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Innovation input and output: differences among sectors

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Abstract

This research investigates deals with the impact of various innovation activities on innovation output by using Spanish CIS3 data on 3,247 innovative firms and applying several Knowledge Production Functions. It is confirmed that different innovation activities lead to differences in both the propensity to innovate and innovation output, depending on the technological characteristics a firm has. In general, internal R&D leads to product innovation, while machinery acquisition leads to process innovation. Size, group belonging and protection of innovations are important determinants for innovation output, but show either a positive or negative relation, depending again on the firm's innovation strategy.

JEL classification: O33

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1 Introduction

The beneficial outcomes of innovation are widely studied and documented. The general consensus is that innovation has a positive impact on firm performance and economic development. For getting a better understanding of the innovation process and the decisions that are taken on firm level regarding this process, this research focuses on the relation between the innovation activities and innovation outcome. Specifically, I will look at how firms allocate their resources among the different innovation activities (internal to the firm or acquisition of external technology) and how this affects the innovative output. Hereby I will take sector perspective, due to the different technological characteristics and opportunities that exist among sectors.

Pavitt (1984) showed that different innovation strategies exist, depending on the technological opportunities and characteristics of the sector in which a firm operates. He defined four sector groups based on technological characteristics (sources of technology, production and use of innovations, means of appropriation and firm size): (i) supplier dominated firms, (ii) scale intensive firms, (iii) science based firms and (iv) specialized suppliers. A fifth group, information intensive firms, was added later (see e.g. Pavitt et al., 1989).

- Firms from the Science-based sectors are large firms that rely mainly on internal R&D for generating a mix of product and process innovations with a strong link to university or other publicly funded basic research. These industries require highly skilled personnel in science and engineering. Example sectors are chemical industry and electronics.
- Firms from the Specialized suppliers sectors are rather small in size and are cooperating closely with clients. The focus is on product innovations, which are used in the production process of the clients. Interactive learning, highly client specific solutions and practical development skills are essential. An example is the machinery sector.
- Scale intensive sectors are production intensive companies with rather simple production, and often with mass products. The focus is on cost-cutting process innovations. R&D activities predominantly serve internal purposes and serve to adapt the acquisition of new (embedded) technologies. Examples are firms from the transport equipment sector and steel sector.

- Firms from the Supplier dominated sectors tend to be oriented towards process innovation. Technological innovations are mainly acquired from outside the firms. In-house R&D and engineering capabilities are considered to be weak, while design and marketing are important capabilities. An example is the textile sector.
- Lastly, Information intensive are firms that focus on process innovation through the combination of internal knowledge with the acquisition of high-tech machinery and equipment. Examples are the financial sectors.

By using Spanish CIS3 data Spain and applying a Knowledge Production Function (Griliches, 1979) with innovation outcome as dependent variable and (internal and external) innovation inputs, and taking into account Pavitt´s sector groups, we would expect that firms from

A secondary focus of this research is the interaction of the internal and external innovation activities and its impact on innovation outcome. Literature suggests that the successful absorption of external knowledge requires a certain level of internal knowledge (see e.g. Cohen and Levinthal, 1990). Again taking into account the technological characteristics of the firms, it is expected that the combination of internal and external innovation activities has a positive impact on innovation output.

Section 2 provides a literature review and summarizes the empirical evidence on the relation between innovation input and output and complementarity effects. Section 3 discusses the available measures for innovation input and innovation output. It will also go deeper into the strengths and weaknesses of these measures. Section 4 discusses the data, while section 5 presents some descriptive statistics. Section 6 provides an explanation of the methods used and Section 7 shows the results. Finally, Section 8 will conclude.

2 Literature review and empirical findings

For measuring the relation between internal and external innovation expenditures and innovation output, the econometric models developed by Griliches (1979) and Crépon *et al.* (1998) will be applied. Griliches (1979) divided the innovation-performance relation into three equations, where the second equation – the knowledge production function – relates innovation inputs to innovation output. In particular, Crépon *et al.* (1998) developed a framework including three relationships: (i) the innovation input linked to its determinants, (ii) the knowledge production function relating innovation input to innovation output, and (iii) the productivity equation relating innovation output to productivity growth.

The available literature on the relation between innovation input and output mainly concentrates on the relation between R&D (as an input) and patents or innovation introduction (as an output), mainly due to data availability. The introduction of the CIS waves has initiated an increase in this field of research with an increasing variation in measures. Recent work comes from Griffith, Huergo, Mairesse and Peters (2006), Beneito (2006), Mairesse and Mohnen (2005), Conte and Vivarelli (2005), and Lööf and Heshmati (2002a).

Klomp and Van Leeuwen (1999) showed that firms that perform R&D on a permanent basis show a significant higher innovation output than firms not performing R&D on a continuous basis. Lööf and Heshmati (2002a) focused on the relation between expenditures on innovation input and its effect on innovation output, as part of the model for measuring the relation to performance. They found that a 10 percent increase in investment in innovative activities per employee increases innovation sales by nearly 3 percent. Besides, they found that the most important source of knowledge for innovation comes from within the firm, while competitors seem to be most important external sources of knowledge for innovation.

Mairesse and Mohnen (2005) found several positive relations between R&D (measured by employee or as a ratio of total sales) and innovation introduction (measured by probability to innovate and introducing products that are new to the market or to the firm). Looking at sector differences, they found that innovation output was generally more sensitive to R&D in low-tech sectors than in high-tech sectors. The findings of Griffith, Huergo, Mairesse and Peters (2006) are in line with these results. On studying the marginal effects of R&D intensity in four European countries (UK, France, Germany and Spain), they found that a greater R&D effort per employee leads to a higher probability of having a process innovation and a product innovation. However, no distinction was made between intramural and extramural R&D in both studies.

Concerning the acquisition of embedded knowledge and technology, Catozzella, Conte and Vivarelli (2008) investigated the impacts of total R&D investments and technology acquisition on innovation output. They found that R&D is strictly linked to product innovations, while technological acquisition is crucial for process innovations. With regard to sector differences, low-tech firms seem to rely more on technological acquisition, while high-tech sectors rely more on R&D input. This is in line with Ortega-Argilés, Potters and Vivarelli (2008) who found that firms in high-tech sectors rely heavily on R&D for labour productivity, while in low-tech sectors this relation is less strong. Firms in more traditional sectors with lower technological opportunities for generating new products concentrate mainly on other innovation inputs for improvements of their production processes, such as the acquisition of new machinery and equipment.

The complementarity between internal and external innovation activities is confirmed in empirical research and case studies, depending on firm and environmental characteristics. Freeman (1991) provided an overview of early research on the importance of the use of external sources, combined with internal R&D, for successful innovation. The main conclusions were that the use of networks and the linkages with external sources of scientific and technical information and advice are decisive in determining the success of a single innovation.

The interest for this research goes to the interaction affects between internal and external innovation activities. Some empirical contributions on this topic come from Cohen and Levinthal (1989 and 1990). They find a strong relation between a firm's own R&D efforts and the use of external sources associated with more basic science. This relation depends on the industry's technological characteristics, such as the importance of basic fields of science for innovation.

Arora and Gambardella (1994) made the relation between firm and sector characteristics and the importance of external innovation activities. They argue that firms differ significantly in their ability to benefit from these collaborative relationships. This ability depends on the type of internal knowledge: scientific and technological know-how. The former is especially effective for screening projects and the latter for applying external knowledge.

Veugelers and Cassiman (1999) showed how firm and environmental characteristics affect the choice of internal know-how development and external acquisition. They found that small firms are more likely to focus either on exclusive internal or external innovation activities, while large firms are more likely to combine both. Also the appropriation regime affects: a strict regime is related to less external innovation activities.

3 Measures for innovation input and output

3.1 Innovation inputs

In order to get a better understanding of the innovation strategies (i.e. the use of innovation inputs) of sectors with different technological opportunities, the focus of this research will be on the impact of internal innovation inputs and external innovation inputs on the innovation output. This section will discuss the innovation inputs of interest for this research.

3.1.1 R&D

Probably the most widely studied input to innovation is research and development (R&D) expenditures. The Frascati Manual (2002) defines R&D as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". The term R&D, in this sense, covers three activities, namely (i) basic research (experimental or theoretical work undertaken primarily to acquire new knowledge, without any particular application or use in view), (ii) applied research (original investigation undertaken in order to acquire new knowledge towards a specific practical aim or objective), and (iii) experimental development (systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new or improved materials, products, services or processes).

R&D is often used as a proxy for innovation. Although the advantages of R&D as an indicator are clear (widely available over long time periods on firm, sector and national level), it is only one of many inputs to innovation. There have been several estimations of the relative importance of R&D as part of the total innovation inputs, ranging from 20 to 40 per cent (see e.g. Brouwer and Kleinknecht (1997)).

Other disadvantages of using R&D as only proxy of innovation are related to measurement issues. Firms –particularly SMEs – tend to underreport informal and small scale R&D activities, unless innovative activities are performed. These R&D or innovation activities do not show up in financial reporting but do show up in innovation surveys that include somehow simplified questions about R&D (Kleinknecht 1987). Furthermore, different interpretations of the definition of R&D in surveys, secrecy, and regional splitting may lead to biased data on R&D investment. This may lead to disturbing comparisons across sectors, regions and countries (Brouwer et al, 2000).

3.1.2 Internal vs. external R&D

In the CIS3, a distinction is made between intramural and extramural R&D. It refers to the same type of activities, but performed by other firms, organisations, such as public and private research organisations (see Frascati Manual, 2002). For this research, this distinction is important, since it gives insight in a firm's choices for performing own R&D or outsourcing it. Both will be measured as ratios of the turnover (intensity).

Internal and external R&D are treated separately since the objectives and outcomes of both are somewhat different. Simply stated, internal R&D can serve solely and is mainly aimed at (radical) product innovation. On the other hand, external R&D is mainly combined with internal R&D and is used for more incremental innovations. For example, Beneito (2006) – analyzing Spanish survey data – made a distinction between intramural and extramural R&D and found that intramural R&D is the main source for more significant innovations (represented by patents), while extramural R&D is more productive in terms of incremental innovations (represented by utility models). Furthermore, "isolated" intramural R&D leads to both process and product innovations, while contracted R&D does not lead to significant innovations (measured by patents), unless they are combined with in-house capabilities (the 'absorptive capacity' hypothesis, see Von Tunzelmann and Acha (2005)). When looking at the combined effect of internal and external R&D and relating it respectively to significant and incremental innovations, each type of R&D input shows increasing elasticities in that kind of innovations where it is more productive in relative terms. Thus, internal R&D becomes more important for significant innovations, while external R&D becomes more important for incremental innovations.

In the same line, Loshkin et al. (2008), found complementarity between internal and external R&D, with a positive impact of external R&D only evident in case of sufficient internal R&D and thus confirm the enhancing absorptive capacity of internal R&D.

The different innovation behaviour was also shown by a study by Piga and Vivarelli (2004). They found that firms from the specialized suppliers and science-based sectors are more likely to conduct their R&D internally and that outsourcing relationships with suppliers are associated with a firm's propensity to engage in external R&D. Furthermore, it was found that performing R&D with other firms is more likely to be found in firms having objectives in the areas of both process and product innovation and that a firm with a concentrated ownership structure is more likely to seek other firms as partners. Finally, Bönte (2003) showed that the decision between internal and external R&D does matter and found strong evidence of a positive relationship between productivity and the share of external R&D (measured as stock) in total R&D stock.

3.1.3 Other innovation inputs

It is obvious that the inclusion of questions on expenditures on non-R&D innovation activities is much richer than the classical R&D expenditures data. However, since many firms do not have precise information on all these innovation inputs, the response rate will decrease and answers might be rough estimates in stead of precise amounts.

The CIS3 provides expenditure data on the following innovation activities (see also the OECD's Oslo Manual, 2005):

- In addition to acquiring R&D, firms may also acquire technology and know-how related to the development and implementation of innovations. Acquisition of external knowledge and technology may be in the form of e.g. patents, non-patented inventions, licences, know-how, trademarks, designs and scientific and technical services for innovation activities. The big difference with extramural R&D is the uncertainty involved. Extramural R&D has many risks involved on the outcomes of the innovation activities, while the acquisition of licences and know-how is more straightforward and involves less uncertainty.
- Innovation activities also involve the acquisition of machinery and equipment that are required for the implementation of new or improved products or processes. Examples are advanced machinery, computer hardware and computer hardware specifically purchased to implement new or significant improved products and processes. These acquisitions can be put directly into use since the technology is already embodied in the equipment and machinery. The objective is to implement new products and process innovations.

3.2 Innovation outputs

Because of the diversity and complexity of possible innovation output, no single measure can be expected to proxy a firm's innovation completely. Some widely used innovation outputs are:

- Intellectual property rights

The general assumption behind IPR statistics is that firms that file more applications are more innovative. However, they cannot be taken for granted as output of innovation. They are indicators of inventions that do not necessarily lead to commercialisation and thus innovation. Unless the disadvantages of using IPR as an innovation output, there is a wide literature on the relation between innovation (mainly R&D) and patents (see e.g. xxxx). The general consensus is that there is a positive relation between the two.

- Innovation count and innovator (yes/no)

This indicator involves the listing of innovations made by a firm, usually constructed through surveys. Although this measure is very clear, innovation counting is often seen as arbitrary, because of the difficult frontiers between innovations and non-innovations and important and less important innovations. Adding this to the fact that innovation counts are not available for firms in most countries, makes it a little practical for research. CIS3 provides data on whether a firm introduced a product and process innovation in the three years before the survey (2000) or not (yes/no) – data on innovation count are not included.

- Firm performance

The key objective of innovation is a better firm performance. For this reason, data on sales due to innovative products are suitable indicators to measure a firm's innovative actions; however all of them have disadvantages because they can be influenced by other factors than innovation. The most widely used measure is productivity (normally labour productivity), as defined by Value Added over Labour input. See the next section for a thorough literature review on this topic.

The focus in this research is to be able to point out differences in the impact of the various innovation activities. Therefore, a knowledge production function will be applied where both the introduction of product and process innovations and the contribution of the sales of innovative products in the total turnover will be investigated. Unless the lack of information on the importance and quality of the introduced innovations, the first two indicators show a firm's propensity to innovate, while the share of turnover due to innovative products is commonly used to indicate the intensity of innovation (see e.g. Lööf and Heshmati, 2002; Mairesse and Mohnen, 2002). It is a direct measure of successful *product* innovation, measuring innovations that were introduced into the market and that resulted in a positive cash-flow (Kleinknecht, Van Montfort and Brouwer, 2000). Due to questionnaires design, no impact measure of process innovations is taken into account.

3.3 Exogenous variables

Besides the detailed information on expenditures on innovation activities and its output, the CIS questionnaire provides also extra (general) firm information. This information should be taken into account when controlling for firm-specific characteristics. Examples of these characteristics are size, sector belonging and market spread (including export intensity). For a firm, these characteristics are decisive in the choice to engage in innovation or not.

Besides this general firm information, CIS3 also collects data on other characteristics that are more related to the innovation process. This information type is mainly collected as dummy variables or as Likert-scale variables. Some examples of characteristics that influence the innovation process and its outcomes are the participation in different types of innovation cooperation, the encounter of financial obstacles that might limit a firm's possibilities for investing in innovation projects and the application of innovation protection methods.

Various studies have showed the possible effects all these characteristics can have on innovation output. Schumpeter (1912, 1942) already described the effects of size. The impact of access to finance is described by e.g. Mairesse and Mohnen (2002).

3.4 Variables used in this research

The table below shows the variables that are selected for performing the analysis. The first five (INPDT, INPCS, INNO, INPDTINPCS and TURNINN) are measures of innovation output, while the last four (RRDIN, RRDINX, INNEX and INNEXX) are measures of innovation input.

Table 1: Used variables

	Variable	*Explanation*
Output	INPDT	Introduction of product innovation (1=yes)
	INPCS	Introduction of process innovation (1=yes)
	INNO	Introduction of product *or* process innovation (1=yes)
	INPDTINPCS	Introduction of product *and* process innovation (1=yes)
	TURNIN	Share of sales due to innovative products
Input	RRDINX	Expenditures on internal R&D by turnover
	RRDEXX	Expenditures on external R&D by turnover
	RMACX	Acquisition of machinery and equipment by turnover
	ROTHX	Acquisition of other knowledge by turnover

Control Variables – Firm Characteristics	lturn	Firm size – in natural logarithm of turnover
	gp	Group belonging - dummy
	sigmar	Focus market – ranging from local (1) to international (4)
	lexp	Export intensity – in natural logarithm of share of export in turnover
	sector	Sector (NACE) – dummies for the 37 sectors
	pavitt	Pavitt sector groups – 7 groups as described in Section 1
	lemphi	Employees with high education - in natural logarithm
	invmill	Inversed Mills ratio for selection of innovative firms among all firms
Control Variables – Innovation related	coop_research	Cooperation with research institute or university – dummy
	coop_market	Cooperation with market party – dummy
	h_economic	Hampered innovation activity due to economic factors – average importance from 0 to 3
	h_internal	Hampered innovation activity due to internal factors – average importance from 0 to 3
	h_other	Hampered innovation activity due to other factors – average importance from 0 to 3
	paap	Patent application - dummy
	paval	Valid patent – dummy
	protect_form	Formal protection method – dummy
	protect_strat	Strategic protection method – dummy
	otherinnexp	Other innovation input – natural logarithm of share of other innovation exp. in turnover
	otherinnoutput	Other innovation output, such as organization, marketing design innovation – dummy

3.5 Selection bias

Due to the design of the questionnaire, a selection bias is encountered. An important characteristic of the dataset used in this study is that the CIS3 questionnaire requires firms to declare their innovative inputs only if they have introduced innovation outputs. Therefore, the empirical analysis will be limited to a sample of innovative firms, while an analysis of the role of innovation inputs in making a firm innovative or not cannot be performed.

In order to deal with this selection bias, a Heckman selection model will be applied. More details about this technique can be found in Section 5.

4 Data and descriptive statistics

This paper uses (Spanish) firm-level data, drawn from the CIS 3, on 8,024 firms on the years 1998-2000. A number of firms that were just established (202 observations) or showed turnover increases (288 observations) or decreases (113 observations) of more than 10% due to mergers, acquisitions and vending of parts of the firm were excluded. Also firms with missing values for the introduction of either a product or process innovation (3 observations) and not yet completed or abandoned innovation activities (3 observations) were taken out. The final dataset consists therefore of 7,415 firms divided over 37 NACE sectors. These 37 NACE sectors were divided into seven sector groups. First, the four groups of the original Pavitt's taxonomy, consisting of Science based, Supplier dominated, Scale intensive and Specialized suppliers sector groups. Second, a fifth sector group – Information intensive –was later added (see Pavitt *et al.*, 1990). Furthermore, the CIS3 database consist also of non-manufacturing firms (originally outside the scope of Pavitt's sector) and therefore two additional sector groups have been created, namely Transport and Others. Table 2 provides an overview of the assignation of the two-digit NACE sectors to the seven sector groups.[1] The final dataset contains a total of 7,418 firms of which 3,199 firms declared to have introduced an innovation.

[1] For this "translation", I used various sources. the basis was formed by Pavitt, 1984 and I compared the outcomes with similar exercises as performed by Vossen, 1998, O'Mahony and Van Ark, 2003 and Brandenburg et al. 2007.

Table 2: Assignation of NACE sectors to Pavitt's sector groups*

Pavitt's taxonomy	***NACE***	***Sector***
Supplier dominated	17	Manufacture of textiles
	18	Manufacture of wearing apparel; dressing and dyeing of fur
	20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	21	Manufacture of pulp, paper and paper products
	36	Manufacture of furniture; manufacturing n.e.c.
	37	Recycling
Scale intensive	10	Mining
	14	Other mining and quarrying
	15	Manufacture of food products, beverages and tobacco
	25	Manufacture of rubber and plastic products
	26	Manufacture of other non-metallic mineral products
	27	Manufacture of basic metals
	28	Manufacture of fabricated metal products, except machinery and equipment
	34	Manufacture of motor vehicles, trailers and semi-trailers
	35	Manufacture of other transport equipment
	40	Electricity, gas, steam and hot water supply
	41	Collection, purification and distribution of water
Specialized suppliers	29	Manufacture of machinery and equipment n.e.c
	30	Manufacture of office machinery and computers
	33	Manufacture of medical, precision and optical instruments, watches and clocks
Science based	23_24	Manufacture of coke, refined petroleum products, nuclear fuel, chemicals and chemical products
	31	Manufacture of electrical machinery and apparatus
	32	Manufacture of radio, television and communication equipment and apparatus
	73	Research and development
Information intensive	22	Publishing, printing and reproduction of recorded media
	64	Post and telecommunications
	65	Financial intermediation, except insurance and pension funding
	66	Insurance and pension funding, except compulsory social security
	67	Activities auxiliary to financial intermediation
	72	Computer and related activities
Transport	60	Water transport
	62	Air transport
	63	Supporting and auxiliary transport activities; activities of travel agencies
Others	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
	74	Other business activities

*Sources: Pavitt, 1984,; Vossen, 1998; O'Mahony and Van Ark, 2003 and Brandenburg et al. 2007

4.1 Characteristics in total population

Table 3 presents some basic characteristics of the seven sector groups, divided into innovators and non-innovators. We can see the differences between the various sector groups, and more strikingly, between innovators and non-innovators within the same group.

Firms from the sector groups Specialized suppliers and Science based show the highest share of innovators, while the Transport sector shows the lowest share. Looking at size, innovators in all sector groups are larger in terms of turnover than non-innovators, confirming the positive relation between innovation and firm size (see e.g. xxxx). (Innovating) firms from Information Intensive and Science Based sectors are the largest on average.

Another clear difference is that the main market for innovators is somewhat larger than for non-innovators that show a lower average score on the Likert-scale of the extension of their market and have a lower share of their turnover due to export. Firms from the Scale Intensive and Science Based sectors show the largest market, while firms from Information Intensive and Specialized Suppliers sectors export less and obtain a larger part from its turnover from the local market.

Table 3 Population characteristics for the 7 sector groups, divided into innovators and non-innovators

	Others		***Transport***		***Information intensive***		***Supplier dominated***	
	INNO *206*	NON INNO *480*	INNO *120*	NON INNO *310*	INNO *389*	NON INNO *415*	INNO *623*	NON INNO *1101*
Innovators (share of sector group pop)*	0.199		0.173		0.438		0.323	
Turnover (in €)	9918905	6796898	19900000	4812644	44800000	6963767	5663318	2396580
	1216376	531680	5081927	711348	18100000	851674	455992	139729
# Employees with high education	10.08	3.57	21.90	2.65	46.09	11.73	3.12	10.08
	1.51	0.32	8.91	0.43	11.00	1.32	0.27	1.51
Most significant market**	2.15	2.12	2.44	2.21	2.15	1.90	2.67	2.24
	0.11	0.06	0.15	0.08	0.06	0.05	0.06	0.04
Export over turnover	0.06	0.06	0.08	0.05	0.03	0.03	0.14	0.07
	0.01	0.01	0.03	0.01	0.01	0.01	0.02	0.01

	Specialized suppliers		***Scale intensive***		***Science based***	
	INNO *256*	NON INNO *224*	INNO *1107*	NON INNO *1425*	INNO *498*	NON INNO *264*
Innovators (share of sector group pop)	0.478		0.350		0.557	
Turnover (in €)	19600000	4899821	9076471	3123383	34700000	7170469
	2286541	310359	1236561	285819	9404822	969510
# Employees with high education	8.02	2.14	9.51	3.27	28.93	5.38
	0.70	0.13	1.28	0.45	5.64	0.66
Most significant market*	2.36	1.99	2.80	2.27	2.80	2.34
	0.04	0.03	0.06	0.07	0.09	0.08
Export over turnover	0.11	0.06	0.18	0.09	0.19	0.11
	0.01	0.00	0.02	0.01	0.01	0.02

* The shares of innovators have been calculated by applying the weighting factor that has been allocated by Eurostat
**1=Local/regional within country, 2= Local/regional within neighboring countries, 3=National, 4=International

4.2 Different innovation strategies

Table 4: Correlation table between innovation inputs - all firms

All firms	*lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.263***	1			
	(0.000)				
lrmacx	0.002	0.060***	1		
	(0.890)	(0.001)			
lroekx	0.096***	0.103***	0.161***	1	
	(0.000)	(0.000)	(0.000)		
lrothx	0.278***	0.193***	0.161***	0.251***	1
	(0.000)	(0.000)	(0.000)	(0.000)	

Looking at all firms it becomes clear that innovation expenditures are in general positively correlated amongst each other, i.e. firms tend to spend money on various innovation activities and not just one. However, expenditures on internal R&D and the acquisition of machinery are not correlated, which may indicate that firms choose for either one of the two.

Table 5: Correlation table between innovation inputs – Science based

Science based	*lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.321***	1			
	(0.000)				
lrmacx	0.076*	0.177***	1		
	(0.088)	(0.000)			
lroekx	0.111**	0.131***	0.186***	1	
	(0.012))	(0.003)	(0.000)		
lrothx	0.285***	0.230***	0.330***	0.266***	1
	(0.000)	(0.000)	(0.000)	(0.000)	

The Science based sector group, described as firms that mainly rely on internal R&D, shows a similar pattern to the overall dataset.

Table 6: Correlation table between innovation inputs – Specialized suppliers

Specialized	*Lrrdinx*	*lrrdexx*	*lrmacx*	*Lroekx*	*lrothx*

suppliers					
Lrrdinx	1				
Lrrdexx	0.258***	1			
	(0.000)				
Lrmacx	0.008	-0.052	1		
	(0.895)	(0.404)			
Lroekx	0.136**	-0.025	0.200***	1	
	(0.028)	(0.694)	(0.001)		
Lrothx	0.398***	0.173***	0.159**	0.239***	1
	(0.000)	(0.005)	(0.010)	(0.000)	

Specialized suppliers are product innovators expected to combine internal expertise with external R&D and knowledge. This can be seen in the positive correlations between internal R&D and external R&D and other knowledge.

Table 7: Correlation table between innovation inputs – Scale intensive

Scale intensive	*lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.294***	1			
	(0.000)				
lrmacx	-0.080***	0.024	1		
	(0.007)	(0.428)			
lroekx	0.120***	0.185***	0.163***	1	
	(0.000)	(0.000)	(0.000)		
lrothx	0.236***	0.246***	0.123***	0.260***	1
	(0.000)	(0.000)	(0.000)	(0.000)	

Scale intensive firms concentrate mainly on process innovation by acquiring machinery. Therefore, it is interesting to see the negative correlation between internal R&D and the acquisition of machinery: firms decide either to invest in R&D for process innovation or acquire this embedded in machinery.

Table 8: Correlation table between innovation inputs – Supplier dominated

Supplier dominated	*Lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				

lrrdexx	0.208***	1			
	(0.000)				
lrmacx	0.087**	0.003	1		
	(0.031)	0.940			
lroekx	0.068*	0.102**	0.167***	1	
	(0.090)	0.012	(0.000)		
lrothx	0.319***	0.164***	0.168***	0.248***	1
	(0.000)	(0.000)	(0.000)	(0.000)	

According to the earlier description, firms from the Supplier dominated sector group focus mainly on process innovation by acquiring embedded technology and combine that with design and marketing capabilities. The latter can be very well observed in the positive correlation between all innovation activities with other activities which include activities such as training, marketing and design of products.

Table 9: Correlation table between innovation inputs – Information intensive

Information intensive	*Lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.251***	1			
	(0.000)				
lrmacx	-0.104**	0.042	1		
	(0.043)	(0.423)			
lroekx	0.197***	0.244***	0.104**	1	
	(0.000)	(0.000)	(0.043)		
lrothx	0.219***	0.186***	0.030	0.160***	1
	(0.000)	(0.000)	(0.564)	(0.002)	

Information intensive firms combine high-tech machinery with internal knowledge. In the correlation matrix it can be seen that there is a negative relation between acquisition of machinery and internal R&D, which indicates that firms choose to invest in either one or the other.

Table 10: Correlation table between innovation inputs - Transport

Transport	*lrrdinx*	*lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.134	1			
	(0.157)				

lrmacx	0.118	0.338***	1		
	(0.207)	(0.000)			
lroekx	0.106	-0.063	0.175*	1	
	(0.261)	(0.507)	(0.060)		
lrothx	0.131	0.336***	0.200**	0.067	1
	(0.162)	(0.000)	(0.031)	(0.474)	

Table 11: Correlation table between innovation inputs - Others

Others	*Lrrdinx*	*Lrrdexx*	*lrmacx*	*lroekx*	*lrothx*
lrrdinx	1				
lrrdexx	0.127*	1			
	(0.071)				
lrmacx	0.061	0.140**	1		
	(0.391)	(0.046)			
lroekx	0.077	-0.013	0.242***	1	
	(0.277)	(0.854)	(0.001)		
lrothx	0.093	-0.051	0.201***	0.444***	1
	(0.188)	(0.470)	(0.004	(0.000)	

4.3 Characteristics of innovators

Table 12 presents the (weighted[2]) averages of the expenditures on innovation activities and the innovation output. The sector group characteristics as described in Section 1 are confirmed. Firms from the Science based sectors indeed rely heavily on internal R&D and focus on a mix of product and process innovation (highest fraction of firms that introduced both a product and a process innovation). Scale intensive firms focus mainly on process innovation and rely heavily on the acquisition of machinery. The same applies to the Supplier dominated sector group, with the observation that the largest share of R&D and knowledge is acquired. For the Information Intensive sector group, the combination of Internal R&D and acquisition of machinery lead to high product and process innovation.

Table 12: Innovation input and output characteristics by sector group – 3,199 innovators*

	Others	*Transport*	*Information intensive*	*Supplier dominated*	*Scale intensive*	*Specialized suppliers*	*Science based*

[2] For calculating the averages, the survey design has been taken into account. CIS3 provides information on sampling weights, cluster sampling and stratification.

Innovation output							
INPDT	0.671	0.537	0.700	0.615	0.658	0.807	0.856
	0.057	0.069	0.029	0.036	0.020	0.032	0.022
INPCS	0.621	0.790	0.679	0.728	0.712	0.627	0.651
	0.061	0.053	0.030	0.032	0.021	0.043	0.032
INPDTINPCS	0.292	0.327	0.380	0.344	0.370	0.435	0.508
	0.052	0.066	0.032	0.031	0.021	0.043	0.036
TURNIN	0.228	0.416	0.359	0.376	0.309	0.319	0.310
	0.025	0.061	0.024	0.032	0.016	0.029	0.022
Expenditures on Innovation Input							
RRDINX	0.010	0.001	0.023	0.006	0.012	0.018	0.071
	0.004	0.001	0.003	0.001	0.003	0.003	0.018
RRDEXX	0.001	0.001	0.002	0.007	0.002	0.001	0.014
	0.000	0.001	0.000	0.005	0.001	0.000	0.010
RMACX	0.007	0.022	0.039	0.050	0.057	0.019	0.047
	0.002	0.011	0.005	0.015	0.017	0.004	0.027
ROEKX	0.001	0.001	0.003	0.001	0.004	0.001	0.029
	0.000	0.000	0.001	0.000	0.003	0.001	0.021
RTOT	0.021	0.033	0.085	0.070	0.086	0.047	0.192
	0.005	0.017	0.009	0.020	0.022	0.005	0.065

*Standard errors in every second row

When turning to simple correlations for testing correlation between the innovation inputs and outputs, only few relations become significant for the whole subset of innovators. Only the relations between internal R&D and three innovation output indicators are found to be positive and significant. The other innovation input expenditures do not show significant any relationships to either of the output measures (for the whole set of innovators).

Table 13 Correlation matrix for innovators (3,199 firms)

	INPDT	*INPCS*	*INPDTINPCS*	*TURNIN*
RRDINX	0.064***	-0.014	0.049***	0.079***
	0.000	0.437	0.007	0.000
RRDEXX	-0.004	0.014	0.010	-0.009
	0.836	0.437	0.586	0.681
RMACX	-0.012	0.012	-0.001	-0.011
	0.499	0.514	0.978	0.618
ROEKX	0.016	0.000	0.016	-0.001
	0.373	0.994	0.385	0.963

Annex I provides the same correlation matrices separated for each sector group. Here, already some differences in innovation strategies and the effects these strategies have on output can be distinguished. The positive effect of internal R&D is in many of the sector groups positively correlated with some measure of innovation output, except for process innovation. This is in line with earlier research, where was demonstrated that internal R&D has a positive impact on product innovation. The interpretation of the negative correlations between some of the inputs and outputs – especially between machinery and equipment acquisition and product innovation – can be somewhat difficult. This might be explained by the fact that when more advanced machinery and equipment is implemented, the focus seems to be mainly on increasing efficiency of the production process rather than on the introduction of new products. In other words, there is a trade off between product and process innovation. However, more thorough research here is necessary. This will be done by applying a Knowledge Production Function where the simultaneous effect of the innovation inputs on the innovation output will be measured.

4.4 Conclusions

In this section it is shown by descriptive statistics that firms with different technological characteristics apply different innovation strategies. Not only are some sector groups more innovative than others, but there are also differences in which activities are essential in the innovation process and how this is innovation output differs.

In the next sections, a production function will be applied to check for relations between innovation output and innovation input, while also taking into account firm characteristics and technological characteristics.

5 Methodology

5.1 Basic KPF

The basic knowledge production function, as defined by Griliches (1979) is as follows:

$$IO_i = \alpha_i + \beta_1 RRDINX_i + \beta_2 RRDEXX_i + \beta_3 RMACX_i + \beta_4 ROEKX_i + \sum_h \gamma Z_i + \varepsilon_i \qquad (1)$$

RRDINX, RRDEXX, RMACX and ROEKX (see Section 3.1) represent the various innovation inputs. IO represents the different innovation output measures, namely INPDT, INPCS (, INPDTINPCS) and TURNIN (see Section 3.2). Z takes into account a set of exogenous control variables (see Section 3.3).

5.2 Selection equation

For the selection equation, the firm characteristics from Section 3.3 will be used for estimating the probability a firm innovated.

5.3 Bivariate probit

The different possible outcomes of innovation – product or process – ask for a proper econometric approach. Since product and process innovation are positively correlated (see e.g.), this has to be taken into account in the specification of the knowledge production function.

Heckman (1976) proposed a two-stage estimation procedure using the inverse Mills' ratio to take account of the selection bias. In a first step, a regression for observing a positive outcome of the dependent variable is modelled with a probit model. The selection model is specified as follows:

$$Z\gamma + u_1 > 0 \qquad (2)$$

, where Z is the vector of variables used for predicting whether a firm is innovative or not.

The estimated parameters are used to calculate the inverse Mills ratio, which is then included as an additional explanatory variable in the second stage, the bivariate probit regression. The biprobit model measures the impact of the regressors on the dummy outputs (INPDT, INPCS), while the inverse Mills ration corrects for the selection of only innovative firms (3,199) among all firms (7,418) and allowing for the correlation between the residuals. The biprobit regression model is specified as follows:

$$\begin{cases} Y_{1i}^* = \alpha_{1i} + X_{1i}\beta_1 + \varepsilon_{1i}; \quad Y_{1i} = 1 \quad \text{if} \quad Y_{1i}^* > 0, Y_{1i} = 0 \text{ otherwise} \\ Y_{2i}^* = \alpha_{2i} + X_{2i}\beta_2 + \varepsilon_{2i}; \quad Y_{2i} = 1 \quad \text{if} \quad Y_{2i}^* > 0, Y_{2i} = 0 \text{ otherwise} \end{cases} \qquad (3)$$

, where $Y_i = 1$ indicates the introduction of a product or process innovation, X_i is a vector of the regressors from the Knowledge Production Function (1) including the inverse Mills' ratio – calculated in the first stage of the Heckman selection model (2). The following holds: $u_1 \sim N(0,\sigma)$, $\varepsilon_{1,2} \sim N(0,1)$ and $corr(u_1, \varepsilon_{1,2}) = \rho$. If ρ is zero, the standard regression provides unbiased estimates; if not, then the standard estimates are biased.

For testing whether two separate probit models are sufficient in stead of one bivariate probit model, a likelihood ratio test is performed. This test verifies whether this correlation coefficient significantly differs from zero. The error terms are distributed as follows:

$$\begin{pmatrix}\varepsilon_1 \\ \varepsilon_2\end{pmatrix}\Bigg| X \sim \Phi\left(\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}1 & \rho \\ \rho & 1\end{pmatrix}\right) \qquad (4)$$

, where Φ is the standard normal distribution and ρ is the correlation coefficient. If it is indeed differs from zero, then the application of the biprobit model is justified, otherwise two separate probit models would have been sufficient.

5.4 Double sample selection

The share of sales due to new product (TURNIN) is the only innovation output measure that is available on a continuous scale. It is important to note here that there is a sample selection bias in measuring this variable, since it is only available for innovative firms that introduced a product innovation. Thus, innovative firms that only introduced a process innovation cannot answer this question. Table 14 shows how this sample selection works out. A total of 947 firms are innovative, but have not introduced a product innovation and hence the share of sales due to new products is not available.

Here, the reasoning is that a standard censored regression model cannot be applied, since such a model would assume that TURNIN for these 947 firms could not be observed since these firms do not introduce a product innovation. This type of censoring might not be the case because these firms actually focus on process innovation in stead. Therefore it is necessary to limit the research on the 2,330 firms that indeed aimed at introducing a product innovation while taking into account the selection bias that emerges from leaving the 947 non-product innovators out of the analysis. As in the former section, this will also be solved by introducing a Heckman selection model. However, here a double sample selection model is needed.

Table 14: Sample selection for share of sales due to new products

	INPCS		
INPDT	0	1	Total
0	78	869	947
1	889	1,441	2,330
Total	967	2,310	3,277

For dealing with this sample selection bias, a two-part model – as used by Catozzella, Conte and Vivarelli (2008) – is applied. This model contains a probit model for – in this case – TURNIN being either zero or positive and a standard regression model for the positive values of TURNIN. Since product and process innovation are correlated, the probit model has been substituted by a bivariate probit model that allows for correlation between the residuals. The specification of the model is then as follows:

$$\begin{cases} TURNIN^* = X_i^{'}\beta + \upsilon_i; \quad TURNIN^* = TURNIN \text{ if } INPDT^* > 0, 0 \text{ otherwise} \\ INPDT_i^* = \alpha_i + X_i\beta + \varepsilon_i; \quad INPDT^* = INPDT \text{ if } INPDT^* > 0, 0 \text{ otherwise} \end{cases} \qquad (5)$$

, where the first equation measures the share of sales due to innovative products for firms that realized a product innovation and the second equation measures the probability of introducing a product innovation. The latter is actually the same as the bivariate probit model (3) , this time acting as a selection model for selection product innovators. As such, the selection biases for being innovative – by inserting the inverse Mills ratio as result of (2) – and the selection bias for being product innovator are dealt with and the correlation between product and process innovation decisions is taken into account.

5.5 Innovation activities

The same Heckman selection model will be applied to distinguish specific innovation strategies among the sector groups. The selection equation for being innovative or not remains the same while in the second stage the dependent variables will be whether a firm invested in innovation activities (internal R&D, external R&D, acquisition of machinery and acquisition of external knowledge) or not. This exercise has been repeated for every sector group as defined earlier in order to see the different innovation strategies among these groups. X shows the results.

6 Results

6.1 Selection model

The outcomes are shown in Table 15. The p-value of the Wald-test is less than the criterion of 0.05, so the null hypothesis can be rejected, indicating that including all variables results in a statistically significant fit of the model. The non-significant impact of size (lturn) is remarkable, but might be explained by differences in firm size that are included in the Pavitt sector groups. These sector groups have a significant impact on a firm's propensity to innovate, as found already in the descriptive statistics.

Innovation in the past, protected by a valid patent (paval) does not lead automatically to innovation output in the present, while other innovation output (otherinnoutput) does have a positive effect on the introduction of either a product or process innovation. Contra-intuitive are the positive and significant impact of economic, internal and other hampering factors that firms experienced on the propensity to innovate. This shows that firms that are more actively involved in innovation activities will find more hampering factors than firms that are less actively involved.

Table 15: Selection Equation for innovation

inno	*coefficient*	*p value*
lturn	0.003	0.939
gp	0.265***	0.004
sigmar	0.058	0.151
lexp	0.000	0.948
lemphi	0.146***	0.000
paap	0.638***	0.000
paval	-0.021	0.876
heconomic	0.821***	0.000
hinternal	0.426***	0.000

hother	0.216**	0.024
protect_form	0.081	0.549
protect_strat	0.551***	0.000
otherinnacti	0.650***	0.000
Specialized Suppliers	-0.530	0.132
Scale Intensive	-0.836**	0.023
Supplier Dominated	-0.638**	0.039
Information Intensive	0.151	0.633
Transport	-0.898*	0.052
Others	-0.712***	0.003
sector dummies	Included	
Constant	-1.301**	0.014
Number of observations	7395	
Wald test	16.15	0.000
Wald test Pavitt	3.29	0.003
Wald test sectors	2.21	0.000

6.2 Product and process innovation: taking into account a selection bias

A bivariate probit model estimates the impact of the innovation expenditures on both the likelihood to introduce a process innovation and a product innovation. See Table 16 for the results. As expected, we see that different innovation activities lead to different innovation output. Internal R&D is the only activity that has a positive and significant impact on product innovation, while the acquisition of machinery and other external knowledge lead to process innovation.

Looking more closely at firm characteristics we see that firm size has a significant impact on innovation output, but this varies between product and process innovation. While smaller firms are more prone to introduce a product innovation, larger firms seem to focus more on process innovation. Interesting here would be to include a variable that is measuring the age of the firm for testing whether young (small) firms mainly concentrate on product innovation and after growing start to concentrate on process innovation. However, such a variable is not available.

Table 16: Bivariate probit model

	inpdt		*Inpcs*	
	Coef.	P>t	Coef.	P>t
Lrrdinx	0.056***	0.000	-0.012	0.143
Lrrdexx	-0.009	0.441	0.006	0.581
Lrmacx	-0.032***	0.000	0.059***	0.000

Lroekx	0.017	0.131	0.027**	0.025
Lturn	-0.066***	0.006	0.091***	0.000
Gp	0.198*	0.059	0.067	0.490
Lemphi	-0.044	0.275	-0.007	0.864
Lexp	0.009	0.209	-0.009	0.193
Sigmar	0.002	0.972	0.010	0.844
Lrothx	0.107***	0.000	0.006	0.787
Funding	-0.020	0.821	0.334***	0.000
coop_market	0.170	0.326	-0.151	0.380
coop_resea~h	-0.195	0.307	-0.026	0.887
Hamper	-0.018	0.838	0.016	0.855
heconomic	-0.196***	0.007	0.037	0.609
Hinternal	0.029	0.663	0.072	0.287
Hother	0.138**	0.013	-0.043	0.447
protect_form	0.297***	0.005	-0.188**	0.048
protect_st~t	0.294***	0.003	0.049	0.611
otherinnou~t	0.236**	0.027	-0.023	0.844
Invmills	-0.183	0.282	0.103	0.541
Science_ba~d	0.405*	0.072	-0.255	0.246
Specialize~s	0.301	0.187	-0.344	0.125
Scale_inte~e	0.163	0.418	-0.166	0.416
Supplier_d~d	0.153	0.475	-0.058	0.794
Informatio~e	0.275	0.196	-0.281	0.193
Others	0.272	0.266	-0.441*	0.075
_cons	0.978**	0.046	-1.182**	0.015
number of observations		3138		
Wald test	9.18	0.000		
Wald test Pavitt	0.84	0.605		
Rho	-0.763			
likelihood ration test if rho=0				

Outstanding is the non-significance of the inclusion of the Pavitt sector groups. The Wald test for inclusion of these dummies is non significant. One explanation for this result might be that – once innovative firms are selected – the separate innovation activities have similar effects on innovation output amongst these sectors. Thus, in general, internal R&D is positively related to product innovation and acquisition of machinery is positively related to process innovation. However, what matters is the innovation strategy, i.e. the combination of different innovation inputs. Thus, the next question is: how can these different innovation strategies been distinguished by applying a regression model? Before answering this question, first the relation between the third innovation output measure (part of turnover due to innovative sales) and the innovation input and firm characteristics as above will be tested. Above results are also influenced due to the fact that is only referred to a firm's propensity to introduce either a product or process innovation, but does not provide information on the impact on innovation performance.

6.3 Innovation performance

The following Table 17 shows the results of the relation between the input (different innovation activities and firm characteristics) and the innovation outcome, measured as turnover due to new products. The results confirm more or less the expectations. Only internal R&D activities have – as expected – a positive impact on innovative sales, although only on a 10% significance level. Other innovation activities (design, training) do not show positive impacts. The implementation of other creative improvements (strategic, management, organization, marketing and esthetic changes, represented by the variable OTHERINNACT) has a positive and significant impact on innovation performance. This shows that e.g. marketing and esthetic changes – although not considered as technological innovation – are an important source for performance improvement for firms. Firm size has a negative impact on sales due to innovative products, probably due to the fact that it is easier for smaller firms to obtain a higher share by introducing few innovative products.

Table 17: Truncated regression with TURNIN as dependent

lturnin	*Coefficient*	*P value*
lrrdinx	0.005*	0.063
lrrdexx	0.003	0.297
lrmacx	0.003	0.246
lroekx	0.003	0.277
lrothx	0.003	0.618
coop_market	0.035	0.547
coop_resea~h	-0.079	0.184
heconomic	0.066***	0.000
hinternal	-0.025	0.181
hother	-0.027*	0.080
paap	0.166***	0.002
paval	-0.122***	0.005
protect_form	-0.002	0.957
protect_st~t	0.120***	0.004
lturn	-0.036***	0.000
gp	-0.013	0.685

sigmar	0.048***	0.001
lexp	-0.001	0.667
lemphi	0.006	0.680
otherinnact	0.105*	0.058
invmills2	0.216**	0.016
Science_ba~d	-0.177**	0.018
Specialize~s	-0.178**	0.015
Scale_inte~e	-0.213***	0.001
Supplier_d~d	-0.121*	0.058
Informatio~e	-0.080	0.252
Others	-0.375***	0.000
_cons	0.267	0.220
Number of observations	2001	
Wald test	114.28***	0.000
Wald test Pavitt	49.04***	0.000

Unlike in the former paragraph, the joint impact of the Pavitt sector groups is significant, as can be seen in the joint significance test. This result indicates that – other than propensity to introduce a product or process innovation – the importance of innovative products for a firm (measured as part of total sales) depends on a firm's technological characteristics of a firm. The following table provides an overview per sector group.

Table 18: Truncated regression with lturnin as dependent variable - by sector groups

Lturnin	*Science based*	*Specialized suppliers*	*Scale intensive*	*Supplier dominated*	*Information intensive*	*Transport*	*Others*
lrrdinx	0.011**	-0.005	0.007	0.001	0.010*	-0.037	-0.001
	(0.043)	(0.343)	(0.172)	(0.885)	(0.081)	(0.042)	(0.927)
lrrdexx	0.002	0.005	0.002	0.004	0.001	0.048	0.000
	(0.610)	(0.432)	(0.750)	(0.551)	(0.913)	(0.000)	(0.959)
lrmacx	0.007*	0.014***	-0.003	-0.004	0.001	-0.008	0.013**
	(0.092)	(0.008)	(0.552)	(0.329)	(0.813)	(0.199)	(0.020)
lroekx	0.001	0.014**	0.009	-0.010	-0.005	0.028	-0.005
	(0.815)	(0.027)	(0.202)	(0.238)	(0.412)	(0.005)	(0.432)
lrothx	-0.005	-0.031**	0.028*	0.010	0.033**	-0.101***	-0.036*
	(0.670)	(0.049)	(0.070)	(0.487)	(0.025)	(0.000)	(0.067)
coop_market	0.034	-0.281**	0.067	-0.033	0.103	0.261	0.580*
	(0.664)	(0.026)	(0.585)	(0.834)	(0.344)	(0.091)	(0.094)
coop_resea~h	-0.033	0.142	-0.065	-0.345*	-0.213	-0.256	-0.509
	(0.681)	(0.157)	(0.632)	(0.059)	(0.069)	(0.219)	(0.150)
heconomic	0.088***	0.047	0.075**	0.030	0.084**	-0.082**	0.025

	(0.006)	(0.163)	(0.030)	(0.350)	(0.022)	(0.038)	(0.509)
hinternal	-0.104***	-0.103**	0.090**	-0.077*	-0.049	-0.018	-0.005
	(0.003)	(0.024)	(0.036)	(0.054)	(0.245)	(0.763)	(0.900)
hother	-0.017	0.154***	-0.092***	-0.023	-0.004	0.081	-0.065*
	(0.603)	(0.000)	(0.006)	(0.468)	(0.899)	(0.126)	(0.065)
paap	0.161*	0.238**	0.150	0.213*	-0.109	0.578**	0.462**
	(0.052)	(0.013)	(0.237)	(0.075)	(0.390)	(0.026)	(0.031)
paval	-0.065	0.021	-0.103	-0.368***	-0.026	-	-0.445*
	(0.337)	(0.754)	(0.272)	(0.001)	(0.801)	-	(0.070)
protect_form	-0.006	0.010	-0.013	-0.005	0.080	-0.969***	0.052
	(0.920)	(0.870)	(0.845)	(0.942)	(0.278)	(0.000)	(0.501)
protect_st~t	0.073	0.082	0.118	0.068	-0.048	0.665***	-0.004
	(0.358)	(0.361)	(0.293)	(0.431)	(0.620)	(0.000)	(0.978)
lturn	-0.013	-0.084**	-0.008	-0.014	-0.060***	-0.013	-0.048**
	(0.470)	(0.032)	(0.598)	(0.567)	(0.000)	(0.708)	(0.015)
gp	-0.106*	0.060	-0.106	0.152**	0.009	-0.192*	-0.102
	(0.085)	(0.373)	(0.156)	(0.049)	(0.895)	(0.054)	(0.178)
sigmar	-0.007	-0.027	0.035	0.027	0.087***	0.189***	0.021
	(0.837)	(0.506)	(0.278)	(0.398)	(0.009)	(0.000)	(0.481)
lexp	-0.003	0.009	-0.001	0.001	-0.006	-0.023**	0.006
	(0.451)	(0.162)	(0.903)	(0.899)	(0.267)	(0.011)	(0.224)
lemphi	-0.032	0.090**	-0.020	-0.067*	-0.006	0.044	-0.034
	(0.203)	(0.023)	(0.570)	(0.065)	(0.846)	(0.133)	(0.413)
otherinnact	0.085	0.221*	0.250	0.016	-0.233	-0.258**	-0.160
	(0.437)	(0.071)	(0.108)	(0.886)	(0.132)	(0.030)	(0.320)
invmills2	0.072	0.224	0.482*	-0.049	-0.180	-0.145	-0.181
	(0.730)	(0.376)	(0.062)	(0.787)	(0.483)	(0.292)	(0.499)
_cons	0.137	0.734	-0.753	0.445	1.022**	0.711	1.256**
	(0.716)	(0.263)	(0.149)	(0.357)	(0.021)	(0.198)	(0.049)
/sigma	0.265	0.229	0.342	0.291	0.271	0.127	0.144
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

In Table 18 we see that for firms from the Science based sector group, internal R&D has the most positive and significant impact on share of turnover due to innovative products. This is as expected. Internal R&D also has a positive and significant (although on 10% level) impact on innovation performance. Specialized suppliers, characterized as product innovators, generate a higher share of sales due to innovative products by combining the acquisition of machinery with the external knowledge acquisition from their clients.

7 Concluding remarks

This researched focused on the effects of technological characteristics of innovation expenditures on the innovation output. Technological characteristics of firms were captured in the five Pavitt sector groups (Science based, Specialized suppliers, Supplier dominated, Scale intensive, and Information intensive), extended with two additional groups, namely Transport and Others. Three measures are used for innovation output: propensity of introducing a product or process innovation and the share of innovative sales.

The selection bias that was inherent to the collection of survey data was taken into account by applying a Heckman selection model. The first selection between innovative and non-innovative firms showed that the technological characteristics, together with other firm characteristics (such as) were important factors for this selection.

The second step of the Heckman selection model dealt with a bivariate probit model where the choice between product and process innovation were measured, while taking into account the selection bias by inserting the inverse Mills ratio as calculated from the first step. It became clear that the type of innovation output depends on the innovation activities. Internal R&D leads to product innovation and acquisition of machinery leads to process innovation, without behaving differently among sector groups.

The third measure of innovation outcome, namely the share of sales due to innovative products, had to deal with a double sample selection problem, since only innovative firms that introduced a product innovation could be taken into account. By adding an extra selection model to the first one, this was taken into account. Internal R&D has a positive and significant impact on innovation performance and this differs among sectors, due to differences in the importance of intenal R&D among sectors.

Several firm characteristics have a significant impact throughout the application of the Heckman selection models. Innovative firms are more often part of an enterprise group, have more employees with high education and have implemented more strategic and organizational changes than non innovative firms. Product innovators are more likely to be smaller in size and to implement a protection measure (either formal or strategic), while process innovators are larger firms that are less likely to protect their (process) innovations. For smaller firms it is also easier to obtain a higher share of sales due to innovative products and these firms are more likely to apply for a patent.

This study attempted to show the different impact of the various innovation activities and showed that differences in innovation behavior between sector groups indeed exist. Although a general pattern of innovation activities and outcome can be seen, the combination of these activities is crucial in determining a firm's innovativeness.

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Annex I: Innovation input – innovation output correlation

All firms	***inpdt***	***inpcs***	***lturnin***
lrrdinx	0.296***	-0.018	0.060***
	(0.000)	(0.304)	(0.007)
lrrdexx	0.073***	0.048***	0.031
	(0.000)	(0.007)	(0.158)
lrmacx	-0.104***	0.268***	0.079***
	(0.000)	(0.000)	(0.000)
lroekx	0.088***	0.100***	0.034
	(0.000)	(0.000)	(0.130)

Science based	***inpdt***	***inpcs***	***lturnin***
lrrdinx	0.254***	-0.080*	0.119**
	(0.000)	(0.071)	(0.020)
lrrdexx	0.101**	0.042	0.068
	(0.023)	(0.341)	(0.187)
lrmacx	0.087**	0.151***	0.179***
	(0.049)	(0.001)	(0.001)
lroekx	0.091**	0.078*	0.070
	(0.040)	(0.079)	(0.174)

Specialized suppliers	***Inpdt***	***Inpcs***	***lturnin***
lrrdinx	0.400***	-0.121*	0.033
	(0.000)	(0.051)	(0.648)
lrrdexx	0.061	-0.138**	0.162**
	(0.326)	(0.026)	(0.026)
lrmacx	-0.055	0.328***	0.188***
	(0.372)	(0.000)	(0.010)
lroekx	0.110*	0.030	0.073
	(0.075)	(0.635)	(0.319)

Scale intensive	***Inpdt***	***Inpcs***	***Lturnin***
lrrdinx	0.281***	-0.007	0.036
	(0.000)	(0.817)	(0.345)
lrrdexx	0.088***	0.077***	0.046
	(0.003)	(0.010)	(0.235)
lrmacx	-0.193***	0.282***	0.018
	(0.000)	(0.000)	(0.636)
lroekx	0.060**	0.082***	0.074*

	(0.046)	(0.006)	(0.054)

Supplier dominated	***inpdt***	***inpcs***	***lturnin***
lrrdinx	0.311***	0.073	-0.057
	(0.000)	(0.068)	(0.270)
lrrdexx	0.033	0.095**	-0.125**
	(0.420)	(0.019)	(0.015)
lrmacx	0.015	0.242***	-0.107**
	(0.713)	(0.000)	(0.036)
lroekx	0.022	0.077*	-0.019
	(0.592)	(0.056)	(0.711)

Information intensive	***Inpdt***	***Inpcs***	***Lturnin***
lrrdinx	0.358***	-0.100**	0.201***
	(0.000)	(0.050)	(0.001)
lrrdexx	0.109**	0.020	-0.011
	(0.034)	(0.697)	(0.857)
lrmacx	-0.056	0.147***	0.073
	(0.277)	(0.004)	(0.243)
lroekx	0.130**	0.042	0.068
	(0.012)	(0.418)	(0.284)

Others	***Inpdt***	***Inpcs***	***lturnin***
lrrdinx	0.139**	0.035	0.196**
	(0.049)	(0.617)	(0.041)
lrrdexx	0.005	0.029	0.044
	(0.940)	(0.677)	(0.646)
lrmacx	-0.237***	0.390***	0.235**
	(0.001)	(0.000)	(0.013)
lroekx	0.241***	0.275***	-0.046
	(0.001)	(0.000)	(0.633)

Transport	***inpdt***	***inpcs***	***lturnin***
lrrdinx	-0.070	0.211**	-0.040
	(0.453)	(0.023)	(0.781)
lrrdexx	0.070	0.151	0.094
	(0.456)	(0.107)	(0.518)
lrmacx	0.042	0.061	0.194
	(0.649)	(0.515)	(0.169)
lroekx	-0.104	0.190**	0.175

	(0.267)	(0.040)	(0.220)