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TECHNOLOGICAL INNOVATION AND PRODUCTIVITY IN LATE-TRANSITION ESTONIA: ECONOMETRIC EVIDENCE FROM INNOVATION SURVEYS

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Technological Innovation and Productivity in Late-Transition Estonia: Econometric Evidence from Innovation Surveys

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Abstract

There is growing interest in modelling the relationship between innovation and productivity in developing and transition economies due to their attempts to establish knowledge-based economies and to increase business R&D. Our paper investigates whether there is a significant relationship between technological innovation and productivity in the manufacturing sector of Estonia. We use firm-level data for the analysis from two waves of Community Innovation Surveys (CIS3 and CIS4) from 1998–2000 and 2002–2004, which is then combined with financial data about firms from the Estonian Business Register in order to study the effect of innovation at higher

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leads. We apply a structural model that involves a system of equations on innovation expenditure, innovation outcome and productivity. Our results show that during 1998–2000 only product innovation increased productivity, while in 2002–2004 only process innovation had a positive effect on productivity. This can probably be explained by the different macroeconomic conditions in the two periods.

JEL Classification: O31, O33, C31, O10

Keywords: productivity; innovation; Estonia.

1. INTRODUCTION

In highly developed countries, economic growth relies to a significant extent on technological innovation. As developing and transition countries are further behind the technology frontier, their sources of economic growth have naturally been somewhat different. For example, the initial growth during the transition period in Central and Eastern European (hereinafter CEE) countries was based on initial capital accumulation and imitation of technologies applied elsewhere. In order to sustain these growth rates in the future and to catch up with the standard of living in Western Europe, these countries will need to rely increasingly on their own innovation as an engine for growth. Productivity, measured as the ratio of output to input (e.g. the sales or value added per worker), is the crucial variable determining the ability of a country to improve its standard of living (Krugman 1990). In order to catch up with high-income countries the currently comparatively low-labour productivity in the CEE (compared to the EU average) has to increase substantially[1].

The reasons for the lower productivity in CEE countries include, among others, lower levels of technology, less developed institutional framework, lower quality of organisational and management expertise and patterns of specialisation in the international division of labour – that is, the less favourable industrial structure of the economy (see e.g. Stephan 2002). It has been argued that following Michael Porter's division of economies into factor condition based, investment driven and innovation driven stages (Porter 1998), CEE countries have been in the "investment-driven" stage (e.g. Kurik, Lumiste, Terk and Heinlo 2002). Thus, their competitive advantage has been the cheap production input (mainly labour), and the development of enterprises is largely based on investments in the tangible (finances and equipment) and intangible (skills, knowledge, experience) capital.

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[1] According to Eurostat, in 2005, the unweighted average of labour productivity per person employed in purchasing power standards in the 10 new Central and Eastern European EU member states was 59% of the EU27 level.

Currently, the new EU member states are losing their traditional sources of international competitiveness, such as low labour costs (caused *inter alia* by their integration into the European Union). Also, policy-makers in CEE countries are increasingly emphasizing the importance of building knowledge-based economies. It is emphasized in national policy documents that business expenditure on R&D, which is currently at relatively low levels,[2] should especially increase. Thus, it is important to analyze whether in transition and post-transition countries innovation expenditure is being transformed into a knowledge output and the latter into growth and productivity.

There are a number of studies on the relationship between innovation and firm-level productivity in highly developed countries, starting with the classic paper by Crépon, Duguet and Mairesse (1998) (hereinafter we refer to their approach as CDM model). In their paper, they used a structural model where R&D expenditure, innovation output and productivity are modelled in a sequential manner. In the first step, the firm's decision to innovate and the size of the subsequent investment in innovative activities are modelled. In the second step, knowledge inputs such as the size of expenditures on R&D are assumed to generate an innovation output – patents, product or process innovations and sales from new products. This step in the model is the knowledge production function. Finally, the 3rd step is an output production function where an innovation output is supposed to impact on the firm's productivity. In short, the idea is to model not just the link between R&D expenditure and productivity, but the whole innovation process. Several such studies have been carried out for developed countries by Griffith, Huergo, Mairesse and Peters (2006), Lööf,

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[2] The share of business expenditure on research and development in Estonia was 36.5% in year 2004 36.5% in Estonia. The share of business R&D in the old EU member states (EU15) was 55% of total R&D expenditures. Also, total R&D expenditure as a percentage of GDP was much lower in Estonia than in EU15 (respectively 0.9% and 1.9%). According to the strategy document "Eesti edu 2014" (The Success of Estonia 2014), the investments in R&D should increase to 3% of GDP, of which at least 50% constitute investments made by the private sector (Riigikantselei 2004).

Heshmati, Asplund and Nas (2003), Janz, Lööf and Peters (2004), to mention just a few. These have mostly confirmed the presence of the assumed links of the CDM model – that innovation expenditure affects innovation output and the latter affects productivity. These studies have been based on data from innovation surveys, like the Community Innovation Survey (hereafter CIS) organized in all European Union member states.

There are also studies on developing countries, mostly on Latin-American countries. Benavente (2006) uses the CDM model to study innovation and firm performance in Chile. Raffo, Lhuillery and Miotti (2007) compared innovation and productivity links among European (France, Spain, Switzerland) and Latin-American (Argentina, Brazil, Mexico) countries. However, there are few studies on transition countries. Roud (2007) used the CDM model for Russia. His results were consistent with the findings of studies on Western European countries. Innovative activities in firms in Russia were constrained by a lack of finances and somewhat by a lack of human resources. They were promoted by state support and, in fact, were mostly technology purchases instead of internal R&D. Another study, by Stoevsky (2005) found that the CDM model was valid for Bulgaria as the theoretically postulated links were present. Innovation output was found to increase with innovation inputs, and business performance was dependent on innovation output. Surprisingly, the probability of engaging in innovation activities was independent of firm size. Vahter (2006) analyzed the Estonian CIS3 data without a CDM model, but by regressing total factor productivity on various variables (such as firm size, Herfindahl index, industry and location dummies). He found that there was a statistically significant productivity premium for firms with product or process innovation in the year 2000. He also found the low persistence in R&D activities in firms. This finding suggests that instead of R&D expenditures it may be more appropriate to study the effects of total investment on innovative activities.

In this paper we use the model by Crépon et al. (1998) for the study of links between innovation inputs, innovation outputs and productivity in Estonia, a small economy in Central and Eastern Europe, during the late transition (or post-transition) period, years 1998–2000 and 2002–2004. We contribute to the literature from different angles. First, while the studies usually use only one wave of the innovation survey (e.g. many studies have used only CIS3), we use two waves – CIS 3 and 4. This enables us, for example, to study the impact of changing macroeconomic conditions on the links in the CDM model. The first period, 1998–2000, was characterized by a recession caused by the Russian crisis that caused GDP growth to drop from 11% in 1997 to 4% in 1998 and to 0.3% in 1999. The loss of the Russian export market forced many manufacturing enterprises to restructure and enter new markets. This reorientation was relatively successful (Eamets, Varblane and Sõstra 2003) and it required changes in the firms' products and production. The second period was characterized by strong economic growth (annual average 7.7%). Descriptive evidence suggests that, while the number of firms with innovation increased greatly between the 2 periods, the returns of innovation in terms of sales growth or productivity decreased considerably (Terk et al. 2007). This could mean that during the periods of strong macroeconomic growth firms could increase productivity without innovation because of growing market demand and exploitation of economies of scale.

The second contribution is due to the fact that we combine the innovation survey data with the Estonian Business Register's firm level financial data for all firms for 1995–2005. This allows us to compare the relationship between innovation and productivity at different leads of the latter variable. This is important as the lack of a relationship between innovation and productivity in some studies is explained by, among other explanations, the assumption that there are no lags between the implementation of innovation and the impact on productivity. Although some earlier studies have also matched innovation data with other firm-level statistics (like Stoevsky 2005), the advantage of our study is that the matching was successful for nearly all of the firms and the financial data is rather rich (about 150 items from balance sheets and profit and loss statements). In principle, the impact of innovation on productivity may vary over time. On one hand, the effect of innovation may grow if it takes time before the benefits of innovation materialize. On the other hand, the effect may diminish over time if the firm's competitors undertake the same innovations.

The rest of the paper is structured as follows. Section 2 provides an overview of the econometric model that we use. Section 3 includes a description of the data we are using, and provides a short summary of the main characteristics of innovative firms in Estonia and undertakes preliminary data analysis about the links between innovation and productivity. Section 4 presents the results of the econometric analysis and the last section concludes with some policy implications and suggestions for further research.

2. ECONOMETRIC MODEL

Our empirical analysis relies on an adapted version of the commonly used structural model developed by Crépon et al. (1998) (CDM hereafter). The CDM model explains the productivity of firms in terms of knowledge or innovation output, and innovation output itself in terms of investment in R&D. The standard presentation of the CDM model includes two equations related to R&D, one innovation output equation (knowledge production function) and one equation defining the production function. Different studies have chosen different econometric models and explanatory variables. Here we mostly follow Griffith et al. (2006), but the set of explanatory variables is somewhat different and we also make some other small amendments to the model.

The model that we use can be written down as follows. Let us use $i = 1, \dots, N$ to index firms. Equation (1) models the firm's latent (unobserved) propensity to innovate, g_i^*:

(1) $g_i^* = \beta_0 x_{0i} + \varepsilon_{0i}$.

Here, x_{oi} is a vector of variables that determine this innovation effort, β_0 is the associated coefficient vector, and ε_{0i} an error term. Let us use g_i to denote the observed indicator variable that equals 1 for R&D reporting firms and 0 for firms not reporting R&D. A firm invests in R&D (or generally knowledge producing activities, i.e. $g_i = 1$) if $g_i^* > c$, where c is some constant threshold level. Correspondingly, if $g_i^* \le c$, then $g_i = 0$. The term g_i^* represents some decision criterion about whether to engage in innovative activities; for example, the expected return on investment in research and development (Crépon et al. 2006).

If a firm engages in innovative activities (i.e. if $g_i^* > c$), we can observe the current R&D expenditure (or total innovation expenditure[3]) of firm *i*, denoted as r_i. The variable r_i^* denotes the latent intensity of research for firm *i*. The two variables, r_i and r_i^* are related in the 2nd equation of our model as follows:

$$(2)\ r_i = \begin{cases} r_i^* = \beta_1 x_{1i} + \varepsilon_{1i} & if \quad g_i = 1 \\ 0 \quad if \quad g_i = 0 \end{cases}.$$

In equation (2) x_{1i} is a vector of explanatory variables and ε_{1i} an error term. Note that the error terms in (1) and (2) are assumed to have joint normal distribution, with a zero mean:

$$(3)\ \begin{pmatrix} \varepsilon_{0i} \\ \varepsilon_{1i} \end{pmatrix} \xrightarrow{iid} N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_0^2 & \rho\sigma_0\sigma_1 \\ \rho\sigma_0\sigma_1 & \sigma_1^2 \end{pmatrix} \right),$$

where σ_0 and σ_1 are standard errors of ε_{0i} and ε_{1i} respectively and ρ is their correlation coefficient. In order to estimate the model, the standard error σ_0 is normalized to 1. We have used the generalized Tobit model to estimate equations (1) and (2). Equation (2) looks at the size or intensity of the R&D activities (e.g. the amount of R&D expenditure per employee). Instead of R&D expenditure (as used by several other papers) we use total expenditure on innovative activities. The reason for that is the relatively small number of Estonian companies undertaking R&D

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[3] In CIS surveys, the total expenditure on innovation activities consists of in-house R&D, R&D ordered outside, acquisition of machinery, equipment and software and acquisition of other external knowledge.

activities (see also the next section). This variable has also been used instead of R&D expenditure by a few earlier studies (Chudnovsky, Lopez and Pupato 2006; Stoevsky 2005).

We define the vectors x_{0i} and x_{1i} of the explanatory variables as $x_{0i} = (l_i, f_i, p_i, m_i, I_i)$ and $x_{1i} = (f_i, p_i, m_i, c_i, j_i, o_i, I_i)$, where l_i is firm size (log of number of employees), f_i is a vector of dummy variables denoting different sources of public funding, p_i is a dummy variable denoting usage of formal protection (like trademarks, copyright, etc); m_i is a dummy variable denoting exposure to international competition (it takes value 1 if the firm's main market is international); c_i is a vector of dummy variables denoting different ways of innovation co-operation; j_i is a vector of dummy variables denoting sources of innovation related information for the firm. Finally, o_i is a vector of dummy variables denoting different obstacles to innovation and I_i is the set of industry dummies. These explanatory variables have been used in earlier studies applying the CDM model (Griffith et al. 2006; Lööf et al. 2003). The precise definitions of the variables can also be found in Appendix 1.

Equation (4) is the knowledge or innovation production function relating (potentially unobserved) knowledge (innovation output) to the innovation input and other variables:

(4) $t_i = \alpha_K r_i^* + \beta_2 x_{2i} + \varepsilon_{2i}$.

Here, variable t_i is the innovation output or knowledge proxied both by the product and process innovation indicators (dummy variables), x_{2i} is a vector of explanatory variables, ε_{2i} an error term, which is assumed to be normally distributed with a zero mean and variance σ_2^2, and is also assumed to be independent of error terms ε_{0i} and ε_{1i}. The vector $x_{2i} = (l_i, I_i, p_i, f_i, p_i, j_i)$ includes firm size variable l_i, industry dummies I_i, protection variable p_i, dummy variables for different sources of public funding f_i and a vector of dummy variables for different sources of information j_i.

As it can be seen, the latent innovation effort, r_i^*, enters the knowledge production function as an explanatory variable. It is instrumented; in other words, its predicted value from the 1st step of the equation (generalized Tobit model) is used in order to account for both the selectivity and endogeneity of r_i^* in equation (4). The endogeneity comes from the fact that unobservable firm characteristics may increase both the firm's innovation effort and its ability to come up with technological innovation (Griffith et al. 2006).

While the original CDM model used patents or the share of sales of new products in total sales as the knowledge output variable, later studies have used the process and product innovation dummies (Griffith et al. 2006), or alternatively the sale of new products per employee (Lööf et al. 2003). The rationale for using these proxies of innovation output instead of patents is that patents are only a partial measure of innovation. Innovation output, especially in transition economies, can to a large extent be in other forms than patents; also the patenting activity is rather modest in transition countries[4]. Especially for small firms, acquiring patents, notably international ones, could be too costly. Thus, we use process and product innovation dummies as proxies for innovation output.

It is clear that these two decisions, to have product innovation and process innovation, are correlated and there is no natural sequencing about which is first. To account for the fact that the use of process and product innovation by a firm is highly interdependent, we estimated equation (4) as a bivariate probit model, the dependent variables being respectively the dummy variables for product innovation (P_i) and

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[4] According to CIS4, only 3.2 per cent of Estonian firms had applied for patents. The corresponding average figure from the CIS3 for the EU15 was 9 per cent (Terk et al. 2007).

process innovation (Q_i). Note that, in the bivariate probit model, the distribution of the disturbance terms is assumed bivariate normal. In order to test the robustness of the results and to compare these with the ones from the previous studies, the equation (4) was also estimated as two univariate probit models.

The last equation in the model is the output production function (productivity equation) assuming Cobb-Douglas technology, where in addition to labour and capital, knowledge inputs are also included (Crépon et al. 1998; Lööf et al. 2003). The novelty of the model introduced by Crépon et al. (1998) is that it is the innovation output (technological innovation or sales due to innovation) rather than input (like R&D expenditure) that influence productivity. Thus the output production function can be written down as

(5) $q_i = \alpha_T t_i + \beta_3 x_{3i} + \varepsilon_{3i}$,

where variable q_i stands for the log of productivity (sales per employee or value added per employee), x_{3i} is a vector of standard control variables in the productivity analysis, ε_{3i} is an error term, which is assumed to be normally distributed with a zero mean and a variance of σ_3^2. The vector of inputs, x_{3i}, is defined as $x_{3i} = (k_i, l_i, P_i, Q_i, X_i)$, where k_i is the log of physical capital per employee ($k_i = \log K_i$), $\hat{P}_i$ and $\hat{Q}_i$ are the predicted values respectively for the product and process innovation dummies from step 2, X_i is a dummy variable showing whether the firm is an exporter or not. The latter variable, as well as the size variable, is lagged two periods in order to account for its very likely endogeneity (more productive firms are more likely to export). Note that although the dependent variable is labour productivity, since the list of control variables also includes capital-labour ratio (capital intensity), we are in fact estimating the effects of innovation on total factor productivity, not on labour productivity. In many applications of the CDM model constant returns to scale is assumed, but as we have included the firm size variable in vector x_{3i}, we may have also increasing or decreasing returns to scale.

The whole model can be summarized as follows. In the 1st step, the two equations model the two-step innovation decision procedure. The first equation represents the firms' decisions whether to exercise innovation efforts, the equation 2 models the size of the effort. The two equations are modelled as generalized Tobit model. In the 2nd step, two probit models are estimated for product and process innovations including, from the 1st step, the predicted values of the innovation effort variable as one of the explanatory variables. Alternatively, we estimate also a bivariate probit model for product and process innovations. The last equation in the model is the output production function (productivity equation), where innovation output is now used as one of the inputs (Crépon et al. 1998, Lööf et al. 2003). The productivity equation is estimated using the predicted values from the 2nd step probit models to proxy explanatory variable t^* that accounts for the endogeneity of the innovation output variables.

3. DESCRIPTIVE STATISTICS AND PRELIMINARY DATA ANALYSIS

Similar studies have so far mostly used CIS2 and CIS3 data and have usually been based on developed countries, but more recently several studies on developing and transition countries have also been made. Here we study Estonian data from CIS3 (covering 1998–2000) and CIS4 (2002–2004). CIS3 data includes 3,161 firms and CIS4, 1,747 firms. In our analysis we concentrate on manufacturing enterprises, and in the two surveys there are respectively 1,467 and 992 manufacturing enterprises. The surveys were conducted by the Statistical Office of Estonia. The response rates in the surveys were rather high, 74% in CIS3 and 78% in CIS4, while the EU average has remained 55% (Terk et al. 2007). There are almost 1,100 firms that are represented in both surveys. One of the advantages of our study is the fact that we combine the innovation survey with the firms' financial data. The CIS data was combined with the Estonian Business Register's firm level data[5].

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[5] In our case merging the innovation survey with financial data was relatively straightforward; however, it is not so in all countries, because the unit of observation may differ, e.g. that may be plant, firm or concern.

That database includes the financial information for all Estonian firms for the period 1995 to 2005. The Estonian Business Register's database includes financial reports (balance sheets and income statements) for all firms. The information is rather detailed as the total number of different items in annual reports is about 158 and includes for example information on the number of employees, sales, valued added, intermediate inputs etc. Thus, we can calculate a relatively long time series of various productivity variables.

The descriptive statistics of the variables used either in regression or descriptive analysis can be found in Appendix 1. The main findings from CIS3 in Estonia have been covered by Kurik et al. (2002), the main findings from CIS4 by Terk et al. (2007). Summarizing the results briefly, the main characteristics of the innovative activities of Estonian enterprises are as follows. The proportion of firms with innovative activities was 36% during 1998–2000 (CIS3) and 49% during 2002–2004 (CIS4). The EU average from CIS3 was 44 per cent (Terk et al. 2007). Firms that are larger, have foreign ownership or belong to a larger corporate group, have more innovative activities than the rest (Ibid. 2007). Whereas in CIS3 manufacturing sector firms reported more innovative activities than those in the services sector, in CIS4 the situation was the other way around. Another peculiarity of Estonia and other CEECs has been the much larger share of spending on machinery and equipment in total innovation expenditures of innovating firms if compared to the ‘old members’ of the EU. At the same time, the share of intramural R&D expenditure is still significantly lower (Terk et al. 2007). Innovation cooperation with enterprises within the value chain is frequent, however, cooperation with universities is rare – almost three times lower than on average in the old EU member states.

Next we move onto the preliminary data analysis about links between innovativeness and productivity. The following table (Table 1), shows the unconditional means of labour productivity, the capital-to-labour ratio, total factor productivity using various innovation indicators (e.g. process innovators, product innovators, firms with R&D expenditure etc.)[6]. As we can see, both measures of labour productivity (sales and value added per employee) on average have higher values in the case of innovators compared to non-innovators, and that holds across various measures of innovativeness and kinds of innovations. Process innovators have slightly higher labour productivity than product innovators. Capital intensity is also higher in the case of innovators. One possibility is that as investing in new machinery and equipment is a rather common type of innovation in Estonia, firms reporting innovation are likely to also have higher capital intensity[7].

Labour productivity for the group of firms with both product and process innovation is quite close to labour productivity for firms with only one type of innovation. Total factor productivity (TFP), calculated using the Levinsohn-Petrin (2003) procedure to account for the endogeneity of inputs[8], is larger among innovators for all of the innovation indicators we have used in case of CIS3. This premium is also more pronounced in the case of TFP than in the case of labour productivity. In case of CIS4, relative differences in TFP between innovators and non-innovators are much smaller and in some cases even in favour of non-innovators. Finally, concerning organizational innovation, differences in productivity among innovators and non-innovators is on a similar scale as with technological innovation.

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[6] All the variables used in the analysis, such as sales, value added *et cetera,* are deflated by respective deflators of the system of national accounts provided by the Statistical Office of Estonia.

[7] On the other hand, the relationship between capital intensity and innovativeness could also be negative. Firms having made investments in the past may report both high capital and no innovation at the time of survey if at the time of survey there is no need for innovations due to earlier innovations; in the CIS4 survey that was the 2nd most common out of 10 factors hampering innovation activities for 54% of non-innovative firms (Terk et al. 2007).

[8] The Levinsohn-Petrin method (2003) for estimating TFP corrects for the endogeneity bias resulting from the correlation between the unobservable productivity shock and the input choices of a profit-maximising firm. The endogeneity bias is in this method dealt using the intermediate inputs as a proxy for the productivity shock.

Table 1. Average labour productivity in CIS3 and CIS4

Innovation variable	Activity/ expenditure present	Sales/ employees		Value added/ employees		Capital intensity		Total factor productivity	
		CIS3	CIS4	CIS3	CIS4	CIS3	CIS4	CIS3	CIS4
R&D expenditure	No	16.4	24.1	6.3	8.7	3.4	5.1	4.3	8.9
	Yes	28.9	35.2	9.5	12	6.5	8	18.3	6.9
Innovation expenditure	No	17.3	25.1	6.5	8.9	3.6	5.8	4.6	7.7
	Yes	31.9	40.4	10.3	13.8	7.1	8.2	26.4	10
Process innovation	No	16	24.1	6.2	8.8	3.4	5.4	6.6	9
	Yes	30.1	35.8	9.8	12.1	6.7	7.7	12.3	7
Product innovation	No	16.8	24.1	6.4	9	3.6	5.8	6.4	8.5
	Yes	26.2	35.3	9	11.6	5.8	7.1	12.4	7.8
Novel product innovation	No	18.5	26.2	6.8	9.4	4.1	6	6.7	8.2
	Yes	29	39.3	9.7	12.5	5.6	8	16.1	7.8
Process and product innovation	No	17.5	25.1	6.5	9.2	3.7	5.9	7.1	8.4
	Yes	29.7	38.5	10.1	12.3	6.9	7.5	12.2	7.9
Organizational innovation			23.8		9		5.6		7.5
			35.5		11.5		7.4		9.2

Note. Information in all tables is about Estonian manufacturing industry. Productivity and capital intensity are for 2000 (CIS3) and 2004 (CIS4). All values are in thousands of Euros. The Estonian kroon is fixed to the Euro at the rate of 1 EEK = 15.6466 Euros. All monetary values are in the 2001 prices. TFP is estimated using the Levinsohn-Petrin method. See Appendix 1 for definitions of innovation variables.

Table 2 shows the percentage difference between the productivity levels of innovators and non-innovators at various points in time after the innovation survey – that is, not only in the last year of the innovation survey (either 2000 or 2004), but also 1 and 2 years after the survey. The effect of innovation on productivity may either grow or decrease over time; the duration of the impact may also differ between product and process innovation if it is easier for a firm's competitors to imitate process innovations than product innovations (Garcia, Jaumandreu and Rodriquez 2004). Table 2 has some evidence that the difference is lower in higher leads. For example, 1 or 2 years after the CIS3 survey, for both the process and product innovators, the difference between labour productivity levels (i.e. innovator's premium) is up to 22 percentage points lower. For TFP that pattern is not so clear – for example, for process innovators the TFP gap is higher at lead 1, but lower at lead 2 relative to the value at lead 0.

The comparison of CIS3 and 4 shows that in CIS4 the productivity difference between innovators and non-innovators decreases more rapidly. In general, the differences are much bigger in CIS3 both for product and process innovation. Such evidence is in concordance with the conclusions of a study of Estonian Development Fund (Eesti Arengufond 2008), where it was concluded that growth in labour productivity during 2000–2005 has been higher in industries oriented to the domestic market, not depending on their level of innovation. Thus, during the more recent period, the level of innovation has not always been the key factor of competitiveness in the manufacturing industry, thus causing the smaller difference in productivity between innovators and non-innovators. Terk et al. (2007) explained that during 2002–2004 it was possible to increase the scale of operations with the existing products and services and the whole period is characterized by the growing economies of scale due to the growth of both domestic and international markets; thus, the lack of motivation to innovate is one of the biggest problems in the innovation process.

Table 2. Innovator’s productivity premium – by innovation variable, wave of CIS, and time period

Innovation variable	CIS wave	Sales/ employees			Value added/ employees			Total factor productivity		
		0	+1	+2	0	+1	+2	0	+1	+2
R&D expenditure	3	76%	74%	71%	51%	46%	44%	275%	197%	136%
	4	45%	46%		37%	14%		-9%	-31%	
Innovation expenditure	3	84%	83%	76%	59%	53%	48%	426%	287%	233%
	4	60%	56%		54%	27%		49%	33%	
Process innovation	3	88%	85%	76%	56%	46%	43%	75%	106%	69%
	4	48%	49%		37%	21%		-8%	-54%	
Product innovation	3	56%	54%	55%	41%	42%	29%	98%	76%	60%
	4	46%	38%		28%	6%		8%	-14%	
Novel product innovation	3	56%	58%	60%	44%	38%	26%	169%	130%	120%
	4	49%	46%		32%	15%		-4%	34%	
Process and product innovation	3	70%	68%	71%	54%	48%	40%	69%	100%	60%
	4	52%	51%		33%	19%		10%	-40%	

Note. Information in the table is about Estonian manufacturing industry. Time 0 denotes year 2000 in the case of CIS3 and year 2004 in the case of CIS4. There are no numbers in the table for the 2-year lead for CIS4, as we have data on productivities up to year 2005 that correspond to lead 1 for CIS4. See Appendix 1 for description of innovation variables.

Similar patterns can be observed even more clearly if instead of productivity levels we look at productivity growth rates, as in Table 3. While in the case of CIS3 (years 1998–2000), firms with innovation expenditures or innovation output had higher labour productivity growth rates, that does not hold for CIS4 (2002–2004). In the latter case the difference was much smaller and in many cases in favour of firms without innovation expenditures or innovation output.

The weaker and less robust impact that innovation has on productivity growth in the second period again contributes to the idea that the impact from innovation during strong economic growth is lower[9]. Concerning TFP, the difference between the productivity levels of innovators and non-innovators decreases in the 2nd period relative to the 1st period in case of product innovation (from 8.4 to 5.9 percentage points; in the case of novel product innovation that becomes even negative), but not in the case of process innovation (where it increases from 6.5 to 7.1 percentage points). Thus, although strong growth may give firms more resources that can be invested in R&D, it may also reduce the potential returns (at least in the short run). Similarly, Terk et al. (2007) noted that while in 1998–2000 innovative firms had significantly higher sales growth than non-innovative firms (respectively 16.9 and 4.4.%), then in 2002–2004 the difference was negligible (respectively 14.4 and 13.0%). This indicates that during the period of fast economic growth[10] (the latter period in this case) it is possible to increase sales without innovating thanks to growing demand for a firm's products. Notably, the level of innovation still mattered for sales growth in manufacturing.

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[9] The results were roughly the same both when we controlled for the outliers and when we did not.

[10] During 1998-2000 the average rate of GDP growth was 5% in Estonia due to the impact of the Russian crisis that severely hit the Estonian economy. During 2002-2004, the average rate of economic growth was 7.8%.

Table 3. Annual percentage productivity growth rates by innovativeness

Innovation variable	CIS wave	Activity/ expenditure present	Sales/ employees	Value added/ employees	Total factor productivity
All firms	3		10.5	12.1	16.2
	4		12.6	10.9	10.3
Innovation expenditure	3	No	9.7	10.4	14
	3	Yes	12.5	16.7	22.9
	4	No	13.3	11.9	9.1
	4	Yes	11.6	9.3	12.2
R&D expenditure	3	No	10	10.5	14.3
	3	Yes	12.5	19.8	26.8
	4	No	12.5	11.1	7
	4	Yes	12.9	10.1	23.1
Process innovation	3	No	8.8	9.9	13.8
	3	Yes	13.2	17.2	20.3
	4	No	13.3	11.1	7.8
	4	Yes	11.2	10.4	14.9
Product innovation	3	No	8.7	9.7	13.2
	3	Yes	13	16.9	21.6
	4	No	13.3	11	8.1
	4	Yes	11.3	10.6	14
Novel product innovation	3	No	10.2	11.8	15.6
	3	Yes	12.3	14.3	21.2
	4	No	13.1	10.7	12.4
	4	Yes	10.6	11.7	0.4

Note. Information in the table is about Estonian manufacturing industry. Productivity growth is measured respectively for CIS3 during 1998–2000 and for CIS4 during 2002–2004. See Appendix 1 for description of innovation variables.

Table 4 presents the productivity growth rates according to the presence of various effects of product and process innovation, as self-reported by enterprises in the innovation survey. This table helps us to capture some ideas about the manner that innovations might affect productivity growth in our data. Generally, concerning the effect of innovative activities, product oriented effects (increased choice, improved quality, enlarged market) were mentioned more often than process oriented effects (increased productivity, reduction of labour costs, increased flexibility in production) (Terk et al. 2007). The simple fact that productivity growth is indeed faster for those that gave a positive answer to the question, whether they had an increase in productivity due to innovations, should convince us that these self-reported effects have some connection with reality. “Increased range of goods and services” is one of the most frequent innovation effects (26% of innovative firms on CIS3, 36% in CIS4) and it has a modest (especially in the case of labour productivity) effect on productivity. Entry into new markets during 1998–2000 is very important: if an effect is present, the growth of value added per employee increases by 5.7 percentage points; during 2002–2004, productivity growth was lower for firms with foreign market entry by 3.4 percentage points. That is in accordance with the extensive reorientation of foreign trade relations in Estonian companies from CIS countries to western European countries at the end of 90’s as an impact of the crisis in Russia (Eamets et al. 2003).

Labour productivity is also increased by improved flexibility of production. “Reduced environmental impacts” is also associated with both higher labour and total factor productivity. “Meeting regulatory requirements” has in most cases more limited or even a negative effect on productivity growth. However, this has been quite important for innovations that were needed in order to align the production processes with EU regulations. If we compare the reduced labour and materials costs that result from innovation, the first is, as expected, much more important in the 2nd period while during 1998–2000 also the first one was quite important.

Table 4. The median productivity growth rates according to different self-reported innovation effects among innovative enterprises

The effect of process or product innovations	Wave of CIS (3 or 4)	Effect exists: no/yes	Frequency of the effect, %	Sales/employees	Value added / employees	Total factor productivity
Increased range of goods and services	3	No	74.0	6.2	6.2	8.9
	3	Yes	26.0	6.3	4.6	2.2
	4	No	61.3	10.0	8.7	7.3
	4	Yes	38.7	8.8	7.1	7.1
Entered new markets or increased market share	3	No	80.3	4.6	4.0	3.8
	3	Yes	19.7	13.6	9.7	13.4
	4	No	65.5	9.7	9.3	7.4
	4	Yes	34.5	9.3	5.9	6.8
Improved quality of goods and services	3	No	70.9	6.2	5.3	6.8
	3	Yes	29.1	6.7	6.2	5.8
	4	No	62.7	9.9	8.1	7.4
	4	Yes	37.3	9.5	7.6	7.0
Improved flexibility of production or service provision	3	No	79.4	5.0	5.7	6.7
	3	Yes	20.6	9.7	5.3	6.6
	4	No	79.0	9.0	7.9	7.3
	4	Yes	21.0	11.3	8.6	6.9

Table 4 (*continuation*)

The effect of process or product innovations	Wave of CIS (3 or 4)	Effect exists: no/yes	Frequency of the effect, %	Sales/employees	Value added / employees	Total factor productivity
Reduced labour costs per unit of production	3	No	90.4	5.8	5.3	5.8
	3	Yes	9.6	11.3	7.7	12.0
	4	No	81.3	8.8	7.4	6.1
	4	Yes	18.7	12.2	10.9	10.6
Reduced materials and energy per unit output	3	No	92.4	5.9	5.1	5.3
	3	Yes	7.6	14.7	13.8	16.3
	4	No	84.0	9.6	8.0	7.0
	4	Yes	16.0	9.9	7.7	10.3
Reduced environmental impacts	3	No	92.2	6.1	5.4	6.0
	3	Yes	7.8	10.7	7.5	17.4
	4	No	88.2	9.5	7.7	7.0
	4	Yes	11.8	10.5	9.8	10.1
Met regulatory requirements	3	No	87.9	6.5	5.8	6.5
	3	Yes	12.1	1.6	1.6	6.8
	4	No	85.3	9.6	7.5	7.0
	4	Yes	14.7	9.5	9.9	9.1
Increased productivity	4	No	72.2	8.2	7.0	5.0
	4	Yes	27.8	13.7	13.9	14.7

Note. The productivity growth is measured respectively for CIS3 during 1998–2000 and for CIS4 during 2002–2004.

4. EMPIRICAL RESULTS

The innovation investment equations

The results of the generalised Tobit model for innovation investment are presented in Table 5. Note that most of the variables included in both equations (selection equation and outcome equation) are significant. Also they mostly have expected signs and are mostly in line with results from the existing literature.

If the most significant market for the firm is the international market, then this significantly increases both the probability of engaging in innovative activities as well as the size of the innovation investment. These firms may have more resources to invest in innovative activities and a higher ability to undertake R&D. The finding that the coefficient of this variable has higher values in the 2nd period demonstrates clearly how the strong macroeconomic growth during 2002–2004 (supported by the strong domestic demand) resulted in less innovation incentives among firms oriented to domestic markets relative to firms oriented to international markets. The use of means of formal protection increases both the probability of engaging in innovative activities and the size of the innovation investment as that ensures that the firms making the investment can reap the benefits of that investment. The first part of this last finding is similar to the results of Griffith et al. (2006) in Western-European countries: France, Germany, Spain and the UK.

The impact of the public funding dummy is also similar to results from other countries (Griffith et al. 2006) [11]. Given its limited size

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[11] We did not include separately dummies for national funding and EU funding, as only a handful of firms have received funding from the latter source. While EU structural funds are an important source of funding for various R&D programmes in Estonia since 2004, funding from structural funds is included under national funding in R&D statistics. EU funding includes e.g. funding from the EU framework programmes. Local funding variable has not been included in the equations because differently from some other EU countries most of the local governments in Estonia are rather small and unable to provide any important finances towards R&D (perhaps with the exception of Tallinn, the capital).

in Estonia compared to Western Europe, it could perhaps be surprising that public funding has a strong positive and significant impact on the size of the innovation expenditures. The positive impact of public funding shows that public support has not crowded out private expenditure on innovation. However, the effect of public funding is possibly overestimated here as we have not controlled for the fact that public support is not assigned to firms randomly, but that it is correlated with some observable firm characteristics (see e.g. David, Hall and Toole (2000) about the results of studies in this area).

Table 5. Innovation investment equation

	Engagement in innovative activities (0/1)		Innovation investment intensity	
Variables	CIS3	CIS4	CIS3	CIS4
International competition	0.061 (2.35)***	0.209 (4.79)***	0.140 (1.97)**	0.573 (4.68)***
Formal protection	0.280 (7.58)***	0.239 (4.81)***	0.454 (4.24)***	0.486 (3.14)***
Public funding	0.472 (5.76)***	0.487 (8.33)***	1.122 (3.81)***	1.417 (5.49)***
Log number of employees	0.066 (6.91)***	0.056 (3.49)***		
Innovation cooperation				
Other enterprises within the group			–0.024 (0.33)	–0.003 (0.02)
Competitors			–0.075 (0.94)	–0.139 (1.26)
Customers			0.045 (0.62)	0.017 (0.13)
Suppliers			0.072 (0.96)	0.154 (1.18)
Sources of information				
Sources within the firm or other firms within the group			0.056 (1.29)	0.165 (2.25)**

	Engagement in innovative activities (0/1)		Innovation investment intensity	
Variables	CIS3	CIS4	CIS3	CIS4
Competitors			–0.078 (1.01)	0.090 (0.80)
Customers			–0.001 (.)	–0.011 (0.13)
Suppliers			0.124 (2.27)**	0.238 (3.06)***
Obstacles to innovation				
Lack of appropriate sources of finance			–0.139 (2.92)***	–0.136 (1.88)*
Innovation cost too high			0.091 (1.9)*	0.047 (0.64)***
Lack of qualified personnel			–0.039 (0.84)	–0.075 (1.03)
Lack of information on technology			0.062 (1.30)	–0.044 (0.56)
Lack of information on markets			0.085 (1.87)*	0.173 (2.38)***
Rho			0.875 (0.048)	0.396 (0.155)
Observations	1321	953	369	406
Log-likelihood			–1373.1	–1289.0

Notes. Absolute values of z statistics in parentheses; in case of rho, standard errors are in parentheses. * significant at 10% level; ** significant at 5% level; *** significant at 1% level. Reported are the marginal effects for the probability of engagement in innovative activities and the expected value of innovation investment. Industry dummies have been included in regression equations.

As a next step we describe the impact of firm size. Cohen and Klepper (1996) summarized the findings on the relationship between firm size and R&D into a number of stylized facts. According to these both the likelihood of a firm reporting positive R&D as well as the amount of R&D conducted increases with firm size. At the same time, the R&D intensity (e.g. share of R&D expenditures in sales) for companies engaged in innovation activities is often found to be independent of size. Thus, R&D rises monotonically with firm size and R&D expenditures are roughly proportional to firm size. We find that larger firms are more likely to engage in innovative activities than small firms. This well-documented result from the literature has been obtained in applications of the CDM model in Western European countries (Griffith et al. 2006) and also in developing countries (e.g. Benavente 2006). This is consistent with the Schumpeterian hypothesis that large firms in concentrated markets innovate more.

None of the innovation cooperation[12] variables is statistically significant. This is perhaps not so surprising given that the cooperation partners – such as universities and R&D institutions – are used to a limited extent in Estonia. We might have expected it to be significant in the case of suppliers and customers. Still, the insignificance of these values is probably not due to the specific situation in Estonia. Also, Lööf et al. (2003) did not find any cooperation dummies to be significant in the case of Nordic countries, although in these countries innovation cooperation is much more intensive. Among the different sources of information for innovation, the parameters for suppliers and sources within the firm are significant. This is consistent with our previous knowledge of innovation processes among Estonian firms (Ukrainski and Varblane 2006). Although we would expect the values of the parameters for sources of information variables to be positive, some earlier studies have also found some of these to have a negative impact in the expenditure equation and thus a substitute for R&D investments (Lööf et al. 2003).

Concerning obstacles to innovation, the lack of appropriate sources of finance is significant and negative. That factor was indicated most often as a factor inhibiting innovation in the Estonian CIS[13]. In the case of ‘innovation cost being too high’, the impact is unexpectedly positive. A possible explanation could be that in the

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[12] Aside from those included in the reported regressions, we have also tried different other cooperation partners like universities etc., but these turned out to be insignificant, too.

[13] Some other studies have shown that liquidity constraints (financing constraints) are a significant impediment to investments in fixed assets in Estonian firms (Mickiewicz, Bishop and Varblane 2006).

case of more costly innovations a larger expenditure is also needed, so that firms with higher innovation expenditures report the high cost of innovation to be a problem. A similar story may apply for the variable ‘lack of information on markets’.

Knowledge production functions (innovation output)

Table 6 presents the regression coefficients of the innovation output equations – knowledge production functions. A bivariate probit model is used to study the determinants of product and process innovation. As we can see, the predicted innovation expenditure intensity has a positive impact for both product and process innovation. Thus, greater innovation effort per employee implies a higher probability of having any process or product innovation.

The protection of innovation through formal methods is more important for product than process innovation. Previously, Griffith et al. (2006) obtained a similar result. This could be explained simply by the fact that protection using formal methods is more often applied to product than process innovation. Firm size has an insignificant impact on product and a positive impact on the probability of process innovation, thus only in the case of process innovation is the Schumpeterian hypothesis confirmed. The explanation is that most product innovations are probably rather incremental, and thus, do not require large expenditures on R&D that only large firms can afford. If innovation usually occurs via the adaptation of existing technologies via the purchase of machinery and equipment, firm size need not to be so important.

Table 6. Knowledge production functions estimated as bivariate probit models

Variables	Pr(Product innovation=1)		Pr(Process innovation=1)	
	CIS3	CIS4	CIS3	CIS4
Innovation investment intensity	0.172 (3.69)***	0.148 (2.31)**	0.107 (2.67)***	0.113 (1.87)*
Formal protection	0.126 (2.31)**	0.225 (3.96)***	0.004 (0.1)	0.072 (1.25)
Public funding	–0.070 (0.64)	0.390 (5.00)***	0.113 (0.84)	0.160 (1.61)
Log number of employees	0.017 (1.33)	–0.012 (0.62)	0.034 (2.89)***	0.068 (3.81)***
Sources within the firm or other firms within the group	0.373 (7.99)***	0.425 (9.07)***	0.312 (6.74)***	0.167 (3.14)***
Competitors	0.101 (1.64)	0.026 (0.37)	0.331 (4.97)***	0.368 (5.92)***
Customers	0.332 (4.76)***	0.322 (5.47)***	0.127 (2.04)**	0.099 (1.57)
Suppliers	0.173 (1.46)	0.045 (0.38)	–0.008 (0.1)	0.125 (1.26)
Observations	1312	953	1312	953
Log-likelihood	–1040	–922	–1040	–922

Notes. Absolute values of robust z statistics parentheses * significant at 10%; ** significant at 5%; *** significant at 1%. The t-statistics in parenthesis are robust. The coefficients reported are the marginal effects from the probit model on the sample mean values. Industry dummies have been included in all regression equations. Industry dummies are found to be jointly significant in both specifications, the corresponding p-value is 0.000.

The variables of the various sources of information for innovation have mostly expected signs. Customers are important sources of information for product innovation (and process innovation in the CIS3) and competitors for process innovation. The positive value for the competitors variable might show that firms are not able to prevent other firms from obtaining information about their production processes and that knowledge spills over to other firms. As expected, sources within the firm are highly important for both types of innovation and time periods. Note that Lööf et al. (2003) in their paper found this variable to have a negative impact on product innovation in Norwegian firms.

In CIS4, public innovation funding positively affects product but not process innovation; in CIS3 the impact is statistically insignificant. According to the Estonian CIS4 survey, 9.7% of product and 10.4% of process innovators declared that they have received national funding for innovations. The logic for including the funding variables in the knowledge production function is that various subsidies could help the firms to reach from the innovation input to its output more easily. Thus, according to our results we found that public support increases innovation expenditure but there is less evidence that there is any positive effect on knowledge creation apart from the link through higher expenditure.

Table 7 includes the results of the knowledge production function estimated using univariate probit models. The results are mostly in-line with those in Table 6, still there are some differences. For example, the dummy for suppliers as an important source of information has become significant in case of process innovations. The relationship between innovation expenditure and the probability of having any process or product innovations is somewhat weaker during the second period. On the one hand, this might be explained by decreasing marginal returns to innovative activities, whereas in the period covered by CIS4, available resources in firms were much larger and their total expenditure on innovation grew almost two times (Terk et al. 2007). One the other hand, the weaker relationship may also be caused by higher errors of measurement of R&D and innovation expenditure. However, the evidence seems to be the opposite – in the second period the errors were probably smaller[14]. The innovation expenditure variable is now significant in both time periods and types of innovations, and firm size has statistically significant positive effect only on process innovations in case of CIS4.

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[14] For example, in the case of Estonia it has been revealed that the same firms report very different R&D expenditures in the innovation survey and R&D survey. Both in the case of CIS3 and CIS4, internal R&D expenditures were higher according to the innovation survey than the R&D survey. The difference between the two surveys was smaller in the case of CIS4 (Heinlo 2006). Lower measurement errors should rather increase than decrease the significance of parameter estimates.

Table 7. Knowledge production function estimated as univariate probit models

	Product innovation (0/1)		Process innovation (0/1)	
	CIS4	CIS3	CIS4	CIS3
Innovation expenditure	0.141 (2.15)**	0.152 (3.06)***	0.086 (1.41)	0.121 (2.89)***
Formal protection	0.239 (4.16)***	0.139 (2.37)***	0.079 (1.38)	0.006 (0.14)
Public funding	0.423 (5.14)***	–0.054 (0.41)	0.156 (1.51)	0.090 (0.22)
Log number of employees	–0.018 (0.93)	0.017 (1.27)	0.065 (3.68)***	0.083 (0.56)
Sources within the firm or other firms within the group	0.441 (9.43)***	0.421 (8.32)***	0.170 (3.06)***	0.042 (3.55)***
Competitors	0.063 (0.50)	0.213 (1.43)	0.155 (1.54)	0.298 (6.05)***
Customers	0.331 (5.48)***	0.361 (4.55)***	0.119 (1.81)*	–0.027 (0.34)
Suppliers	0.028 (0.37)	0.109 (1.53)	0.391 (6.33)***	0.131 (1.95)*
Observations	951	1297	951	1300
Pseudo-R^2	0.286	0.335	0.198	0.258
Log-likelihood	–461.2	–537.1	–513.1	–551.3

Notes. Absolute values of robust z statistics parentheses * significant at 10%; ** significant at 5%; *** significant at 1%. The t-statistics in parenthesis are robust. The coefficients reported are the marginal effects from the probit model at the sample mean values. Industry dummies have been included in all regression equations. Industry dummies are found to be jointly significant in both specifications, the corresponding p-value is 0.000.

Output production function

Table 8 presents the estimates of the output production function (productivity equation); productivity is hereby measured either as the log of the sales or value added per employee. Since the dependent variable is the natural log of productivity, the presented parameters are the elasticities or semi-elasticities of labour productivity with respect to innovation dummies and other firm-level variables. In addition to the level of productivity, we also use the growth rate of productivity as the dependent variable. Klette and Kortum (2002) summarised that while productivity and R&D

are positively related, productivity growth is not strongly related to R&D. Although the dependent variable is labour productivity, as capital intensity is included in the list of explanatory variables, we are in fact measuring the effect of innovation on total factor productivity. In all estimations reported below the predicted values for product and process innovations from a bivariate probit model were used. When using instead the predicted values from the univariate probit models, the results were rather similar.

Table 8. Output production function (productivity equation): predicted values for product and process innovation from a bivariate probit model

Variables	Sales/employees		Value added/employees	
	CIS3	CIS4	CIS3	CIS4
Capital intensity	0.340 (19.48)***	0.268 (14.84)***	0.274 (14.74)***	0.196 (10.44)***
Product innovation	0.168 (2.24)**	0.027 (0.77)	0.207 (2.47)**	0.002 (0.04)
Process innovation	–0.027 (0.31)	0.182 (3.80)***	–0.055 (0.55)	0.151 (2.61)***
Organizational innovation		0.132 (2.71)***		0.097 (1.88)*
Export dummy (–2)	0.328 (6.41)***	0.201 (3.06)***	0.290 (5.41)***	0.127 (1.89)*
Log number of employees (–2)	–0.059 (2.77)***	–0.058 (2.41)**	–0.043 (1.78)*	–0.062 (2.34)**
Constant	8.872 (38.64)***	9.365 (13.42)***	8.442 (34.80)***	9.765 (15.38)***
Observations	1142	916	853	676
R-squared	0.50	0.47	0.40	0.38

Absolute values of t statistics in parentheses. Industry dummies are included in all regressions. * significant at 10%; ** significant at 5%; *** significant at 1%. Industry dummies are found to be jointly significant in both specifications, the corresponding p-value is 0.000.

As the results in Table 8 show, capital has an expectedly positive significant coefficient in the production function[15]. Exporters are found to be more productive than non-exporters[16]. This is a rather normal result in the literature, and need not show the impact of exports on productivity, but might be caused by the fact that more productive firms self-select into export markets (Wagner 2007). The log of number of employees has a negative sign, hence the constant returns to scale hypothesis is rejected. The goodness-of-fit can be considered satisfactory given that it is similar to what has been observed in earlier studies in the field.

The most interesting finding from Table 8 concerns the innovation dummies. If CIS4 data is used, only process innovation has a positive significant effect on TFP, but not product innovation; this result holds for both of dependent variables used. Using earlier data – from CIS3 – gives exactly the opposite result, in 1998–2000 the main contribution of innovation to productivity in firms seems to be via product innovation. In earlier studies (Griffith et al. 2006, Lööf et al. 2003) that use CIS3 data, product innovation is more often found to have a significant effect on productivity[17]. The estimates are quite large: in CIS4, process innovation increases productivity by 12 or 22% depending on the measure of productivity used in CIS4. The value for product innovation is 12–14% in the case of CIS3. In the sample from Griffith et al. (2006), the values were at most 7% for process innovation and 18% for product innovation. In a catching-up economy there might be relatively many unused opportunities for productivity improvements that are related to both products and processes, thus relatively high rates of return on innovation could be viewed as

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[15] Some earlier studies, like Griffith et al. (2006), have used in the place of capital intensity the investment intensity due to the lack of the capital variable in the data.

[16] A possible concern is that this variable is probably highly endogenous. It could be alleviated in our estimations by that the dummy is lagged two periods. We tried also estimations with excluding the export dummy from productivity equations; that did not have any significant impact on the estimation results.

[17] Griffith et al. (2006) explained that with the problems of measuring the productivity like the lack of firm-level price deflators so that industry deflators are used instead.

normal. Also, the descriptive tables did not provide any evidence that product innovation was more important in the first and process innovation in the second period, but rather that the impact of both types of innovations decreased. Finally, the dummy for organizational innovation is positive and significant; its value is smaller than that of the process innovation variable. Thus, this is one of the first evidence of the positive impact of organizational innovation on productivity within the CDM model framework. Raffo et al. (2007) found organizational innovation to affect productivity positively only in case of Brasil, but not in case of other countries.

Several potential explanations of our results can be outlined. One explanation could be that in the second period, the growing labour costs became a larger problem than in the first period – drawing the attention of firms more towards the potential of cost savings, including cost cutting via process innovation. Additionally, in the 2nd period changes in processes might have been necessary in order to increase production to meet the growing demand. Secondly, the period of the CIS3 survey included the Russian crisis in 1998 that severely hurt many Estonian manufacturing companies exporting to Russia, so that in order to survive they needed to restructure heavily and re-orientate their trade from East to West (Eamets et al. 2003). Indeed, in the first period, product innovation was heavily correlated with export growth rates (product innovators had 15% higher export growth rates), while not so much in the second period (the difference was only 4%). Thirdly, there is anecdotal evidence that Estonian manufacturing firms are quite often not specialized enough and have too large a product portfolio. Under such conditions, if product innovations increase the variety of goods offered, they need not have any positive impact or have only limited positive impact on productivity and profitability. In our case, increasing the range of goods and services was indicated to be one of the most frequent impacts of innovative activities, indicated respectively by 26% and 36% of innovative firms in CIS3 and 4 (Terk et al. 2007). When excluding these firms from the estimations with CIS4 data (results not reported, but available upon request), the value of the product innovation dummy grows somewhat, but remains statistically insignificant. Finally, one of the potential explanations is that the share of sales of new products declined over time from 16.3% in CIS3 to 13.5% in CIS4, despite the growing frequency of product innovations (Terk et al. 2007).

Table 9. Output production function: productivity growth equation

Variables	Sales/employees		Value added/employees	
	CIS3	CIS4	CIS3	CIS4
Capital intensity growth	1.028 (5.75)***	0.440 (3.12)***	0.752 (3.49)***	0.488 (2.59)***
Product innovation	0.738 (0.32)	–0.521 (0.63)	–0.533 (0.18)	1.002 (0.67)
Process innovation	1.475 (0.55)	–0.029 (0.03)	2.719 (0.77)	–2.038 (1.13)
Organizational innovation		2.416 (2.03)**		1.520 (0.89)
Export dummy	0.809 (0.52)	–1.343 (0.88)	1.868 (1.00)	–2.024 (0.96)
Growth rate of log number of employees	–0.416 (6.19)***	–1.138 (13.54)***	–0.488 (6.09)***	–1.008 (9.16)***
Constant	–3.541 (0.87)	–19.534 (1.24)	4.493 (0.92)	56.896 (3.01)***
Observations R-squared	919 0.12	833 0.25	657 0.13	597 0.17

Notes. Reported are coefficients from instrumental variables regression. Absolute values of t statistics in parentheses. Industry dummies are included in all regressions. * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable is from the last year of either the CIS3 or CIS4 survey, thus either 2000 or 2004. The explanatory variables: process and product innovation dummy stand for the whole period of either CIS3 or CIS4 study. Capital intensity is from the same year as the dependent variable – the export dummy and log number of employees are from 1998 (in CIS3) or from 2002 (in CIS4).

Our preliminary data analysis in the previous sections of the paper also showed that during CIS3 the difference between productivity growth levels for innovators and non-innovators was higher than in the case of CIS4. Therefore, we also re-estimated the output production function with productivity growth as the dependent variable (see Table 9). Compared to the productivity level equation, no statistically significant effect is found from technological innovation to productivity growth. However, the signs are sometimes even negative, though the impacts are both smaller in CIS4 than in CIS3 in the case of product and process innovation, if the first measure of the labour productivity is used. This finding matches our previous evidence and also our expectations. Similarly, earlier studies have not found positive impacts in the CDM model when productivity growth is used as the dependent variable. Organizational innovation has a statistically significant positive effect if productivity is measured as the ratio of sales to employees. These productivity growth equations are also characterized by a much lower goodness of fit (R-squared being 12–25).

As we have combined innovation survey data with firm financial data, we also looked at the effect of innovation on productivity at higher leads – not only on the productivity in the last year of the innovation survey, but also 1 and 2 years after the survey. As can be seen from Table 10, in the case of CIS4, the impact of process innovation grows over time, while in CIS3 the impact of product innovation decreases over time. Thus, our evidence is not in accordance with the claims of Garcia et al. (2004) that product innovation has a longer effect than process innovation. Organizational innovation seems to have impact only at the last year of the survey and then become insignificant.

Table 10. Output production function (productivity equation) for different leads of the value added per employee

Variables	CIS3			CIS4	
	+0	+1	+2	+0	+1
Capital intensity	0.274 (14.74)***	0.228 (13.07)***	0.242 (14.44)***	0.196 (10.44)***	0.177 (9.63)***
Product innovation	0.207 (2.47)**	0.146 (1.79)*	0.181 (2.26)**	0.002 (0.04)	–0.014 (0.31)
Process innovation	–0.055 (0.55)	0.046 (0.47)	–0.067 (0.70)	0.151 (2.61)***	0.169 (3.02)***
Organizational innovation				0.097 (1.88)*	0.072 (1.43)
Export dummy (–2)	0.290 (5.41)***	0.306 (5.82)***	0.292 (5.53)***	0.127 (1.89)*	0.119 (1.84)*
Log number of employees (–2)	–0.043 (1.78)*	–0.076 (3.17)***	–0.050 (2.11)**	–0.062 (2.34)**	–0.065 (2.48)**
Constant	8.442 (34.80)***	9.224 (41.20)***	9.174 (40.17)***	9.765 (15.38)***	10.333 (17.08)***
Observations	853	855	862	676	635
R-squared	0.40	0.36	0.37	0.38	0.38

Note. Time 0 denotes year 2000 in the case of CIS3 and year 2004 in the case of CIS4. There are no numbers in the table for the 2-year lead for CIS4, as we have data on productivities for up to 2005 that corresponds to lead 1 for CIS 4. Absolute values of t statistics in parentheses. Industry dummies are included in all regressions. * significant at 10%; ** significant at 5%; *** significant at 1%.

5. CONCLUSIONS AND IMPLICATIONS

There exists a growing volume of literature on the relationship between innovation and productivity in highly developed countries, but there are few papers on the CEE transition economies. We have studied the linkage between innovation inputs, outputs and productivity growth in Estonia. For this, we have used CIS3 and CIS4 surveys for years 1998–2000 and 2002–2004. A novelty here is that the data from the innovation surveys was combined with the Estonian Business Register database. The data was analysed using the CDM model that has been used in several papers. The basic structure of our version of the CDM model was as follows. First we estimated the equation for innovation expenditure intensity, then knowledge production functions using predicted innovation expenditures from the first step and in the third stage we estimated the productivity equation using the predicted innovation output values from the second stage.

Our main conclusions are as follows. The estimated equations performed relatively well and most of the parameter estimates had expected signs. If CIS4 data was used, only process innovation had a positive significant effect on labour productivity, but not product innovation. Using earlier CIS3 data gives exactly the opposite result: product rather than process innovation had a significant impact on productivity. We also found organizational innovation to have a positive impact on productivity.

The estimates of the coefficients for technological innovation were larger than in the study by Griffith et al. (2006) in Western European countries. We provided various potential explanations for these results. Firstly, in the first period, product innovation might have been necessary for firms to restructure and enter new export markets after the loss of traditional export markets in the Russian crisis. In the second period, growing labour costs made it more important to reduce production costs through process innovation; process innovation might have also been necessary to increase production in order to meet the growing demand during the period of strong macroeconomic growth. Concerning productivity growth rates, our preliminary data analysis showed some evidence that the differences between innovative and non-innovative firms were smaller at the time of the CIS4 survey than at the time of the CIS3 survey. This implies that during strong macroeconomic growth it is possible to increase productivity without innovating, since owing to growing market demand firms can exploit economies of scale. However, in the productivity growth regressions none of the dummies for technological innovation were significant.

Concerning the knowledge production functions in our model, as expected, higher innovation expenditure also results in the higher probability that enterprises will come up with either product or process innovation. The relationship between innovation expenditure and innovation output was somewhat weaker in the second period though there were some differences depending on whether the univariate or bivariate probit models were used to estimate the knowledge production functions. We might expect the relationship to be weaker in the 2nd period due to decreasing marginal returns on innovative activities as total expenditure on innovation in the second period was more than twice as high. However, we must consider that there is a non-negligible measurement error of innovation expenditure. The ability to protect innovation using formal means was found to be more important for product than process innovation. Suppliers and competitors are an important source of information for process innovation, customers for product innovation.

Finally, the results of the estimation of the innovation investment equation showed that among firms oriented to international markets both the probability of engaging in innovative activities and the size of innovation expenditure were larger. The dummy for public funding was significant, which may imply that funds have been used efficiently in Estonia. However, due to the likely overestimation of the effect a special study would be needed in order to make any conclusions about that. None of the innovation cooperation variables turned out to be statistically significant in the expenditure intensity equation. On the one hand, we might be tempted to say that the lack of innovation cooperation, in particular R&D networking and interactions with academia, is the factor inhibiting the level of innovation in Estonia (that is the case in many developing and transition countries), but innovation cooperation variables were also insignificant in some studies on Nordic countries where the innovation cooperation situation is quite different. Various sources of information for innovation mattered for both the intensity of innovation investment and the innovation output.

To sum up, our results were mostly in-line with earlier studies in both developed countries (Griffith et al. 2006; Lööf et al. 2006) and developing and transition countries (Roud 2007; Raffo et al. 2007). Our results imply that the significance of process or product innovation varies across different periods, either because these periods are characterized by different stages of economic development or are from different stages in the economic cycle. From the viewpoint of the national innovation system, the question is, whether the bottleneck in the system is the ability to come up with technological innovation or rather to use the innovation to improve firm performance (Raffo et al. 2007). In our case it seems that both problems are to some extent present in Estonia. The productivity of innovation expenditures decreased in the second period, only one type of technological innovation affected productivity in both periods and the differences between the productivity growth rates of innovators and non-innovators decreased during the period of strong economic growth.

Estimating the effect of innovation on productivity remains a challenge for researchers. Among many possible directions for further development, we would outline only the following. First, it would be useful to combine firm-level analysis with industry-level analysis. As Pianta and Vaona (2007) point out, the disadvantage of firm-level studies is that they do not identify whether innovating firms perform better at the expense of competitors (business-stealing effect) or whether there is also an observable positive net effect at the industry level. The second option is to look at how the impact of innovation depends on the management practices of the firms. For example, Bloom, Sadun and van Reenen (2008) showed that the reason US firms have been more successful in increasing their productivity by using information technologies is the different human resource management practices (over promotion, rewards, hiring and firing) in US companies compared to the UK. Thus, combining the CIS-type surveys with management practice surveys could be a promising direction of research. Third, while the bulk of the studies are about the manufacturing sector, the services sector deserves much more attention, not only due to its higher and increasing share in the economy, but also because sometimes (as in the Estonian data) a higher proportion of firms are found to be innovative in services than in manufacturing. Concerning particularly the Estonian case, it would be interesting to analyze the linkage between innovation and productivity separately in the case of domestic and foreign market oriented firms because during the period of strong macroeconomic growth economic performance of the domestic market oriented firms improved a lot while many of the exporting enterprises have been facing growing difficulties due to the raising labour costs.

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Appendix 1. Definitions and summary statistics of variables used in descriptive tables and regression analysis

Variable name	Variable definition	CIS3		CIS4	
		Mean	Std. Dev.	Mean	Std. Dev.
Innovation/knowledge variables					
Product innovation	Dummy, 1 if firm reports having introduced new or significantly improved product	0.12	0.33	0.38	0.49
Novel product innovation	Dummy, 1 if firm reports having introduced new or significantly improved product that is new to firm's market	0.07	0.25	0.10	0.30
Process innovation	Dummy, 1 if firm reports having introduced new or significantly improved production process	0.11	0.31	0.36	0.48
Organizational innovation	Dummy, 1 if firm reports having introduced organizational innovations			0.44	0.50
Innovation expenditure	Total innovation expenditure per employee (in logs)	5.59	45.88	13.53	110.77
Innovation expenditure dummy [a)]	1 if firm reports positive expenditure on innovation	0.13	0.34	0.20	0.40
R&D expenditure dummy	1 if firm reports positive expenditure on R&D	0.09	0.28	0.12	0.32
Sales/employees	The ratio of sales to employees	12.37	1.16	12.71	1.09
Value added/employees	The ratio of value added to employees	11.51	0.96	11.79	0.93
Total factor productivity	Calculated by Levinsohn-Petrin approach; see section 2 for details ('000 Euro)	7.73	38.02	15.05	79.23
Formal protection	Dummy, 1 if firm uses registration of design patterns, trademarks, copyright to protect inventions or innovations	0.08	0.27	0.08	0.27

Appendix 1 (*continuation*)

Variable name	Variable definition	CIS3		CIS4	
		Mean	Std. Dev.	Mean	Std. Dev.
Public support					
Public funding	Dummy, 1 if firm received public funding for innovation projects	0.01	0.11	0.03	0.17
Obstacles to innovation					
Lack of appropriate sources of finance	Dummy, 1 if lack of appropriate sources of finance was at least of medium importance	0.24	0.43	0.27	0.44
Innovation cost too high	Dummy, 1 if innovation costs too high was at least of medium importance	0.23	0.42	0.20	0.40
Lack of qualified personnel	Dummy, 1 if lack of qualified personnel was at least of medium importance	0.16	0.37	0.21	0.41
Lack of information on technology	Dummy, 1 if lack of information on technology was at least of medium importance	0.11	0.31	0.11	0.31
Lack of information on markets	Dummy, 1 if lack of information on markets was at least of medium importance	0.12	0.33	0.11	0.32
Sources of information					
Sources within the firm or other firms within the group	Dummy, 1 if information from internal sources within the firm or group was of high importance	0.07	0.26	0.10	0.31
Competitors	Dummy, 1 if information from competitors and other firms from the same industry was of high importance	0.02	0.14	0.03	0.17
Customers	Dummy, 1 if information from clients or customers was of high importance	0.04	0.20	0.07	0.25
Supplier	Dummy, 1 if information from suppliers of equipment, materials, components or software was of high importance	0.04	0.20	0.06	0.25

Appendix 1 (*continuation*)

Variable name	Variable definition	CIS3		CIS4	
		Mean	Std. Dev.	Mean	Std. Dev.
Innovation cooperation					
Other enterprises within the group	Dummy, 1 if firm had any cooperation arrangements on innovation activities with other enterprises within the group	0.02	0.16	0.05	0.21
Suppliers	Dummy, 1 if firm had any cooperation arrangements on innovation activities with suppliers of equipment, materials, components or software was of high importance	0.04	0.21	0.07	0.26
Customers	Dummy, 1 if firm had any cooperation arrangements on innovation activities with clients or customers	0.04	0.20	0.07	0.25
Competitors	Dummy, 1 if firm had any cooperation arrangements on innovation activities with competitors	0.03	0.16	0.05	0.22
Other variables					
International competition	Dummy, 1 if the firm's most important market is international market.	0.31	0.46	0.70	0.46
Export dummy	Dummy, 1 if firm has positive exports	0.59	0.49	0.71	0.46
Log number of employees	Natural log of the number of employees	51.15	231.64	84.12	241.41
Capital intensity	Natural log of the capital-labour ratio; capital measured as the sum of tangible and intangible assets minus goodwill	10.49	1.56	10.84	1.64

Note. The number of firms in the dataset is 3130 for CIS3 (1998–2000) and 1663 for CIS4 (2002–2004).

The Estonian kroon is fixed to the Euro at the rate of 1 EEK = 15.6466 Euros. All monetary values are in the 2001 prices. The questionnaires of CIS3 and CIS4 surveys can be found respectively in Kurik et al. (2002) and Terk et al. (2007).

a) Innovation expenditure includes the following 4 kinds of expenditures: internal R&D expenditure, external R&D expenditure, acquisition of machinery, equipment and software; acquisition of other external knowledge.

KOKKUVÕTE

Tehnoloogilised innovatsioonid ja tootlikkus Eestis hilisel üleminekuperioodil: ökonomeetriline analüüs innovatsiooniuuringute andmeid kasutades

Kõrgelt arenenud riikides tugineb majanduskasv suures osas tehnoloogilistele innovatsioonidele. Kuigi Kesk- ja Ida-Euroopa üleminekuriikides on majanduskasvu allikad olnud mõnevõrra erinevad tulenevalt nende suuremast distantsist tehnoloogilise rajajoone suhtes ja esialgsest kapitali akumulatsioonist, on majanduskasvu jätkamiseks ja Lääne-Euroopa riikidega konvergeerumiseks innovatsioonide kasvav panus majanduskasvu paratamatu. Majandusteadlaste seas on täheldatav kasvav huvi innovatsioonide ja tootlikkuse vahelise seoses modelleerimiseks arenevate ja üleminekuriikide andmeid kasutades. Selle põhjuseks on muuseas nende riikide soov ülesse ehitada teadmistel-põhinevaid majandusi ja oluliselt suurendada ärisektoris tehtava uurimis- ja arendustöö mahtu.

Käesolevas artiklis kasutatakse innovatsioonide ja tootlikkuse vahelise seose uurimiseks Eestis läbi viidud Euroopa Liidu innovatsiooniuuringute (*Community Innovation Survey* – CIS) andmeid aastatest 1998–2000 (CIS3) ja 2002–2004 (CIS4). Innovatsiooniuuringute andmeid kombineeritakse Eesti Äriregistri andmetega ettevõtete finantsnäitajate kohta. Sellise andmestiku kasutamine võimaldab uurida innovatsioonide ja tootlikkuse vahelise seose varieerumist ajas üle erinevate majandusarengu perioodide, samuti erinevatel ajahetkedel peale innovatsioonide teostamist. Analüüsiks kasutatakse struktuurset mudelit, mis koosneb innovatsioonikulutuste, innovatiivse tegevuse väljundite (toote- ja protsessiinnovatsioonide) ja tootlikkuse käitumist kirjeldavatest võrranditest.

Analüüsi tulemused näitasid, et kui perioodil 1998–2000 oli statistiliselt oluline mõju tootlikkuse tasemele ainult tooteinnovatsioonidel, siis hilisemal perioodil 2002–2004 oli mõju ainult protsessiinnovatsioonidel. Selliseid tulemusi võivad seletada muuseas kahel perioodi Eesti majanduses valitsenud erinevad makroökonoomilised tingimused. Esiteks võisid esimesel perioodil tooteinnovatsioonid olla ettevõtetele vajalikud restruktureerimiseks ja uutele eksporturgudele sisenemiseks Vene kriisiga kaasnenud traditsiooniliste eksportturgude kaotuse tõttu. Teisel perioodil võis protsessiinnovatsioonide suhteliselt suurem tähtsus tuleneda kasvavatest tööjõukuludest tingitud vajadusest tootmiskulude alandamiseks; samuti võisid protsessiinnovatsioonid olla vajalikud tootmise suurendamiseks kasvava nõudluse rahuldamiseks kiire majanduskasvu perioodil. Vaadeldes lisaks tootlikkuse tasemetele ka tootlikkuse kasvumäärasid, andis andmete esialgne analüüs mõningast tõendusmaterjali selle kohta, et erinevus innovatiivsete ja mitteinnovatiivsete ettevõtete vahel oli väiksem (ehki positiivne) CIS4 uuringu ajal võrreldes CIS3 uuringu ajaga. See viitab sellele, et kiire majanduskasvu perioodil on võimalik suurendada tootlikkust ilma innovatsioonideta, sest kiire majanduskasvu tingimustes saavad ettevõtted kasutada mastaabisäästu efekti. Samas tootlikkuse kasvu regressioonides ei osutunud ükski tehnoloogilise innovatsiooni muutujatest statistiliselt oluliseks. Organisatsioonilistel innovatsioonidel oli oluline positiivne mõju nii tootlikkuse tasemetele kui kasvumääradele.

Lisaks eelnevatele tulemustele leidis kinnitust see, et kõrgemad kulutused innovatiivsele tegevusele suurendavad toote või protsessiinnovatsioonide teostamise tõenäosust ettevõtte tasandil. Teisel perioodil oli nimetatud seos mõnevõrra nõrgem, mis võib olla seotud innovatiivse tegevuse kahaneva piirtulususega, kuna ettevõtete kogukulutused innovatsioonile olid teisel perioodil üle kahe korra suuremad. Samas tuleb tulemuste tõlgendamisel arvestada oluliste mõõtmisvigade olemasoluga innovatsioonikulutustes. Hankijad ja konkurendid osutusid olulisteks informatsiooniallikateks protsessiinnovatsioonide ja kliendid tooteinnovatsioonide teostamisel. Innovatsioonikulutustele võrrandi hindamise tulemused osutasid, et rahvusvahelistele turgudele orienteeritud ettevõtetel on suuremad innovatsioonikulutused. Avaliku sektori poolsete toetuste kasutamine innovatsioonikulutuste rahastamiseks evis positiivset mõju kulutuste üldisele suurusele, mis võiks viidata vahendite suhteliselt efektiivsele kasutamisele Eestis.

Rahvusliku innovatsioonisüsteemi funktsioneerimise seisukohalt on antud analüüsi tulemuste juures oluline, kas innovatsioonisüsteemi nö pudelikaelaks on võime tehnoloogiliste innovatsioonidega välja tulla või võime nende abil ettevõtete tegevusedukust suurendada. Tundub, et mõlemad probleemid on mingil määral Eestis olemas. Innovatsioonikulutuste tootlikkus langes teisel perioodil, mõlemal vaadeldud perioodil omas ainult ühte tüüpi tehnoloogiline innovatsioon positiivset mõju tootlikkusele ja innovatiivsete ning mitteinnovatiivsete ettevõtete tootlikkuse kasvumäärade erinevused vähenesid kiire majanduskasvu perioodil. Edasises analüüsis pakuks huvi vaadata innovatsioonide ja tootlikkuse seost eraldi sise- ja välisturule orienteeritud ettevõtetes, nimelt kiire majanduskasvu tingimustes paranes eriti just siseturule orienteeritud ettevõtete tegevusedukus samas kui eksportivad ettevõtted on sattunud aina enam raskustesse seoses kasvavate tööjõukuludega.