examine whether these drivers augment the productivity of innovation output, and find that the interaction of customer driven innovation and innovation output has a positive significant impact on productivity. Hence, the general interpretation of these results is that a strong reliance on external sources has a positive impact on innovative performance and productivity, particularly concerning customer driven innovation.

The composite indicator of innovative status builds on variables for collaboration and formal innovation. Policy interest for both these indicators goes beyond effects on the individual firm. Formal innovation for example represents the production of new knowledge in the economy that can be diffused to other firms, while collaboration is a channel for the exchange of knowledge to take place. Nonetheless, it is still of interest to examine whether there are any direct impacts for the individual firm. In comparison with regressions in the basic model using a variable for innovation cooperation, the coefficient for collaboration is slightly higher and, in contrast to innovation cooperation, is statistically significant in the equation for innovation output. This can suggest that cooperation has a positive impact on innovation output, but less active interaction (which is also included in the collaboration variable) may be equally effective as an exchange of knowledge. The collaboration variable is however, not significant in the productivity equations.

Formal innovation can be considered an input based measure of inventiveness, as opposed to NEWMKT, which is an output-based measure of novel innovative activity. However, we do not find here any evidence that firms engaging in formal innovation have higher performance than other innovative firms.

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Annex

Table A.1. Shares of PP innovative firms that cite external sources as highly important for their innovation activities

	Suppliers	Customers	Competitors	R&D based sources	Public research	Open sources
Foods	11%	33%	6%	10%	8%	16%
Materials	38%	23%	25%	15%	1%	7%
Chemicals	20%	30%	8%	8%	7%	22%
Metals	26%	39%	15%	5%	1%	14%
Machinery	32%	43%	12%	8%	4%	10%
Instruments	14%	43%	23%	17%	7%	12%
Manufactures	9%	42%	11%	15%	8%	9%
Wholesale	33%	22%	14%	8%	2%	9%
Transport	32%	27%	13%	15%	3%	1%
Financial	12%	46%	6%	5%	1%	2%
ICT services	32%	38%	16%	1%	0%	10%
Business services	21%	36%	13%	21%	10%	22%

R&D based sources are Universities, government research institutions and consultants or commercial R&D labs. Public research sources are Universities, and government research institutions. Open sources are journals, conferences, trade shows.

Table A.2. Industry classifications

Sector	**NACE classes**
Foods and Beverages	15-16
Materials	17-23
Chemicals	24
Metals	25-28
Machinery	29
Instruments	30-33
Manufactures	34-37
Wholesale trade	51-52
Transport	60-63
Financial intermediates	65-67
ICT Services	64, 72
Business services	74