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R&D, Innovation and Productivity, and the CIS: Sampling, Specification and Comparability Issues

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**CORPORATE R&D: AN ENGINE FOR GROWTH,
A CHALLENGE FOR EUROPEAN POLICY**

**R&D and its impact
on company performance**

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Abstract

We construct and estimate a modified version of the Crépon, Duguet and Mairesse (1998) model to investigate the links between R&D, innovation output and productivity. We propose a model specification that, among other features, aims to better capture the variance component of the cooperation and obstacles-to-innovation variables. Results based on Finnish CIS data support this alternative specification and highlight the role of process innovations. We also address comparability over time within the same country, by comparing Finnish CIS3 and CIS4 estimates. Despite CIS harmonization, both sample selection issues and nuances in the specification of the variables prove to have a profound effect on the results, and question the validity of this currently popular comparison exercises.

Key words: R&D, innovation, productivity, CIS, sample selection, comparability

JEL classification: O31, L29, D24

TABLE OF CONTENTS

1 -	Introduction	4
2 -	The Data	4
2.1	Sampling and data issues.....	4
2.2	Descriptive statistics	6
3 -	Econometric model and variables used	9
3.1	The CDM model and its successors.....	9
3.2	Main features of our model	10
3.2.1	The estimation strategy	10
3.2.2	Model specification and definition of the variables	11
4 -	Estimates and results.....	14
5 -	Conclusions and policy implications.....	17
6 -	Acknowledgments	18
7 -	References.....	19

1 - Introduction

Research and development (R&D) activities are believed to serve two main purposes. They enhance absorptive capacity (Cohen and Levinthal, 1989), thereby facilitating the imitation of others' discoveries (Griffith, Redding and Van Reenen, 2004) and the absorption of new technologies (Parisi, Schiantarelli and Sembenelli, 2006), and stimulate innovation. This indirectly affects productivity, as innovation effort significantly determines innovation output, and higher innovation output generally correlates positively with productivity (Crépon, Duguet and Mairesse, 1998; Griffith et al., 2006).

Since the pioneering work of Mansfield (1972) and Griliches (1979, 1992, 1998), the relationship between R&D, innovation output and productivity has been the focus of many microeconomic studies. Examples of early works are Odagiri (1984), Odagiri and Iwata (1986), Chakrabarti (1990), and Hall and Mairesse (1995). More recently, studies mainly exploiting data from the Community Innovation Survey (CIS) have contributed to verify the existence of, and to quantify, the link R&D investment - innovation output – productivity, to inform innovation policy. A large number of these studies rely on variants of the model first proposed by Crépon, Duguet and Mairesse (henceforth CDM) in 1998, including, among others, Lööf and Heshmati (2002), Griffith et al. (2006), Chudnovsky, López and Pupato (2006), and the OECD (2009).

The present paper contributes to this literature by addressing and providing empirical evidence on three features of CIS data-based CDM-type models. Firstly, we investigate whether and to what extent differences in the sampling frames within the same country, across different CIS waves, affect the estimates. Secondly, we investigate whether the use of variables aimed to exploit the richness of the information available in the CIS related to firms' cooperation and obstacles to innovation improves the fit of the model we propose. We find that it does improve the overall fit of the model, and that the estimates shed light on the type of hindering factors and collaborations that can affect R&D and innovation. Thirdly, by comparing Finnish CIS3 and CIS4 estimates, we verify the suitability of the new specification proposed and the robustness of the model.

The paper is organised as follows. Section 2 illustrates how the samples were constructed, and provides some descriptive statistics relating to the data used in the study and their sources. Section 3 outlines the econometric model, its main features, and its main differences with the original CDM model and variants of the CDM model in the literature. Section 4 presents the estimates and discusses the results. Section 5 concludes with a summary of the main findings of the analysis, and outlines possible implications for innovation policy.

2 - The Data

2.1 Sampling and data issues

The present study relies principally on data collected through the 3rd and 4th waves of the Finnish Community Innovation Survey. CIS3 data cover the period 1998–2000; CIS4 data refer to 2002–2004. Both CIS3 and CIS4 samples have been obtained through stratified simple random sampling, with census for firms with 100 or more employees in CIS3, and 250 or more employees in CIS4. The target population includes all firms active in Finland during the period considered - whether individual enterprises or firms that are part of a group -, with at least 10 employees, and active in NACE sectors C, D, E, 51, I, J, 72, 74.2, 74.3. In both the CIS waves considered a firm is defined innovative if it has successfully introduced, has tried to

introduce, or is in the process of introducing, a new or substantially improved product or process.

CIS surveys are always retrospective in nature, in that they ask for information on the innovative activities of firms in the previous three years. Only a portion of the information collected is quantitative, whereas most data are collected in the form of the respondents' subjective evaluation, expressed categorically on a Likert type scale.

In the case of Finland, CIS3 and CIS4 questionnaires are almost identical in terms of number and types of questions, with the exception of minor differences in the way some questions are formulated. Moreover, Finnish CIS3 and CIS4 questionnaires both contain "filter questions", i.e. questions that, if answered negatively – thus implying that the firm did not innovate during the period considered – allow respondents to skip the majority of the remaining questionnaire. This ultimately means that very little information can be gleaned about non-innovators and about their employment patterns, main industry, most important markets (e.g. domestic versus foreign), and obstacles to innovation. Such a feature of the CIS somewhat impinges upon the breadth and depth of the analysis that can be carried out. Information on non-innovators is in fact of particular relevance for econometric analysis: the more information that is available on non-innovators, the more precise will be the analysis of innovation determinants; and the better the understanding of differences between innovating and non-innovating firms, i.e. which firms are and which are not innovators.

Despite being very similar in most aspects, Finnish CIS3 and CIS4 differ in with respect to some important aspects. We highlight each in turn.

A first and important difference in the CIS3 and CIS4 samples is that, in addition to the stratified sample, CIS3 also includes a panel of firms known to be innovative on the basis of CIS2 or CIS2.5. This feature of CIS3 may determine a selection bias, and questions the representativeness of the sample. As innovative activities are persistent (Cefis, 2003), these firms are more likely to be innovators than their randomly selected counterparts.

A second major difference between the Finnish CIS3 and CIS4 concerns how the data have been collected. CIS3 sampled firms were contacted via mail, whereas CIS4 firms received both hard copy (surface mail) and e-questionnaire forms.

A third main difference is that while response to CIS3 was voluntary, response to CIS4 was mandatory. Response rates were 50% for CIS3 and 74% for CIS4. This substantial increase in the CIS response rate (almost 50% more) can hence only partially – if at all – be attributed to the way in which firms were contacted and given the possibility to respond. The major factor driving the observed higher CIS4 response rate is most likely to be the fact that responding was compulsory. This shift from voluntary to mandatory response was possibly intended to minimise the possible self-selection biases characterising CIS respondents. As innovation is generally held to be a "good thing", innovative firms may have a greater incentive than non-innovators to respond. This would ultimately result in innovators being over-represented in the respondents' samples, thus jeopardising the representativeness of CIS.

However, making response to the questionnaire mandatory, as in CIS4, seems not to have solved the problem. Finnish-based evidence suggests that, in the absence of a real enforcing or control mechanism, overall non-response rates remain very high. Moreover, the presence of filter questions - enabling firms to minimise their effort by responding they are not innovators - may result in a major increase in both item error and non-response rates. Non-responses and "untrue" response behaviour might be a reflection of firms' attempts to protect strategic or sensitive information, or more simply of their unwillingness to respond. High non-response and item error may indeed be among the reasons why Statistics Finland decided to largely replace and impute Finnish innovation expenditure-related data, in both CIS3 and CIS4. In presence of outstanding differences, firm R&D expenditure figures have been in fact compared with and, when appropriate, replaced by those extracted from R&D surveys. Similarly, expenditure-related figures like, e.g., those mirroring the acquisition of machinery and equipment for innovation activities, have been compared with and sometimes replaced by similar figures

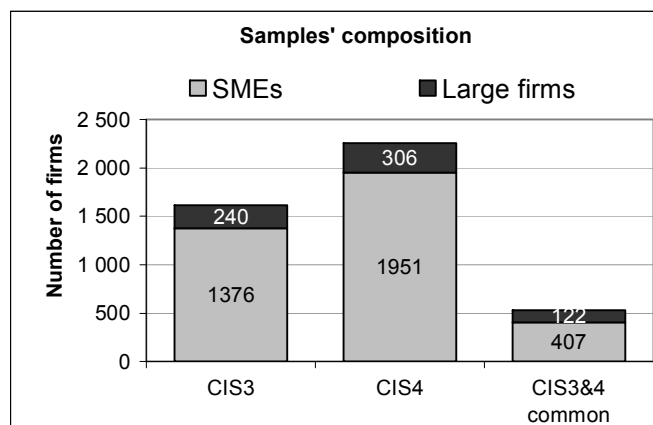
contained in the Structural Business Statistics (SBS). Additional firm information has also been gathered from the SBS. This is the case, for instance, of CIS4 data related to firms' geographic market reach, i.e. whether national or international.

The presence of imputations and replacements, in addition to the other CIS features and differences mentioned above, indeed represent an additional source of concern in the present analysis, due to the biases they may introduce. Nevertheless, and despite the above considerations and concerns about the quality and reliability of CIS data, innovation surveys remain unique and useful tools for attempting to answer important policy relevant questions. We believe the gains that might be derived from relying on CIS data far outweigh the possible drawbacks associated to their use, since they contain innovation-related information that cannot be found anywhere else. Moreover, there is no such a thing as perfect data, and in the case of CIS at least we know what to worry about, and may attempt to address possible biases.

2.2 Descriptive statistics¹

Figure 1 and Table 1 show the composition of CIS3 and CIS4 samples, in terms of Small and Medium Sized Enterprises (SMEs) and large firms, as well as the composition of the sub-sample of firms common to both CIS3 and CIS4. As can be seen, the total number of firms varies enormously between the two CIS waves, but the share of SME and large firms differ only marginally between the Finnish CIS3 and CIS4 samples.

Figure 1: Sample composition



Source: Authors' calculations using Statistics Finland data

Table 1: Sample composition

	SMEs	Large firms	Tot # firms
CIS3	85.1	14.9	1616
CIS4	86.4	13.6	2257
Common CIS3&4	76.9	23.1	529

Table 2 shows the composition of CIS3 and CIS4 samples in terms of high-tech and low tech manufacturing, and knowledge-intensive services sectors. Manufacturing, whether high- or low-tech, accounts for a bigger share of CIS3 firms compared to CIS4, whereas the opposite is true for the service sector.

¹ Descriptive statistics are based on the unweighted samples and, therefore, do not correspond to the official statistical estimates for Finland.

Table 2: Sample composition: percentage of high and low tech firms, and knowledge intensive services²

Sector	CIS3 and CIS4 full samples						Common CIS3&4 sample		
	SMEs		Large firms		Total		SMEs	Large firms	Total
	CIS3	CIS4	CIS3	CIS4	CIS3	CIS4			
High-tech manufacturing	18.4	16.5	4.3	3.0	22.6	19.5	21.8	6.6	28.4
Low-tech manufacturing	36.4	32.1	5.6	5.0	42.0	37.1	37.9	10.4	48.3
Knowledge intensive services	14.9	16.0	1.9	2.1	16.8	18.1	9.3	1.9	11.2
Other services	15.5	21.8	3.0	3.5	18.6	25.3	8.0	4.2	12.1
Total	85.1	86.4	14.9	13.6	100	100	76.9	23.1	100

Source: Authors' calculations using Statistics Finland data

As for firms' innovation patterns, Table 3 shows, for both CIS3 and CIS4, the percentage of firms: innovating over the period considered; introducing product and process innovations; developing technological innovations in-house; introducing "new-to-the-market" product innovations; investing in R&D over the period considered; investing in R&D on a continuous basis. Column 1 shows the percentage of the total number of firms. Columns 2 and 3 respectively, highlight how SMEs and large firms contribute to the overall share, while columns 4 and 5 indicate how the share in column 1 is subdivided between manufacturing and service sectors firms.

We can see that the share of innovating firms - whether in processes or products - decreases slightly (-2.8%)³ from CIS3 to CIS4, and that a much lower share of CIS4 respondents (-9.6%) has introduced "new-to-the-market" products than in CIS3. We also see that, compared to CIS3, CIS4 firms seem less keen on developing technological innovations in-house, and that the share of R&D performers decreases substantially: 50% in CIS3 versus 39.1% in CIS4.

Table 3: CIS3 and CIS4: Innovation patterns, by firms size and industry

Innovators	CIS3 (total number of firms: 1617)					CIS4 (total number of firms: 2258)				
	1. As % of all firms	of which [in %]				1. As % of all firms	of which [in %]			
		2. SMEs	3. Large Firms	4. Manuf.	5. Serv.		2. SMEs	3. Large Firms	4. Manuf.	5. Serv.
Product innovators	44.9	78.2	21.8	69.3	28.4	36.8	79.0	21.0	64.7	33.6
Process innovators	31.0	74.3	25.7	73.1	23.2	35.7	77.5	22.5	60.4	36.4
Product / process innovators	50.8	79.0	21.0	69.6	27.4	48.0	80.1	19.9	62.4	34.6
Developing tech. innovations in-house	37.1	78.0	22.0	73.0	25.5	33.7	79.6	20.4	64.9	33.1
Introducing "new-to-market" product inno.	35.9	78.1	21.9	68.8	29.0	26.3	78.3	21.7	66.2	32.8
R&D performers	50.0	77.1	22.9	72.0	24.8	39.1	77.4	17.2	68.6	28.5
R&D performers on a continuous basis	34.0	70.5	29.5	74.9	22.4	26.9	70.2	29.8	71.9	26.3

Source: Authors' calculations using Statistics Finland data

² See Hatzichronoglou (1997) for the sector classifications.

³ Differences are expressed simply as (CIS3 – CIS4) values.

Two additional features emerge when comparing CIS3 and CIS4 innovators' figures. Firstly, the proportions of innovators, in terms of SME and large firms, remain basically the same across the various categories. Secondly, there are big differences in terms of the contributions of the manufacturing and service sectors, with the latter playing a more important role in CIS4 than in CIS3.

Table 4 shows firms' innovation expenditure as share of total turnover, and its composition in terms of intramural versus extramural R&D spending, as well as acquisition of machinery and equipment and of external knowledge.

Table 4: CIS3 and CIS4 Innovation expenditures and turnover from innovation, by firm size and industry

	CIS3					CIS4				
	All firms	SMEs	Large firms	Manuf.	Serv.	All firms	SMEs	Large firms	Manuf.	Serv.
Total innovation expenditures [as % of total turnover]	3.3	2.1	3.5	4.5	1.4	2.9	1.4	3.4	4.2	1.2
of which [in %]:										
- Intramural R&D	60.3	61.3	60.2	58.6	78.1	67.1	45.4	70.0	72.2	39.8
- Extramural R&D	11.6	11.2	11.7	11.9	7.8	6.2	14.6	5.1	5.7	9.1
- Acquisition of machinery, etc.	17.2	16.9	17.3	18.3	6.0	24.8	29.0	24.3	21.3	43.4
- Acquisition of other external knowledge	14.9	10.6	15.4	15.9	8.1	1.2	11.0	0.8	1.0	7.6
Share of turnover from product innovations [as % of turnover]	10.5	9.8	14.4	11.1	10.2	4.2	4.0	5.6	4.5	4.2
Share of turnover from new-to-market product innovations [as % of turnover]	6.9	6.5	9.3	7.3	6.7	3.2	3.1	4.0	3.5	3.1

Source: Authors' calculations using Statistics Finland data

The lower percentage of total innovation expenditures observed in the case of CIS4 (-0.4%) seems mostly due to SME and the manufacturing sector investing less than in the CIS3 period. We can also see that, overall, CIS4 firms appear to be more inward looking than their CIS3 counterparts, when it comes to investing in R&D, and to be less keen on outsourcing R&D or acquiring external knowledge. The opposite is true for the acquisition of machinery and equipment, where expenditure increases substantially in CIS4.

With respect to the innovation-related output, a striking feature emerges: the share of turnover generated from product innovations plunges from 10.5% in CIS3 to 4.2% in CIS4. The results are similar for the introduction of products claimed by firms to be new to the market.

About firms' degree of internationalisation, Table 5⁴ suggests CIS4 respondents to be indeed more international in terms of markets reached, than CIS3 respondents (featuring an 29.5% in absolute terms, which relative to CIS3 figure corresponds to a 102% increase), while the share of firms collaborating with foreign partners is broadly the same across both survey waves.

Table 5: Firms' collaboration, financial support, degree of internationalization, and patenting

	CIS3 (total number of firms: 1617)					CIS4 (total number of firms: 2258)				
	1. As % of all firms	of which [in %]				1. As % of all firms	of which [in %]			
		2. SMEs	3. Large Firms	4. Manuf.	5. Serv.		2. SMEs	3. Large Firms	4. Manuf.	5. Serv.
Firms active on international markets	27.8	74.4	25.6	81.6	18.4	56.3	83.3	16.7	71.9	27.8
Firms cooperating with foreign partners	21.2	61.7	38.3	74.6	21.9	20.9	66.9	33.1	72.0	25.4
Firms collaborating in innovation activities	34.1	70.7	29.3	70.7	25.5	27.5	72.9	27.1	66.0	29.7
Firms collaborating with academia/ HEIs / research institutes	25.2	64.6	35.4	73.7	22.1	23.3	69.7	30.3	68.8	27.0
Firms that received public financial support for innovation	32.7	70.9	29.1	76.6	20.2	21.6	73.4	26.6	78.3	18.9
Firms applying for patents	18.6	67.3	32.7	81.0	17.3	13.6	62.5	37.5	82.7	16.3

Source: Authors' calculations using Statistics Finland data

CIS4 respondents are generally much less likely to have formal cooperation agreements for innovation projects than their CIS3 counterparts (-6.6%), although the share of firms cooperating with High Education Institutions (HEIs) and research centres is fairly stable. When we compare firms' degree of cooperation and internationalisation across the two surveys we find that CIS4 SMEs and the service sector are substantially more likely to cooperate and to be internationalised. The only countertendencies relate to the use of patents, which are generally decreasing from CIS3 to CIS4, both for SMEs and the service sector. Finally, financial support for innovative activities is much more important in CIS4 than CIS3, with 11.1% fewer firms receiving funding in years 2000-2002 - particularly SME and (slightly so) the services sector.

3 - Econometric model and variables used

3.1 The CDM model and its successors

Since the seminal paper of Griliches and Pakes (1984), full structural models have been used to address the relationship between innovation input, innovation output and productivity, using direct measures of innovative output obtained from innovation surveys. The underlying crucial assumption, first made in the CDM model, is that innovation inputs determine innovation outputs, and that innovation output in turn affects productivity.

In the CDM model the link between R&D, innovation output and labour productivity is formalised as a system of simultaneous equations. The structure of the model is recursive, and is estimated based on French CIS1 data using Asymptotic Least Squares (ALS). The first two equations describe the R&D investment decision. Firms decide whether and how much to invest in R&D: only if the net returns on this investment (which are not observable by the econometrician, but which are known to the firm) are positive, will firms actually record positive R&D expenditures. As it is restricted to successful innovators, this relationship is estimated using a generalised Tobit specification. The third equation is a knowledge production function,

⁴ Columns in Table 5 follow the pattern for Table 3.

which has two versions in the CDM model: in one innovation output is measured by the proportion of sales due to new and improved products; in the second innovation output is measured by patents. The fourth equation is an augmented Cobb-Douglas value-added production function. The latter two steps in the model are estimated for “innovative” firms only, i.e. firms that spend on R&D.

The CDM model corrects for two main problems normally affecting this type of analysis: selectivity and endogeneity. Selectivity means that only a subset of firms invests in R&D. Therefore, when the analysis is restricted to this non-random subset of “R&D spenders”, it is necessary to correct for possible selection biases. Endogeneity implies that some of the explanatory variables and the dependent variables might be simultaneously determined in the model. For example, innovation inputs might be endogenous in the knowledge production function, because firms that are more likely to innovate successfully (in terms of output) might also be those that spend more on innovation. Likewise, innovation output might be endogenous in the output production function, either because of unobserved shocks, correlated with both total sales and the firm’s innovative sales, or because of unobserved firm characteristics (e.g. management quality).

Janz, Lööf and Peters (2004) estimate a variant of the CDM model on pooled firm level data from the CIS3 of Sweden and Germany. This allows them to test for the equality of the model parameters across these two countries. As in the CDM model, the estimates rely on innovative firms only, but, rather than using just R&D expenditure, they use all innovation related expenditures as inputs in the knowledge production function. While allowing for possible feedback effects of productivity on innovation output, Janz, Lööf and Peters do not assume a fully recursive model.

Griffith, Huergo, Mairesse and Peters (2006) apply another variant of the CDM model to data from CIS3 (1998-2000) for France, Germany, Spain and the UK. In contrast to CDM, they estimate the model on all firms in the manufacturing sector, as they believe that firms reporting zero R&D may still have positive knowledge outputs. The underlying assumption here is that the relationship between innovation inputs and innovation outputs is the same for firms that report positive R&D and firms that report zero R&D. The model is estimated separately for each country and, therefore, coefficients are allowed to vary across countries, and their equality across countries cannot be tested.

The OECD Innovation Microdata Project (2009) – in which the authors participated – includes a cross-country CDM-type analysis based on data from CIS4 for the EU countries and data for New Zealand, Australia, Canada, Korea and Brazil, where innovation surveys are formulated in a similar but not fully harmonized way. This very broad geographical coverage has some drawbacks in terms of the richness of the final specification of the model, because it constrains the regressors and controls that can be used. In fact, the variables included in the model constitute a minimum, common denominator set of variables chosen in order that the same model can be applied to all countries. Moreover, due to confidentiality issues, the data were not pooled, thus making it impossible to test the equality of the model coefficients across participating countries.

3.2 Main features of our model

3.2.1 The estimation strategy

The first step in our model is to estimate the determinants of the probability to invest in innovation, and the amount being invested. In contrast to the original CDM and to Griffith et al.’s (2006) models, we use firms’ total innovation expenditure as the innovation input. We do so in the belief that R&D basically mirrors formal innovation activity only, and relying solely on firms with positive R&D expenditures might introduce an additional selection bias. Smaller

firms that conduct their innovative activities more informally could in fact register zero R&D expenditures, but still invest in innovation. In the second step we estimate the model only for innovative firms, defined as firms with positive innovation expenditure and positive innovative sales, and not on all firms, as Griffith et al. (2006) instead do. We are motivated by the belief that holding the underlying relationship between innovation input and output to be the same for all firms, whether innovative or not, is too strong an assumption.

Finally, and similarly to OECD (2009), the third step in our model estimates the elasticity of productivity with respect to product innovation, but only for innovative firms. While acknowledging the importance of process innovation - which was absent from the original CDM model, but included in Griffith et al.'s model - we do not have a separate innovation output equation for process innovations. We prefer to include process innovation as an additional control, in both the product innovation function and the productivity equation, as we believe that the two phenomena are highly interlinked.

We estimate the innovation investment and innovation output equations simultaneously, using a two step limited information maximum likelihood method. Following CDM, we allow for the endogeneity of both input and output of the innovation process, but –unlike Janz, Lööf and Peters (2004) - we do not allow for potential feedback effects of productivity on innovation output. Finally, to avoid the possible biases that may arise when using data coming from different sources, as in the OECD model, we use only the variables available in the innovation surveys. This choice, which is the same made by the OECD (2009), if on the one hand minimises the possible sources of bias, on the other hand leads us to using a very simple productivity measure, namely the log of sales per employee.

3.2.2 Model specification and definition of the variables

Similar to CDM, we use a three-stage four-equation model. The first stage explains the firm's decision to engage (or not) in innovation activities, and the amount of innovation expenditure chosen. It comprises two equations and is estimated using a generalised Tobit model (Heckman, 1979). The first equation accounts for firms' innovative efforts ($innov^*$) and can be formally written as follows:

$$Innov_i^* = X'_{1i} \mathbf{b} + u_i$$

where subscript i indicates firms; X is a vector of regressors that we describe below and u is the error term that we assume is normally distributed. As firms will innovate only if the net gains from this activity are positive, we observe the discrete event of whether firm i is innovative or not, rather than observing the latent variable $Innov^*$. Therefore, the first equation models the probability that the firm is innovative using a probit model:

$$Prob(Innov_i=1) = Pr(Innov_i^* > 0) = Pr(u_i > -X'_{1i} \mathbf{b})$$

X'_1 is a vector of variables affecting the innovation investment decision and includes: size of the firm, measured as log employment ("LEMP"); a dummy for whether the firm is part of a group or not ("GROUP"); a dummy for whether the firm serves foreign markets or not ("FOR_MKT"), as well as industry dummies. The X'_1 vector also includes a set of variables used to capture the intensity of the obstacles firms may face when innovating. These are knowledge, costs and market-related obstacles. Unlike the OECD model, the obstacle related variables are specified here as variables taking values between 0 and 1. "HACOST" accounts for the intensity of cost-related obstacles; "HAKNOW" for intensity of knowledge-related problems; and "HAMARKET" for the market-related hampering factors. The obstacle variables are built from summing the responses to the three questions composing each of the obstacle variables. More precisely, we translate the original Likert scale answers into values from 1 to

3, depending on whether the problem is rated respectively “low”, “medium”, or “high”. Zero values are attributed in the case a firm declares not to have experienced the problem. The figures thus obtained for each problem-related question are added together, to produce a figure in the zero to 9 range (i.e. three questions, each with values from zero to 3). This figure is then divided by 9, i.e. the maximum possible value, to normalise the variable. Lastly, a variable called “OBS” constructed as: $OBS = (“HACOST” + “HAKNOW” + “HAMARKET”)/3$ summarises the overall intensity of all the obstacles. The choice of the covariates used in this equation is mainly dictated by the limited availability of information for non-innovative firms. Conditional on the firm being innovative, we observe a firm’s innovation investment intensity to be:

$$\begin{array}{llll} InnExp = X'_2 \mathbf{d} + e_i & \text{if} & Innov = 1 & \text{and} \\ InnExp = 0 & \text{if} & Innov = 0 & \end{array}$$

The second equation in the first stage is an innovation expenditure equation, where the dependent variable is innovation expenditure per employee. The equation estimates the role of exogenous covariates on the amount of innovation expenditure. We assume the error terms u and e to be jointly normally distributed, with mean zero and covariance ρ , and estimate the two equations as a generalized Tobit equation, by maximum likelihood.

Relative to the first equation, we use additional regressors. In particular, we include a dummy accounting for whether the firm cooperates or not (“COOP”) and a set of four variables accounting for the various types of cooperation, their intensity and their geographical reach. The dummy “COOP” takes the value 1 if firms have any kind of collaboration whatsoever, i.e. if they answered yes to at least one of the collaboration-related questions. “COOP_own_chain” takes positive values⁵ if the firm responds as cooperating internally (i.e. with other branches/units of the same enterprise), and/or with suppliers and clients, and zero otherwise. Similarly, the variable “COOP_out_private”, accounts for the firm’s collaboration in innovative activities with competitors and consultants. Finally “COOP_out_public” captures the firm’s degree of collaboration with HEIs and universities, as well as research centres.⁶ The cooperation-related variables are constructed in such a way as to capture whether the firms is inward-looking – i.e. it mainly relies on its “own chain” when innovating, or outward looking - implying that it seeks the support of external partners, both private and public institutions. In addition, the variable “COOP_intern” accounts for the degree of internationalisation in firms’ collaborations. It is constructed as a ratio in which the numerator is the number of international collaboration-related items that firms ticked in the questionnaire, and the denominator is the numerator plus the number of all national collaboration-related items ticked.⁷

A crucial assumption in identifying the parameters of interest is the existence of exclusion restrictions, i.e. variables affecting the decision to invest in innovation, but not the intensity of the innovation effort. Our exclusion restrictions are firm size and obstacles to innovation. The idea is that, while it is well known (Schumpeter, 1942; Cohen and Klepper 1992; and Klette and Kortum, 2004) that larger firms are more likely to invest in innovation, innovation investment intensity - measured as the ratio of total innovation expenditure per employee - is already scaled and therefore less likely to be correlated to size.⁸ Moreover, we believe that the obstacles to innovation that firms may encounter would condition their decisions about whether or not to innovate, but not about how much to invest in innovation.

⁵ Between 1 and 12. Firms were given the possibility to tick all 12 boxes related to the specific type of cooperation considered. In turn, each type of collaboration, i.e. within own firm, with suppliers, and with clients, was subdivided into 4 regions, depending upon the geographic level of the collaboration: national, within Europe, with the USA, with the rest of the world.

⁶ “COOP_out_private” and “COOP_out_public” values range between 0 and 18, as they are based on two questions each and are related to four regions, as in the case of “COOP_own_chain”.

⁷ If none of these boxes were ticked, the variable takes zero value.

⁸ Griffith et al. (2006) find that size is insignificant when included in the investment intensity equation.

Finally, from this first step we estimated the inverse Mills ratio, to be used as an additional regressor in the second and third steps of the model, to control for selectivity. Also, we predict innovation expenditure.

In the second step of the model, we estimate a knowledge production function where the dependent variable, log innovative sales per employee, depends on: the intensity of investment in innovation (“LISPE”); firm size; whether or not the firm is part of a group; a dummy accounting for whether or not the firm has carried out process innovation (“PROCESS”); the cooperation variables, as described above; the industry dummies, and dummies for the obstacles to innovation-related regressors. Since we estimate the model for innovative firms only, we include the Mills ratio estimated in the first stage to correct for selectivity. We also present the results where, in addition to selectivity, we control for potential endogeneity of innovation expenditure in the knowledge production function. Endogeneity might arise because of unobserved heterogeneity or because of omitted variables, i.e. factors that we do not control for but that can influence firms’ innovation output and are likely to affect innovation inputs (e.g. positive temporary shocks; unobserved managerial ability, etc.). Endogeneity might also arise because of “simultaneity”, as the innovation surveys ask for innovation inputs and outputs related to the same years. The way we chose to proceed is to use predicted rather than actual innovation expenditure in the knowledge production function. The identification restriction here is that public financial support only affects innovation outcome through increased innovation investment and, similarly, that – once we condition for the cooperation activity of the firm – serving foreign markets only affects innovation output through increased innovation expenditure.⁹ Formally, the innovation outcome equation can be written as:

$$Innov_output = X'_3 \mathbf{g} + v_i$$

Innov_output is measured as log innovative sales per employee and the vector of covariates X'_3 contains the variables mentioned above, plus the actual log innovation expenditure per employee (“LRTOTPE”). When correcting for potential endogeneity, we use predicted values. In the third and last stage of the model we estimate the innovation output productivity link using an augmented Cobb-Douglas production function.

$$\ln(\text{sales per employee}) = X'_4 \mathbf{p} + v_i$$

The dependent variable is log sales per employee (“LLPPE”). The right hand side variables include: firm size; the group dummy, the innovation process dummy; the Mills ratio to correct for selectivity; and log innovative sales per employee. The output production function is estimated using Instrumental Variables 2-Stage Least Squares (IV 2SLS), to account for the potential endogeneity of log innovative sales per employee.

Since in the last two stages of the model we use predicted values (Mills ratio and predicted innovation input), we need to correct for standard errors and account for this feature in the model. We do so by bootstrapping standard errors in the innovation and the output production functions.¹⁰

⁹ The latter is a very strong assumption since we are not allowing international technology transfer to have any other potential roles than those resulting from formal cooperation agreements.

¹⁰ Note that bootstrapping takes account of both selectivity and endogeneity, but is not derived from the statistical properties of our model. An alternative way of correcting for standard errors is proposed by Lewbel (2005). Conversely, CDM estimated errors are corrected for selectivity and endogeneity since they are estimated using ALS.

4 - Estimates and results

Here, we estimate the model described above, separately for the Finnish CIS3 and CIS4 data. The aim is to verify the link between R&D, innovation output and productivity, and also to see how results differ within the same country, depending upon how the samples have been built. Before presenting the estimates and discussing the results, we provide two more tables (Tables 6 and 7) showing the means and standard deviations of the variables used in the model for CIS3 and CIS4, and for the sample of firms common to both. These figures are meant to make some of the features discussed in section 2.1 numerically explicit, and will help the interpretation and discussion of the estimates shown in Table 8.

Table 6: Mean values and standard deviations of CIS3 and CIS4 variables

Variable	CIS3 μ	CIS3 σ	CIS4 μ	CIS4 σ	$\frac{(CIS3 \mu - CIS4 \mu) * 100}{CIS3 \mu}$
COOP	0.34	0.47	0.27	0.45	-19.57
COOP_inside	1.15	2.23	1.13	2.21	-1.52
COOP_intern	0.04	0.10	0.04	0.11	8.68
COOP_outpri	0.56	1.31	0.61	1.23	7.81
COOP_outpub	0.48	1.02	0.49	1.00	1.45
FINSUP	0.31	0.46	0.22	0.41	-31.34
GROUP	0.51	0.50	0.55	0.50	7.55
HACOST	0.29	0.29	0.29	0.29	-1.16
HAKNOW	0.29	0.27	0.32	0.26	9.64
HAMARKET	0.24	0.24	0.33	0.26	38.31
HATOT	0.27	0.24	0.31	0.24	14.15
LEMP	4.04	1.37	4.09	1.28	1.22
LISPE	2.95	1.33	2.81	1.56	-4.62
LLPPE	4.80	0.96	5.06	0.93	5.47
LRTOTPE	1.15	1.58	1.02	1.58	-11.66

Source: Authors' calculations using Statistics Finland data

Table 7: Mean values and standard deviations of CIS3 & CIS4 common sample variables

Variable	CIS3 μ	CIS3 σ	CIS4 μ	CIS4 σ	$\frac{(CIS3 \mu - CIS4 \mu) * 100}{CIS3 \mu}$
COOP	0.41	0.49	0.37	0.48	-8.51
COOP_inside	1.54	2.54	1.75	2.74	13.63
COOP_intern	0.05	0.12	0.06	0.12	21.26
COOP_outpri	0.74	1.53	0.89	1.46	21.36
COOP_outpub	0.61	1.14	0.76	1.25	23.15
FINSUP	0.39	0.49	0.31	0.46	-20.54
GROUP	0.62	0.49	0.66	0.47	7.77
HACOST	0.28	0.28	0.32	0.28	13.23
HAKNOW	0.30	0.26	0.36	0.25	21.25
HAMARKET	0.23	0.23	0.39	0.25	66.67
HATOT	0.27	0.22	0.35	0.22	31.48
LEMP	4.69	1.29	4.69	1.33	-0.05
LISPE	2.97	1.30	2.96	1.44	-0.45
LLPPE	4.91	0.88	5.11	0.82	4.00
LRTOTPE	1.13	1.51	1.00	1.52	-11.55

Source: Authors' calculations using Statistics Finland data

Table 6 shows substantial changes between the values of the CIS3 and CIS4 variables related to: overall cooperation (COOP), financial support (FINSUP), total obstacles encountered (HATOT), market obstacles (HAMARKET), and R&D expenditures (LRTOTPE). In particular, the differences for HAMARKET's and FINSUP are higher than 30%, compared to the differences among the other variables, which range between 10% and 20%.

Table 8 presents the estimates of our model for the CIS3 and CIS4 samples.

With respect to the Heckman selection equation, i.e. the equation modelling the decision about whether or not to invest in innovation, we see that being present in foreign markets and being bigger in terms of number of employees correlates significantly and positively with investment in innovation. The hampering factors firms may encounter when deciding to innovate also positively and generally significantly correlate with the decision to innovate. This result is somewhat counter-intuitive, as one would expect the obstacle-related variables to be significant, but to exhibit negative coefficients. However, we believe these results might be mirroring a sort of "ex-post rationalisation" by the innovators. In other words, it might be that those firms putting effort into and managing to solve the innovation-related problems encountered might also be those that documented the existence of these problems, thus making the coefficients significant and positive.

From the innovation input equation – modelling the decision related to the size of the R&D investment - it emerges clearly that there is a significant and positive correlation between the intensive margin of the R&D investment and the fact that firms cooperate (COOP) and obtain financial support (FINSUP). Conversely, the non significance of the GROUP-related coefficients in the Heckman part of the model does not allow us to say anything about whether and to what extent being part of a group may affect the R&D investment decision, at either the extensive or intensive margins. Conversely, belonging to a group is significantly and positively correlated to both innovation outcome and productivity. This is true regardless of the CIS sample considered. Moreover, the GP coefficients are extremely similar in size, varying between .204 and .262.

Table 8: CIS3 and CIS4 model estimates

COEFFICIENT	CIS3								CIS4							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Heckman Outcome	Heckman Selection	Producti. (LLPPE)	Inno outcome (LISPE)	ivLLPPE_hat	LISPE_hat	bstrap_llppe	bstrap_lispe	Heckman Outcome	Heckman Selection	Producti. (LLPPE)	Inno outcome (LISPE)	ivLLPPE_hat	LISPE_hat	bstrap_llppe	bstrap_lispe
GROUP	-0.120 (0.12)	0.00375 (0.080)	0.204*** (0.063)	0.224** (0.11)	0.240*** (0.063)	0.230** (0.12)	0.240*** (0.059)	0.230 (0.17)	0.184 (0.13)	0.0948 (0.070)	0.246*** (0.065)	0.223 (0.14)	0.237*** (0.073)	0.262* (0.15)	0.237*** (0.076)	0.262 (0.17)
FOR_MKT	0.474*** (0.13)	0.260*** (0.083)							0.176 (0.21)	0.494*** (0.086)						
COOP	0.493*** (0.12)								0.481*** (0.12)							
FINSUP	0.703*** (0.12)								0.457*** (0.12)							
Sector dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
LEMP		0.227*** (0.030)	0.0884*** (0.030)	-0.351*** (0.10)	0.0732** (0.030)	-0.515*** (0.12)	0.0732** (0.036)	-0.515*** (0.13)		0.247*** (0.028)	0.0962*** (0.029)	-0.284*** (0.10)	0.0996*** (0.031)	-0.328*** (0.10)	0.0996*** (0.033)	-0.328*** (0.11)
HACOST		0.283* (0.16)		-0.341 (0.23)		-0.487** (0.24)		-0.487 (0.36)		0.0834 (0.13)		-0.426* (0.23)		-0.381 (0.24)		-0.381 (0.26)
HAKNOW		0.846*** (0.19)		-0.880** (0.43)		-1.093** (0.50)		-1.093* (0.63)		0.514*** (0.17)		-0.0574 (0.35)		-0.0439 (0.36)		-0.0439 (0.39)
HAMARKET		0.114 (0.21)		-0.644** (0.30)		-0.664** (0.31)		-0.664 (0.45)		0.687*** (0.17)		-0.781** (0.37)		-0.780** (0.38)		-0.780* (0.47)
LISPE			0.433*** (0.066)		0.339*** (0.094)		0.339*** (0.089)				0.329*** (0.072)		0.355*** (0.11)		0.355** (0.15)	
PROCESS			-0.105* (0.059)	0.332*** (0.099)	-0.0600 (0.061)	0.362*** (0.10)	-0.0600 (0.067)	0.362*** (0.11)			-0.0688 (0.057)	0.274** (0.12)	-0.0780 (0.068)	0.304** (0.13)	-0.0780 (0.085)	0.304** (0.13)
MILLSstrict			0.160 (0.14)	-2.095*** (0.65)	0.105 (0.14)	-2.627*** (0.83)	0.105 (0.15)	-2.627*** (0.96)			0.201 (0.12)	-1.129** (0.56)	0.208 (0.13)	-1.144** (0.57)	0.208 (0.14)	-1.144* (0.60)
COOP_inside				0.0327 (0.027)		0.0576** (0.029)		0.0576** (0.027)				-0.0322 (0.037)		-0.0242 (0.038)		-0.0242 (0.041)
COOP_outpri				0.0425 (0.038)		0.0581 (0.038)		0.0581 (0.038)				0.101 (0.064)		0.0976 (0.064)		0.0976 (0.062)
COOP_outpub				0.0339 (0.049)		0.109** (0.054)		0.109* (0.058)				-0.0186 (0.078)		-0.00184 (0.084)		-0.00184 (0.089)
COOP_intern				-0.500 (0.49)		-0.358 (0.49)		-0.358 (0.52)				0.872 (0.64)		1.351** (0.62)		1.351* (0.69)
LRTOTPE strict_hat						-0.0555 (0.13)		-0.0555 (0.15)						-0.0151 (0.23)		-0.0151 (0.30)
Constant	-0.354 (0.31)	-1.639*** (0.19)	3.336*** (0.35)	6.381*** (1.23)	3.684*** (0.40)	7.873*** (1.54)	3.684*** (0.41)	7.873*** (1.72)	-0.243 (0.34)	-1.786*** (0.18)	3.634*** (0.30)	4.708*** (1.02)	3.556*** (0.39)	4.926*** (1.04)	3.556*** (0.44)	4.926*** (1.16)
LRTOTPE				0.261*** (0.036)								0.198*** (0.043)				
Observations	1546	1546	688	688	688	688	1617	1617	2156	2156	699	699	699	699	2258	2258
R-squared	.	.	0.42	0.27	0.45	0.20	0.45	0.20	.	.	0.36	0.14	0.34	0.11	0.34	0.11
P-value LR test	0.00215								0.0680							

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

As for the other variables entering the innovation output equation, we see that the obstacles to innovation generally (and significantly) impinge upon firms' innovative output. In the CIS3 case, the hindering factor that seems to most severely disrupt innovative output is the lack of the necessary knowledge, with HAKNOW coefficients in the range -0.880 to -1.093.

Conversely, CIS4 innovators rate market-related difficulties to be the most severe hampering factor to innovation, with a HAMARKET value of -0.780. Another regressor entering the innovation output equation that always turns out to be significant, and negative, is the regressor for selection, i.e. the regressor related to the Inverse Mills ratio. MILLSstrict CIS3 values are generally more than double those in CIS4, suggesting that selectivity is a much more important problem in CIS3 than in CIS4 (although in both cases selectivity is an issue). While this result might be expected given the difference in the CIS3 and CIS4 sampling procedures discussed in section 2.1, its robustness increases our concern about the way the samples were constructed.

Another feature common to both CIS3 and CIS4 estimates, is the positive and always significant value of the variable for process innovations in the innovation output equation. Hence, process innovations positively correlate to innovative sales, indirectly suggesting the likely complementarity between process and product innovations. Results for the way that different types of cooperation affect innovative sales are not clear-cut. In the case of CIS3, the estimates seem to suggest that cooperating within the firm, and with public institutions, may have a positive effect, whereas CIS4 estimates point to the positive role of cooperating at the international level. Taken together, the coefficients of the obstacles-related variables and the cooperation-linked regressors seem to suggest the following. In CIS3, firms perceive the lack of the necessary knowledge to be most important factor hindering innovation. Collaborating with universities and research centres seems to ease this lack of knowledge constraint, thus positively affecting innovative output. For CIS4 firms, the most difficult problems seem to be related to the markets targeted, especially international ones - and we know that the percentage of firms active in international markets jumped from 27.8% in CIS3 to 56.3 in CIS4. Collaborating at the international level, therefore, may help firms to address and possibly solve such problems, since we see that international collaborations significantly and positively relate to innovative output.

With respect to how R&D investments affect innovative output, we see that both CIS3 and CIS4 estimates show significant and positive values of the R&D investment coefficient. However, when using predicted values, the R&D coefficient is no longer significant. Hence, further investigation is needed to check the robustness of our estimates to endogeneity and to the use of predicted values.

Finally, concerning firm size, we see that being bigger is negatively correlated with innovation sales, but positively correlated with productivity. In particular, the LEMP coefficients vary between -0.284 and -0.515 in the innovation output equation, while the LEMP values in the productivity equation range between 0.0732 and 0.0996.

The last equation in our model, i.e. the productivity equation, suggests that firm size, belonging to a group and innovative sales are all positively correlated to productivity. The coefficient of the variable accounting for process innovation, on the other hand, has a negative sign, but since it is basically never significant we cannot say that, in our model, process innovations affect productivity.

5 - Conclusions and policy implications

The model we propose, similar to its predecessors in the economics literature, depicts the link from R&D investment to productivity as a relationship consisting of three steps. The first step encompasses firms' decisions about whether and how much to invest in R&D. The second step formalises the link between the investment in R&D and the innovative output that can be

obtained. The third step mirrors the relationship between innovative output and productivity. One important result from this model is that it captures the different characteristics of the CIS3 and CIS4 samples extremely well. In fact, both the signs and sizes of the coefficients generally behave according to expectations and the estimates mirror the data features emerging from the descriptive statistics.

The estimates show that receiving financial support and having (relatively more intense) collaborations are strongly and significantly correlated with a higher probability of engaging in R&D activities. The amount invested in R&D is positively related to the size of the firm (in terms of number of employees) and to the intensity of the obstacles faced.

For innovative output, we see that investing in R&D is positively related to higher sales from innovative goods. Another element that emerges is the positive relationship between product and process innovations: process innovation seems to be complement product innovation and is positively correlated to higher innovative sales. Conversely, we see that innovative output is significantly and negatively affected by the problems firms may have encountered while innovating. Both innovative output and productivity are shown to be positively related to belonging to a group, and to firm size. Finally, and very importantly, innovative sales are positively correlated to productivity.

Our analysis supports the hypothesis of a positive link between investing in R&D, innovation output and productivity, and has several interesting policy implications. Firstly, we observe a positive correlation between the fact that firms collaborate and the size of their investments in R&D. Secondly, we see that obtaining subsidies indeed eases firms' budget constraint and increases the likelihood that firms will invest in R&D. Nevertheless, firms still do encounter problems in their innovative activities, and these are negatively correlated to sales from innovative products. This latter result, coupled with the evidence that belonging to a group correlates positively with both innovative sales and productivity, seems to suggest that innovating is difficult for firms, because of the cost, knowledge and market problems involved. This seems to be especially true for individual firms, i.e. firms that do not belong to a group. Hence, purposeful, well-formulated policies could ease the hampering factors firms encounter by supporting their innovation activities from invention to the marketing of innovation. Policy support should not stop once an innovation output is obtained; it needs to continue to enable firms to transform innovative output into market success.

Thirdly, our results suggest that product and process innovations are complementary. This somewhat questions those policy programmes in which subsidies go preferably to those firms whose innovative activities are expected to result in a product innovation (normally protected by a patent).

Finally, and with respect to the way that innovation data are gathered, there is a need to move from CIS harmonisation to homogenisation of the way the samples are constructed and data collected. This is especially true if the aim is to carry out cross-country comparisons, as sample composition affects representativeness and comparability. In addition, simultaneity problems – based on innovation input and output data referring to the same year – need to be solved in order to better capture innovation dynamics. This can be done by collecting panel data, i.e. by observing firms' innovative behaviours over several years.

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