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## Innovation and labour productivity in the Swiss manufacturing sector: An analysis based on firm panel data

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# Arbeitspapiere/ Working Papers

Spyros Arvanitis

Innovation and Labour Productivity  
in the Swiss Manufacturing Sector:  
An Analysis Based on Firm Panel Data



# **Innovation and Labour Productivity in the Swiss Manufacturing Sector: An Analysis Based on Firm Panel Data\***

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## **Abstract**

This paper investigates (a) the determinants of innovation performance and (b) the impact of innovation performance on labour productivity of Swiss manufacturing firms in the period 1994-2002. The data used in this study come from the KOF panel database and were collected in 1996, 1999 and 2002 respectively based on a questionnaire quite similar to that used in the Community Innovation Surveys (CIS). The use of a wide spectrum of indicators helps to test the robustness of the specification of the innovation equation as well as the robustness of the impact of innovation on economic performance. We find a clear-cut positive effect of innovation on labour productivity.

## 1. Introduction

This paper investigates (a) the determinants of innovation performance and (b) the impact of innovation performance on labour productivity of Swiss manufacturing firms in the period 1994-2002. The study is in the spirit of the paper of Crépon, Duguet and Mairesse, which was published 1998 in the *Economics of Innovation and New Technology* (see Crépon et al. 1998).

Our model of the innovative behaviour of Swiss manufacturing firms builds on the wide consent in economic literature that demand prospects, type and intensity of competition, market structure, factors governing the production of knowledge (appropriability, technological opportunities), resource endowment as well as firm size (as a variable controlling for further unobserved influences) are the main determinants of a firm's innovative activity. Labour productivity depends on physical and human capital as well as on new knowledge and innovation. Economies that develop more and more in the direction of a “knowledge-based economy” are relying increasingly on technological innovation. Hence, it is important to have some insights with respect to the (quantitative) relationship between innovation and economic performance.

The data used in this study come from the KOF panel database and were collected in 1996, 1999 and 2002 respectively based on a questionnaire quite similar to that used in the CIS. Most of the qualitative data refer to a period of three years (1994-1996; 1997-1999; 2000-2002). The database contains, among other things, firm data on several innovation indicators, on various innovation determinants (demand perspectives, conditions of market competition, appropriability conditions and technological opportunities, etc.), on firm performance (value added per employee) and other firm characteristics. We use an (unbalanced) panel of 1691 manufacturing firms.

In a first step, we specify an *innovation equation* containing as independent variables measures of demand expectations; measures of the intensity of price and non-price competition; the number of competitors in the most important market segment a firm is operating in; measures of technological opportunities (sources of external knowledge, technological potential); measures of the effectiveness of imitation protection; measures for skill shortage and shortage of internal financing. Further, it contains controls for industry affiliation and firm size. Firm size is inserted in the form of a polynomial (linear and quadratic term) with respect to the number of employees). This allows testing for scale effects. We use five dichotomous innovation measures (product innovations yes/no; process innovations yes/no; R&D activities yes/no; at least one patent application yes/no; products new to the market yes/no) and three metric measures (R&D expenditure as a percentage of sales; sales share of new products; sales share of considerably modified (already existing) products). The use of a wide spectrum of indicators helps to test the robustness of the specification of the innovation equation. The equations of the five dichotomous variables are estimated (a) by a simple probit for the pooled data using year dummies; (b) a probit with random effects in

order to take into consideration heterogeneity due to the panel character of the data. The equations of the three metric variables are estimated (a) by a simple tobit (for the pooled data using year dummies) in order to take account of the truncation of the variables (a lot of zero values as downward limit); (b) by a tobit with random effects.

In a second step, we specify a *labour productivity equation* (value added per employee) containing a variable for human capital (share of employees with tertiary-level education), a variable for physical capital (value added share of non-labour firm income), a measure of R&D personnel shortage and an instrumented innovation variable. Further, it contains controls for industry affiliation and firm size. As instruments we use the independent variables of the innovation equation specified in the first step. We investigate also in this second equation all eight innovation variables already introduced in the first step. Hence, we estimate eight different models, each one with two methods: (a) two-stage least squares with pooled data and year dummies; (b) generalized two-stage least squares with random effects.

We refrain here from specifying separately equations for innovation input and innovation output, hence to postulate a knowledge production function, because, with the exception of innovation input determining innovation output per definition, all other determinants in both equations are identical. We prefer to investigate directly the (presumably) different impact of innovation input and innovation output on economic performance without the transmitting role of a knowledge production function; for whose identification our mostly qualitative data would be too crude.

The new elements that this paper adds to empirical literature are, first, the use of a broad spectrum of variables covering most factors proposed and discussed in literature as possible determinants of innovative activity; second, the consideration of several innovation indicators, thus allowing testing the robustness of the relationship between innovation and economic performance; third, the use of panel data for the period 1997-2002, since only few studies until now could dispose of panel data.

Section 2 gives a short summary of related empirical literature. In section 3 we present the framework of analysis and the specification of the innovation and the productivity equation respectively. Section 4 deals with the data used in the study. In section 5 we discuss the empirical results. Section 6 contains a summary and some conclusions

## **2. Summary of Empirical Literature**

We concentrate here to empirical studies that (a) develop a multi-equation model for innovation and productivity at the firm level and (b) use CIS-like micro data.<sup>1</sup>

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<sup>1</sup> The volume of Kleinknecht (1996) contains studies on the determinants of innovation for France, Germany, the Netherlands and Switzerland in the mid-nineties; Raymond et al. (2004) give a survey of recent studies of the determinants of innovation. See also the papers in the Special Issue of *Economics and New Technology* of

Crépon et al. (1998) studied the links between productivity, innovation and research based on a structural model that explained productivity by innovation output, and innovation output by research investment based on a cross-section of French firm data. They found that the probability of engaging in R&D increases with its size, its market share and diversification, and with the demand pull and technology push indicators. R&D capital intensity increases with the same variables, except for size (only linear effect). The innovation output, as measured by patents numbers or innovative sales, rises with R&D capital intensity, demand pull and technology push indicators. Finally, firm productivity correlates positively with a higher innovation output, after controlling for labour skill and physical capital intensity. In a further study with French data Duguet (2006) distinguished two types of innovation, namely radical innovations and incremental innovations. He found for a cross-section of French firm data that radical innovations are the only significant contributors to TFP growth.

Lööf et al. (2001), Janz et al. (2003) and Griffith et al. (2005) conducted comparative studies for many countries using the framework of analysis developed by Crépon et al. (1998). The former study covers three Nordic countries (Finland, Norway and Sweden); the latter one compares German firms with Swedish firms. The third study deals with four European countries, namely France, Germany, Spain and the UK. All three studies are cross-section investigations based on CIS-Data. Lööf et al. found that the estimated elasticity of productivity with respect to innovation output is higher in Norway than in the other two countries. Surprisingly no significant relationship was found between innovation and productivity in Finland. The authors are reluctant to draw definite conclusions from these findings because of data errors, differences in model specification or unobserved country-specific effects. Janz et al. analyzed the relationship between productivity, innovation output and R&D expenditure for a pooled sample of German and Swedish firms. The analysis showed that the two main parameter estimates, the elasticity of labour productivity with respect to innovation output and the elasticity of innovation output with respect to innovation input, are not significantly different between the two countries. Finally, the authors of the third study found using different innovation output measures that the innovation output is significantly determined by the innovation effort in all four countries. In contrast to that, productivity effects of innovation showed up only for France, Spain and UK, but not for Germany.

In a recent study based on Irish panel data Love et al. (2005) estimated a recursive system comprising an innovation production function which related knowledge inputs to innovation success, and equations which related innovation to productivity. Results indicated that external sources of knowledge are important determinants of innovation success. Product innovation has a strong positive effect on growth, and has a negative contemporaneous effect,



but positive lagged effect, on productivity. Process innovation has a positive effect on productivity with no lagged effect.

Finally, Lööf and Heshmati (2006) and Van Leeuwen and Klomp (2006) discuss and apply alternative econometric approaches and model specifications. The former study examines using Swedish cross-section firm data the sensitivity of the estimated relationship between innovation and firm performance by carrying out comparisons in a number of ways (assuming different error structure for the same data source, estimating the same model with different data bases, using different classifications of firms' performance and/or innovation, etc.). In the latter study, which is based on Dutch firm data, the value-added production function framework is replaced by a revenue function approach. A positive impact on productivity is found only for revenue per employee but not for value-added per employee.

On the whole, the comparability of existing studies is rather limited due not only to data problems but also to differences with respect to the applied econometric methodology but also with respect to model specification.

### **3. Framework of Analysis**

#### **3.1 Specification of the Innovation Equation**

*Dependent variables.* In view of the complexity of the innovation process, characterized by several stages from basic research to the penetration of the market with new products, an approach relying on a single measure of innovation may leave out important relationships and produce results which are not robust (see e.g. Kleinknecht et al. 2002). In this study we use a set of innovation measures covering several stages of the innovation process, namely five binary indicators (product innovations yes/no; process innovations yes/no; R&D activities yes/no; patent applications yes/no; products new for the (world) market yes/no) and three metric indicators (R&D expenditure/sales; sales share of new products; sales share of considerably modified (existing) products).

*Independent variables.* For specifying the innovation equation we apply an eclectic approach by taking into account a series of important factors that are considered to be relevant for innovation at firm level in economic literature. There is a wide consent that demand growth potential, type and intensity of competition, market structure, firm size as well as factors governing the generation of knowledge (appropriability of the returns of innovations, technological opportunities in the relevant fields of activities) are the main determinants of the innovation activity at firm level. In accordance to this tradition, the empirical model used in this study comprises variables for the most important determinants of innovative activity as considered in the literature (see for example, Dasgupta 1986; Dosi 1988; Cohen and Levin 1989; and Cohen 1995 for reviews of this literature).

We distinguish four groups of explanatory variables. First, we include an indicator for demand conditions: variable D measures the expected development of demand on the relevant product markets in the medium run (next three years).

A second category of explanatory variables is related to the (product) market conditions under which the firms are operating, particularly the competitive pressures they are exposed to. Mostly, market concentration, a structural variable, is taken to reflect competitive pressures. Standard industrial organization models of product differentiation and monopolistic competition typically predict that more intense product market competition, measured by an increase in the substitutability between differentiated products, reduces post-entry rents, and therefore increases market concentration (see e.g. Kamien and Schwartz 1970, Dixit and Stiglitz 1977; see also the discussion in Aghion et al. 2005). In the game-theoretic literature the impact of market structure upon the schedule of innovation is shown to depend critically on the difference of profit rates preceding and following the innovation (see e.g. Reinganum 1981). This dependence being quite complicated, most studies do not come to theoretical unambiguous results with respect to the effects of market concentration on innovation (see Reinganum 1989 for a review of such studies). Recently, Aghion et al. (2005) developed a model that predicts an inverted-U relationship between product market competition and innovation. The authors found strong evidence for this model using U.K. panel data. In sum, whether positive effects in the tradition of Schumpeter are stronger than negative “free competition effects”, as some empirical studies find (see e.g. Geroski 1995, Blundell et al. 1999), has to be resolved at the empirical level. We use three variables to capture the influence of the market environment, namely a measure of the intensity of price competition on a firm’s specific market (variable IPC), a measure of the intensity of non-price competition and a measure of the market structure as reflected by the number of main competitors on a firm’s most important (worldwide) product market. We expect a positive effect of the intensity of non-price competition on innovation. This is in accordance with models of product differentiation, in which product quality is the main dimension of competition among firms and which are interpreted as models of incremental innovation (see e.g. Stoneman 1983, Levin and Reiss 1988). We do not have an a priori expectation with respect to the effect of price competition. A positive effect would confirm the “free competition effect”, a negative one the Schumpeter effect. We do not dispose of a quantitative measure of market concentration of the innovation-relevant market, so we cannot test the hypothesis of a U-inverted relationship. Our variable is defined only for some intervals with respect to the number of main competitors on a firm’s most important (worldwide) product market: up to 5 competitors, 6 to 15 competitors, 16 to 50 competitors, 50 and more competitors. What we can test with these data is the relationship between a certain market environment and innovation. To this end we include three dummies for the three market types (up to 5 competitors, 5 to 15 competitors, 16 to 50 competitors). Also in this case we do not have a priori sign expectations.

A third category of exploratory variables refers to the factors governing the production of knowledge (appropriability, technological opportunities). Theoretical literature focuses primarily on the effect of imperfect appropriability of results of innovation activities on the incentives to innovate (see e.g. Spence 1984). There is a twofold incentive problem. On the one hand, the existence of imperfect appropriability (above a critical level of the underlying knowledge spillovers) decreases the incentives to innovate, because of external losses of innovation rents caused by imperfect appropriability (“outgoing spillovers”). On the other hand, imperfect appropriability also increases the incentives to utilize spillovers coming from outside the firm (“incoming spillovers”). The extent of incoming spillovers depends also on the amount of external knowledge that is available or can be anticipated as being available (technological opportunities).

We use a measure of appropriability based on the firms’ assessment of the overall effectiveness of formal and informal mechanisms of protection of innovation returns (variable APPR; see Levin et al. 1987). We expect a positive effect of this variable. Technological opportunities representing the supply conditions of innovation-generating activities are proxied by two (sets) of variables. The first variable reflects the general technological potential characterizing the fields of activity that are relevant for the firm (variable TPOT). TPOT tries to capture the extent of overall accumulation of “basic knowledge”, part of which comes from science-oriented basic research. We expect a positive effect for this variable. The second (group) of technological opportunity variable(s) measures the importance of several sources of external knowledge for a firm’s innovative activities (see Klevorick et al. 1995). We use information for seven different sources of information, namely users, suppliers (of equipment, components etc.), competitors, affiliated firms, universities, patent disclosures and fairs and exhibitions. We expect a positive effect for the entire set of these variables but only necessarily for each of them.

Fourth, measures for financial and human resources assigned to the generation of new products and new processes are taken into account. Thus, in the innovation equation are also included a measure of shortage of internal financial resources for innovation (variable FIN\_IMPED) and a measure of shortage of skilled labour (variable SKILL\_IMPED). We expect negative effects for both variables.

Furthermore, firm size, an explanatory variables used in most innovation studies (see e.g. Cohen 1995), is also included in the present study. Firm size, which is expected to be positively related to innovation, plays a special role: it may prove to be an independent (additional) determinant of adoption, in which case it stands for firm-specific effects not explicitly modelled (range of activities, management capabilities etc.) and/or it may function as a proxy for other variables in the model in case it is strongly correlated with them (size-dependence of the model variables; see Arvanitis 1997); we concentrate here to the effects as an additional determinant. We use the number of employees in full-time equivalents as a

measure of firm size. We include a linear and a quadratic term with respect to the number of employees (variables  $L$ ,  $L^2$ ) in the innovation equation in order to capture possible nonlinearities. We expect that innovation increases with firm size but at a decreasing rate.

Finally, we control for manufacturing sub-sectors (dummy for high-tech manufacturing) and the time (two time dummies for 1999 and 2002 for the estimates with pooled data). We expect time dummies to reflect the effects of macroeconomic conditions on innovation not already captured by the demand variable  $D$ .

### **3.2 Specification of the Productivity Equation**

The productivity equation (dependent variable: logarithm of value added per employee) contains proxies of the intensity of human capital (variable  $LHK$ ; logarithm of the share of employees with tertiary-level education), a variable for shortage of R&D personnel (variable  $RDSKILL\_IMPED$ ; a specific problem of the Swiss economy especially in boom periods), physical capital (variable  $LC$ ; logarithm of capital income per employee) and knowledge capital approximated alternatively by the five binary and the three metric innovation indicators that already served as dependent variables of the innovation equations. Further, we control for firm being a foreign one or not (dummy variable  $FOREIGN$ ; foreign firm yes/no), for firm size, industry affiliation and time (if necessary). We expect positive effects for the resource endowment variables  $LC$  and  $LHK$  and a negative one for  $RDSKILL\_IMPED$ . Our main hypothesis with respect to the binary innovation indicators is that innovation activities would contribute as an additional production factor to an improvement of labour productivity firms compared to firms that are not involved in such activities (see Griliches 1979, 1995). The use of several binary variables for different kinds of innovation activities allows a serves to test the robustness of the innovation effect on economic performance. Positive effects are expected also for the three metric variables that measure the intensity of innovative activity. The signs for the variable  $FOREIGN$  as well as for the firm size dummies are not a priori clear.

Finally, we take into account the endogenous character of innovative activities by estimating a version of the productivity equation, in which the innovation indicators are instrumented. As instruments we use the independent variables of the innovation equation.

## **4. Data**

The data used in this study were collected in the course of three surveys among Swiss enterprises in the years 1996, 1999 and 2002 using a questionnaire which included besides questions on some basic firm characteristics (sales, exports, employment, investment and employees' vocational education) also several innovation indicators quite similar to those in

the Innovation Surveys of the European Community (CIS).<sup>2</sup> The survey was based on a (with respect to firm size) disproportionately stratified random sample of firms with at least 5 employees covering all relevant industries of the manufacturing sector, the construction sector and selected service industries as well as firm size classes (on the whole 18 industries and within each industry three industry-specific firm size classes with full coverage of the upper class of large firms). We used in this study only data for manufacturing firms. Answers were received from 33.5% (1996), 33.7% (1999) and 44.6% (2002) respectively of the manufacturing firms in the underlying sample. The response rates do not vary much across industries and size classes with a few exceptions (over-representation of machinery, under-representation of clothing/leather and wood processing). The final data set includes 1691 enterprises from all fields of activity and size classes and may be considered as representative of Swiss manufacturing (see table A.1 in the appendix for the structure of the used data set by industry, firm size class and year respectively).

## 5. Results

### 5.1 Innovation Equation

For each binary innovation variable we estimated (a) a probit model with the pooled data for all three years and two time dummies and (b) a probit model with random effects. In both cases heteroscedasticity-robust standard errors according to the White-procedure were computed. All estimations were conducted with STATA, Version 8. The rather high share of variance due to heterogeneity ( $\tau=0.41-0.61$  in Table 1) shows that taking account of random effect is the appropriate methodology for panel data. Table 1 shows the estimates for the five binary variables; it also contains detailed information on the construction of the model variables.

We take the estimates binary variables INNOPD and INNOPC as a reference in order to describe the main pattern of the determinants of innovation activities, which we then compare (a) with the pattern for the other three binary indicators and (b) with that for the three metric variables.<sup>3</sup>

*Demand expectations:* Positive medium-term demand expectations (variable D) in one period have a positive effect on the likelihood to introduce a product and or a process innovation in the next period. This result is accordance to theory and also many other empirical studies based on micro data.

*Competition:* As expected, there is a positive correlation between the intensity of non-price competition and the propensity to introduce product and/or process innovations (variable

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<sup>2</sup> Versions of the questionnaire in German and French are available in [www.kof.ethz.ch](http://www.kof.ethz.ch).

<sup>3</sup> We refrain here from presenting marginal effects instead of coefficients because most of the model variables are dummy variables and the economic interpretation of marginal effects is in this case rather problematic.

INPC). We also find a positive effect of the intensity of price competition but only for process innovation (variable IPC). In this case the “free competition effect” seems to be more important than the Schumpeterian effect. Intuitively, it is quite sensible to assume that high price competition for (obviously) quite substitutable products would be a strong incentive for reducing production costs through process innovation (see e.g. Levin and Reiss 1988).<sup>4</sup>

All three dummies for the market structure have positive and statistically significant coefficients in the estimates for product innovation but not in the estimates for process innovation. This means that all three concentration thresholds define market environments for which the likelihood of product innovations is significantly larger than in the polypolistic market with more than 50 competitors. In the random effect estimates for product innovations the differences between the coefficients of the three dummies are statistically significant but the coefficient for the threshold (6 to 15 competitors) is smaller than the respective coefficients for the other two thresholds (16 to 50 competitors) and (up to five competitors). In the simple probit model with time dummies two thresholds have the same coefficient. Thus, there is no monotonic positive relationship between concentration (as measured by the number of competitors) and the propensity to innovate. How can we interpret economically the effects of the concentration thresholds in the case of product innovations? Rather than the market power in the narrow sense of “high-concentration markets” with permanent high entry barriers they reflect the ability of innovative SMEs to operate in market “niches” (with less than 50 competitors) based on product differentiation due to incremental product innovation.

*Appropriability:* As expected, a high appropriability of innovation returns, as measured by a high effectiveness of formal and informal protection mechanisms (variable APPR), is important for both kinds of innovation.

*Technological opportunities:* The variable TPOT measuring the overall effect of externally available knowledge that is relevant for a firm’s innovative activity shows a statistically significant positive effect in all four estimates for INNOPD and INNOPC. A joint test for the seven single external sources of information showed that the overall effect is positive. Three single sources, namely users, patent disclosures and fairs and exhibitions have a significant positive effect on the propensity to introduce product innovations. Patent disclosures and fairs and exhibitions are a relevant information source also for process innovations. The variable for knowledge from competitors has a negative sign in the estimates for product innovations. Spillovers from competitors are obviously not a means to encourage innovative activities in a firm. The coefficients of the variables for suppliers, universities and affiliate firms are statistically insignificant. On the whole, incoming spillovers are transmitted through only a few channels.

*Shortages of resources:* Lacking enough (internal) financial resources for innovation is a serious obstacle of innovative activities, especially of product innovations, as the negative

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<sup>4</sup> An alternative strategy would be product innovation.

sign of this variable shows. Since we control for a firm's specific demand development as well as for macroeconomic conditions (time dummies) this kind of impediment seems to be of structural nature, thus a possible matter of concern for policy makers. Skill shortages are relevant only for product innovations. Also in this case we identify a structural obstacle of innovative activity that could also reveal a policy problem.

*Firm size:* Also in a panel framework we find the same pattern as in the single cross-sections (see e.g. Arvanitis 1997), namely a significantly positive coefficient for the linear term  $L$  and a significantly negative coefficient for the quadratic term ( $L^2$ ). This non-linear relationship shows that the likelihood to innovate is clearly increasing with firm size but with diminishing rate.

*Control variables:* There is a positive effect for firms in high-tech manufacturing reflecting presumably further advantages of firms in this sub-sector that are not captured by the other model variables. This effect is found only for product innovations. Obviously the differences between high-tech and low-tech manufacturing are not primarily related to differences in the efficiency of production techniques. The signs and the magnitudes of the coefficients of the time dummies in the pooled data probit estimates for product innovations show that the general economic conditions were quite unfavourable for innovative activities in the period 1997-1998 (year 1999) compared to the reference period 1994-1996 and improved in the period 2000-2002 (year 2002). For process innovations the general conditions were in both periods worse than in the reference period. This result is contrary to the theoretical expectation that firms increase their activities with respect to cost-saving process innovations under adverse economic conditions (see e.g. Utterback and Abernathy 1975).

In sum, all four groups of hypothesized variables and firm size as well are statistically relevant. This general finding is in accordance to previous studies (see e.g. Arvanitis and Hollenstein 1996 for a similar analysis with cross-section data of 1993).

*Other binary innovation indicators:* For the dichotomous variable R&D we obtain almost the same pattern as for INNOPD with the exception of the variable APPR (positive but statistically insignificant coefficient) and the variable FIN\_IMPED (negative but statistically insignificant coefficient). A further difference refers to the results with respect to the variable for the market concentration: in this case the coefficients of the dummies become larger with increasing concentration. The coefficients of the time dummies are statistically insignificant. This means that the general economic conditions did not influence the likelihood of conducting R&D but only the R&D intensity (see below).

For the variables PAT and WN we obtain similarities to the reference pattern for product innovations with respect to demand expectations (D), appropriability (APPR), technological potential (TPOT), patent disclosures as an important external information source and firm size. There are also some differences as to the relevance of market conditions: non-price competition is not relevant for PAT and WN, price competition only for WN; for the

likelihood to file patent applications (PAT) we observe, similar to R&D, a (rather weak) tendency of increasing with rising market concentration (Schumpeterian effect). This is not the case for WN. University knowledge seems to be important for patenting. Finally the variables for resource shortages show the expected negative sign but are statistically insignificant in the estimates for PAT and WN. For both indicators general economic conditions improved in the last period 2000-2002.

On the whole, for the four binary indicators referring mainly to product innovations we find a series of robust results across all estimates that are worth noting once more here: positive effects for demand expectations, technological potential, patent disclosures as an important external knowledge source firm size; also positive effects for firms operating on a market niche with up to five competitors; partly also positive impact for the intensity of non-price competition, appropriability conditions and users as relevant knowledge source. Finally, belonging to high-tech manufacturing contributes to a higher innovation performance, even after we control for all other determinants.

#### *Metric innovation variables:*

We estimated (a) a tobit model with pooled data and time dummies and (b) a tobit model with random effects for each of the three metric innovation indicators, namely the logarithm of R&D intensity (LRDS; R&D expenditure divided by sales), the logarithm of the sales share of new products (LNEWS) and the logarithm of the sales share of significantly modified already existing products (LIMPS).<sup>5</sup> All estimations were conducted with STATA, Version 8. Table 2 shows the estimates for the three metric variables; it also contains detailed information on the construction of the model variables. Also in these estimates we find a considerable amount of heterogeneity ( $\tau=0.37-0.64$  in Table 2).

*Demand conditions:* We find also for these indicators significant positive effects of demand expectations on innovation performance.

*Competition:* the intensity of non-price competition is important for input-oriented as well as output-oriented indicators; the intensity of price competition is relevant for the variable IMPS that measures the sales share of considerably modified existing products, which are more price-sensitive than thoroughly new products (variable LNEWS). Market niches with up to five competitors are as market environment significantly more favourable for innovation than a market with more than 50 competitors; this result is valid for all three metric indicators. For the variables LRDS and LIMPS this is valid also for markets with 6 to 15 competitors;

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<sup>5</sup> In order to be able to calculate the logarithms of R&D intensity for firms without R&D expenditures, thus LRDS=0, we put these firms at the minimum value of R&D intensity of the firms with R&D expenditure which was 0.00001. We then calculated the logarithms of RDS and subtracted  $\log(0.00001)=-11.513$  to get 0 values for the firms without R&D expenditures. The minimum value for the sales share of new products was 0.4, thus LNEWS=-0.916, for the sales share of considerably modified already existing products 0.6, thus LIMPS=-0.511; also in this case we performed a linear transformation of the data in order to get zero values for the firms without sales of innovative products.



moreover, the coefficient of the dummy for up to five competitors is significantly larger than that for 6 to 15 competitors. This result we interpret as (weak) evidence for the existence of the Schumpeterian effect of competition. In the estimates for LNEWS we find at clearest the tendency of R&D intensity to increase with increasing concentration.

*Appropriability:* We find positive effects for the variables LRDS and LNEWS; appropriability is not relevant for modified products with a lower degree of innovativeness than thoroughly new products.

*Technological opportunities:* The (anticipated) technological potential is also with respect to these innovation measures variables quite relevant. Users as a knowledge source show positive effects for both categories of innovative products but not for R&D intensity. In the estimates for LRDS and LIMPS we obtain also positive effects for university knowledge. Thus, the acquisition and utilization of science-based knowledge seems to correlate positively with the intensity of innovation activities. On the contrary, the likelihood to get involved in innovation activities is not dependent on such specialized knowledge.

*Firm size:* We obtain the standard pattern as for the binary variables (positive linear term, negative quadratic term).

*Shortages of resources:* The coefficients for the variables for shortages in finance and high-skilled personnel are throughout negative but only in the estimates for LNEWS statistically significant.

*Control variables:* For all three indicators the affiliation to high-tech manufacturing is positively related to a higher innovation performance. The general economic conditions are relevant only for LRDS.

## **5.2 Productivity Equation**

We estimated eight different models, namely five with the instrumented binary innovation variables and three with the instrumented three metric indicators, each one of them with two methods: (a) two-stage least squares with pooled data and year dummies; (b) generalized two-stage least squares with random effects. As instruments were used the independent variables of the innovation equation in Tables 1 and 2. All estimations were conducted with STATA, Version 8. The high share of variance due to heterogeneity ( $\tau=0.53-0.73$  in Tables 3 and 4) shows that taking account of random effect is the appropriate methodology for panel data. Table 3 shows the estimates of the productivity equation with five alternative binary measures of innovation, Table 4 the respective estimates with the three metric innovation indicators. Both tables contain detailed information on the construction of the model variables.

As expected, the coefficients of the variables for resource endowment (LHK; LC) are positive and highly statistically significant across all estimates. The elasticity of capital income per

employee varies between 0.046 and 0.073 in Table 3, meaning that an increase of 1% of this variable is correlated with an increase of 0.046% to 0.073% of labour productivity; the elasticity of the share of employees with tertiary-level education is lower (0.023-0.030) but much more stable across the model versions presented in this table. The coefficient of the variable FOREIGN is also positive and highly significant, which can be interpreted as a hint that foreign firms are, after controlling for all other factors, more productive than domestic ones. Further, the coefficient of the shortage variable RDSKILL\_IMPED is negative and statistically significant in all estimates with the exception of the estimates with INNOPD. This kind of resource shortage should be a matter of particular policy concern.

Now we turn to the binary innovation variables. The coefficients of all five instrumented innovation indicators are positive and statistically significant.<sup>6</sup> They vary between 0.23 (variable WN) and 0.58 (variable R&D). An economic interpretation of these coefficients is that, for example, on average a switch from a firm without product innovations to a firm that has introduced product innovations, is correlated to an increase of 41% to 44% of labour productivity.<sup>7</sup> The smallest impact is found for WN (21%) and the largest for PAT (46%).

We find throughout a significant positive impact also for all three metric indicators. A change of 1% of the R&D intensity (R&D expenditure divided by sales) impacts an increase of 0.052% to 0.056% of productivity, all other things being equal.<sup>8</sup> For comparison, the respective effects for human capital and physical capital are 0.046% and 0.027% respectively. The corresponding effects for the sales share of new products and the sales share of highly improved (already) existing) products are larger, namely 0.100% to 0.113% and 0.135% to 0.141% respectively. Thus, the output-oriented variables LNEWS and LIMPS show a considerably larger effect on economic performance than the input-oriented measure LRDS.

## 6. Summary and Conclusions

The results for the innovation equations can be summarized as follows: Favourable demand conditions are an important precondition for innovative activities to be undertaken by private enterprises (introduction of product and/or process innovations, R&D activities, patenting). They also enhance innovation performance as measured by the R&D intensity (LRSD) or the sales shares of innovative products (LNEWS, LIMPS). Competition pressures are more important for the intensity of innovation activities than for the basic decisions to engage in innovation activities as measured by the binary indicators. The most robust result across all estimates with respect to market environment is that a market niche with up to five competitors is considerably more favourable for a firm than most other market constellations.

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<sup>6</sup> This result is much less clear without instrumented variables.

<sup>7</sup> We calculated the relative increase of labour productivity by the formulas:  $100 \cdot \ln(1+0.072) = 6.9$  and  $100 \cdot \ln(1+0.076) = 7.3$  respectively; see Halvorsen and Palmquist 1980, p. 475.

<sup>8</sup> We found an elasticity of R&D capital of 0.043 in an earlier study based on cross-section data for 1990 (see Arvanitis and Hollenstein 2002).

The finding complements and is not contradictory to the finding with respect to the intensity of price and non-price competition. A monotonic relationship between innovation and market concentration could be found only for single indicators. Further, appropriability conditions are significantly positively related with most innovation indicators. The intense use of patent disclosures and users as knowledge sources is shown to be positively correlated with innovation in most estimates. University knowledge seems to be relevant mainly for innovation performance, less for the basic decision to engage in innovation activities (with the exception of patenting). Shortages of resources are relevant primarily for the basic decision to get involved in innovation activities. Belonging to high-tech manufacturing is throughout a characteristic of above-average innovative firms. Rather unexpectedly, the shares of the innovative product are not dependent on general economic conditions, rather on the development of the specific demand of such products as measured by the variable D. On the contrary, R&D intensity varies with the general economic conditions; for both periods 1997-1999 and 2000-2002 it was on average higher than in the reference period 1994-1996.

The results for the productivity equations can be summarized as follows: we find significantly positive coefficients for all eight instrumented innovation variables. The magnitude of the impact effect on productivity of the five dichotomous variables varies between 21% and 46%. This means that dependent on the concrete innovation indicator the shift from a firm without innovation activities to the one with such activities correlates with a productivity increase of 21% to 46%. Further, a 1% change of the R&D intensity (R&D expenditure divided by sales) impacts an increase of 0.054% of productivity, all other things being equal. The respective effects for the sales share of new products and the sales share of highly improved (already) existing) products are larger, namely 0.106% and 0.138% respectively.

Finally, the persistence of shortages of internal finance of innovation and qualified personnel (in some of the estimates of the innovation equations) as well as of R&D personnel (in most estimates of the productivity equation) points at possible structural problems that should be a matter of concern of economic policy.

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**Tables:**

**Table 1:** Innovation equation: determinants of innovation; several dichotomous innovation indicators

Explanatory variables	INNOPD <sup>(1)</sup>		INNOPC <sup>(1)</sup>		R&D <sup>(1)</sup>		PAT <sup>(1)</sup>		WN <sup>(1)</sup>	
	(Probit pooled data)	(Random Effects)	(Probit pooled data)	(Random Effects)	(Probit pooled data)	(Random Effects)	(Probit pooled data)	(Random Effects)	(Probit pooled data)	(Random Effects)
D <sup>(2)</sup>	0.341*** (0.094)	0.352** (0.140)	0.487*** (0.084)	0.437*** (0.107)	0.453*** (0.094)	0.575*** (0.147)	0.188** (0.078)	0.281** (0.115)	0.426*** (0.075)	0.496*** (0.105)
IPC <sup>(3)</sup>	0.100 (0.086)	0.128 (0.130)	0.173** (0.079)	0.224** (0.100)	0.097 (0.084)	0.122 (0.130)	0.237*** (0.080)	0.331*** (0.122)	0.076 (0.078)	0.099 (0.109)
INPC <sup>(4)</sup>	0.279*** (0.074)	0.443*** (0.120)	0.228*** (0.070)	0.271*** (0.090)	0.208*** (0.073)	0.329*** (0.116)	0.005 (0.069)	0.092 (0.102)	0.009 (0.068)	0.018 (0.094)
Market environment <sup>(5)</sup>										
16 to 50 competitors	0.312** (0.127)	0.559*** (0.212)	0.131 (0.128)	0.205 (0.165)	0.202* (0.124)	0.325 (0.203)	0.167 (0.136)	0.310 (0.204)	0.025 (0.134)	0.043 (0.187)
6 to 15 competitors	0.312*** (0.103)	0.439*** (0.170)	0.175* (0.101)	0.177 (0.133)	0.373*** (0.102)	0.515*** (0.170)	0.299*** (0.110)	0.502*** (0.175)	0.094 (0.108)	0.140 (0.154)
up to 5 five competitors	0.386*** (0.116)	0.611*** (0.195)	0.147 (0.113)	0.167 (0.148)	0.443*** (0.115)	0.674*** (0.196)	0.352*** (0.120)	0.586*** (0.191)	0.293** (0.116)	0.431*** (0.168)
APPR <sup>(6)</sup>	0.060 (0.038)	0.181*** (0.059)	-0.008 (0.033)	0.103** (0.043)	0.027 (0.038)	0.073 (0.056)	0.215*** (0.036)	0.278*** (0.054)	0.066* (0.035)	0.097** (0.048)
TPOT <sup>(7)</sup>	0.314*** (0.084)	0.443*** (0.129)	0.373*** (0.077)	0.455*** (0.101)	0.382*** (0.082)	0.566*** (0.134)	0.158** (0.072)	0.239** (0.107)	0.299*** (0.070)	0.418*** (0.100)
External sources of information <sup>(8)</sup>										
Users	0.253*** (0.075)	0.363*** (0.120)	0.097 (0.072)	0.140 (0.091)	0.172** (0.075)	0.262** (0.119)	0.063 (0.071)	0.093 (0.105)	0.168** (0.069)	0.222** (0.097)
Suppliers	-0.118 (0.087)	-0.119 (0.135)	-0.081 (0.129)	-0.128 (0.168)	-0.126 (0.085)	-0.161 (0.135)	-0.348*** (0.085)	-0.426*** (0.125)	-0.039 (0.080)	-0.052 (0.112)
Competitors	-0.245*** (0.080)	-0.389*** (0.131)	-0.103 (0.075)	-0.139 (0.096)	-0.202** (0.079)	-0.335*** (0.129)	-0.098 (0.075)	-0.151 (0.111)	-0.322*** (0.074)	-0.408*** (0.106)
Affiliated firms	0.062 (0.092)	0.137 (0.149)	0.085 (0.122)	0.095 (0.160)	0.069 (0.071)	0.175 (0.150)	0.056 (0.080)	0.081 (0.120)	-0.038 (0.077)	-0.036 (0.111)

Universities	-0.013 (0.094)	-0.073 (0.145)	-0.001 (0.085)	-0.065 (0.109)	0.117 (0.093)	0.148 (0.148)	0.157** (0.080)	0.299** (0.122)	0.108 (0.078)	0.091 (0.110)
Patent disclosures	0.352*** (0.129)	0.520** (0.208)	0.260** (0.107)	0.350** (0.141)	0.315** (0.131)	0.435** (0.203)	0.755*** (0.098)	1.043*** (0.153)	0.231** (0.092)	0.278** (0.129)
Fairs, exhibitions	0.165** (0.077)	0.281** (0.122)	0.101 (0.072)	0.173* (0.093)	0.218*** (0.074)	0.340*** (0.123)	0.040 (0.072)	0.041 (0.106)	0.064 (0.069)	0.104 (0.098)
FIN_IMPDED <sup>(9)</sup>	-0.294*** (0.084)	-0.433*** (0.133)	-0.153* (0.083)	-0.150 (0.106)	-0.109 (0.084)	-0.115 (0.133)	-0.030 (0.080)	-0.104 (0.126)	-0.087 (0.080)	-0.096 (0.116)
SKILL_IMPDED <sup>(10)</sup>	-0.182** (0.083)	-0.253* (0.130)	-0.024 (0.079)	0.004 (0.102)	-0.129 (0.082)	-0.224* (0.132)	-0.135* (0.082)	-0.158 (0.120)	-0.041 (0.078)	-0.031 (0.111)
L <sup>(11)</sup>	1.4E+03*** (3.5E+04)	2.2E-03*** (4.7E+04)	7.7E-04*** (2.0E-04)	9.3E-04*** (2.2E-04)	1.9E-03*** (3.8E-04)	2.9E-03*** (5.2E-04)	1.2E-03*** (1.9E-04)	1.8E-03*** (2.6E-04)	6.7E-04*** (1.2E-04)	9.2E-04*** (1.8E-04)
L <sup>(12)</sup>	-6.8E-08*** (1.7E-08)	-1.0E-07*** (3.2E-08)	-3.7E-08*** (9.9E-09)	-4.3E-08*** (1.5E-08)	-9.0E-08*** (1.9E-08)	-1.4E-07*** (3.3E-08)	-5.9E-08*** (9.4E-09)	-8.6E-08*** (1.7E-08)	-3.9E-08*** (8.6E-09)	-5.2E-08*** (1.9E-09)
High-tech manufacturing <sup>(12)</sup>	0.349*** (0.076)	0.563*** (0.140)	0.035 (0.071)	0.026 (0.096)	0.437*** (0.075)	0.726*** (0.147)	0.386*** (0.070)	0.614*** (0.123)	0.380*** (0.069)	0.580*** (0.113)
Year 1999	-0.248*** (0.082)	//	-0.625*** (-0.080)	//	-0.096 (0.082)	//	0.140* (0.080)	//	-0.087 (0.078)	//
Year 2002	0.197* (0.106)	//	-0.377*** (0.099)	//	0.147 (0.103)	//	0.330*** (0.089)	//	0.195** (0.087)	//
Const.	-0.412** (0.162)	-0.912*** (0.243)	0.016 (0.154)	-0.620*** (0.190)	-0.638*** (0.163)	-1.027*** (0.245)	-2.137*** (0.170)	-3.032*** (0.314)	-1.432*** (0.159)	-2.055*** (0.247)
N	1691	1691	1691	1691	1691	1691	1691	1691	1691	1691
Pseudo R <sup>2</sup>	0.179		0.113		0.195		0.231		0.142	
LR ( $\chi^2$ )	255***	90***	187***	87***	293***	97***	405***	161***	300***	142***
$\tau$		0.605		0.406		0.610		0.572		0.509
LR ( $\chi^2$ ); $\tau = 0$		41***		20***		42***		62***		54***

Notes: (1) INNOPD (INNOPC): introduction of product (process) innovations yes/no; R&D: R&D activities yes/no; PAT: patent applications yes/no; WN: products new for the (world) market; in 1994-1996, 1997-1999 and 2000-2002 respectively; (2) D: expectations with respect to demand development in the next three years; transformation of a five-level ordinal variable (level 1: , very weak"; level 5: , very strong") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (3) IPC: intensity of price competition; original and transformed variable as D; (4) INPC: intensity of non-price competition; original and transformed as D; (5) market environment: three dummies for the market types: up to 5 main competitors on the (worldwide) product market; 6 to 15 competitors; 16-50 competitors; reference: 50 and more competitors; (6) APPR: overall effectiveness of formal and informal mechanisms of appropriation of innovation returns; transformation of a five-level ordinal variable

(level 1: ,not effective'; level 5: ,very effective") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable);

(7) TPOT: technological potential, i.e. scientific and technological knowledge relevant to the firm's innovative activity; transformation of a five-level ordinal variable (level 1: ,very low'; level 5: ,very high") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (8): importance of seven sources different sources of innovation-relevant external information; transformation of a five-level ordinal variable (level 1: ,not important'; level 5: ,very important") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (9): FIN\_IMPEDI: importance of shortage of internal financing resources as an impediment of innovative activity; original and transformed variable as in (8); (10): SKILL\_IMPEDI: importance of shortage of skilled labour; original and transformed variable as in (8); (11):  $L$ ,  $L^2$ : number of employees (in full-time equivalents); square of the number of employees; (12) High-tech manufacturing: chemicals, plastics, electrical and non-electrical machinery, vehicles; electronics/scientific instruments; reference: low-tech manufacturing: food, beverage and tobacco, textiles, clothing and leather, wood processing, paper, printing, glass, stone and clay, metal, metalworking, watches, other manufacturing, energy; time dummies for 1999 and 2002; reference year: 1996; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level respectively; heteroscedasticity-robust standard errors (White procedure);  $\tau$ : share of variance that can be traced back to heterogeneity.



**Table 2:** Innovation equation: determinants of innovation; metric innovation indicators

Explanatory variables	LRDS <sup>(1)</sup> (Tobit pooled data) Effects	LNEWS <sup>(1)</sup> (Tobit pooled data) Effects	LIMPS <sup>(1)</sup> (Tobit pooled data) Effects	(Tobit Random Effects)
D <sup>(2)</sup>	1.402*** (0.269)	0.697*** (0.112)	0.492*** (0.125)	0.375*** (0.122)
IPC <sup>(3)</sup>	0.515* (0.276)	0.066 (0.114)	0.426*** (0.128)	0.422*** (0.126)
INPC <sup>(4)</sup>	0.644*** (0.239)	0.697*** (0.222)	0.221** (0.096)	0.305*** (0.108)
Market environment: <sup>(5)</sup> 16 to 50 competitors	0.710 (0.466)	0.527*** (0.194)	0.462** (0.189)	0.203 (0.213)
6 to 15 competitors	1.783*** (0.374)	0.570*** (0.158)	0.501*** (0.159)	0.456*** (0.177)
up to 5 five competitors	2.092 (0.409)	2.112*** (0.405)	0.521*** (0.172)	0.485** (0.193)
APPR <sup>(6)</sup>	0.275** (0.122)	0.279** (0.111)	0.104** (0.048)	0.034 (0.054)
TPOT <sup>(7)</sup>	1.488*** (0.250)	1.198*** (0.235)	0.259** (0.103)	0.366*** (0.115)
External sources of information: <sup>(8)</sup>				
Users	0.324 (0.242)	0.220 (0.227)	0.308*** (0.102)	0.251** (0.112)
Suppliers	-0.849*** (0.286)	-0.636** (0.267)	-0.072 (0.119)	-0.139 (0.130)
Competitors	-0.531** (0.255)	-0.542** (0.237)	-0.280*** (0.106)	-0.411*** (0.117)
Affiliated firms	0.168 (0.275)	0.259 (0.272)	0.033 (0.114)	0.242* (0.128)
Universities	0.759***	0.666**	0.038	0.260**

Patent disclosures	(0.275) 1.064*** (0.333)	(0.261) 0.818*** (0.314)	(0.116) 0.173 (0.137)	(0.115) 0.159 (0.134)	(0.129) 0.196 (0.152)	(0.129) 0.213 (0.150)
Fairs, exhibitions	0.404* (0.244)	0.332 (0.230)	0.354*** (0.102)	0.324*** (0.100)	0.271** (0.113)	0.310*** (0.112)
FIN_IMPDED <sup>(9)</sup>	-0.448 (0.283)	-0.301 (0.275)	-0.240** (0.119)	-0.215* (0.119)	-0.205 (0.132)	-0.161 (0.133)
SKILL_IMPDED <sup>(10)</sup>	-0.391 (0.279)	-0.342 (0.263)	-0.199* (0.115)	-0.185* (0.113)	-0.178 (0.128)	-0.152 (0.127)
L <sup>(11)</sup>	7.5E-04*** (2.5E-04)	1.0E-03*** (2.9E-04)	3.6E-04*** (1.3E-04)	3.9E-04*** (1.5E-04)	5.1E-04*** (1.5E-04)	5.9E-04*** (1.6E-04)
L <sup>2(11)</sup>	-4.3E-08*** (1.7E-08)	-5.5E-08** (1.9E-08)	-2.3E-08* (1.2E-08)	-2.4E-08* (1.3E-08)	-3.9E-08*** (1.4E-08)	-4.3E-08*** (1.5E-08)
High-tech manufacturing <sup>(12)</sup>	2.169*** (0.249)	2.345*** (0.277)	0.559*** (0.104)	0.604*** (0.113)	0.494*** (0.116)	0.508*** (0.123)
Year 1999	0.641** (0.273)	//	-0.253** (0.114)	//	-0.144 (0.128)	//
Year 2002	1.287*** (0.307)	//	-0.060 (0.127)	//	-0.049 (0.142)	//
Const.	-1.903*** (0.562)	-1.298** (0.525)	-0.123 (0.238)	-0.186 (0.223)	-0.225 (0.264)	-0.304 (0.249)
N	1691	1691	1691	1691	1691	1691
N(left-censored)		471		518		576
Pseudo R <sup>2</sup>	0.072		0.045		0.038	
LR ( $\chi^2$ )	504***	383***	273***	205***	227***	195***
$\tau$ ( $\chi^2$ )		0.637***		0.460***		0.373***

Notes: (1) LRDS: logarithm of R&D expenditures divided by sales; LNEWS: logarithm of sales share of new products; LIMPS: logarithm of sales share of (already existing) considerably modified products; in 1995, 1998 and 2001 respectively; (2) D: expectations with respect to demand development in the next three years; transformation of a five-level ordinal variable (level 1: ,very weak'; level 5: ,very strong') to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (3) IPC: intensity of price competition; original and transformed variable as D; (4) INPC: intensity of non-price competition; original and transformed as D; (5) market environment: three dummies for the market types: up to 5 main competitors on the (worldwide) product market; 6 to 15 competitors; 16-50 competitors; reference: 50 and more competitors; (6) APPR: overall effectiveness of formal and informal mechanisms of appropriation of innovation returns; transformation of a five-level ordinal variable (level 1: ,not effective'; level 5: ,very effective') to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable);

(7) TPOT: technological potential, i.e. scientific and technological knowledge relevant to the firm's innovative activity; transformation of a five-level ordinal variable (level 1: ,very low'; level 5: ,very high") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (8): importance of seven sources different sources of innovation-relevant external information; transformation of a five-level ordinal variable (level 1: ,not important'; level 5: ,very important") to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (9): FIN\_IMPEDI: importance of shortage of internal financing resources as an impediment of innovative activity; original and transformed variable as in (8); (10): SKILL\_IMPEDI: importance of shortage of skilled labour; original and transformed variable as in (8); (11):  $L$ ,  $L^2$ : number of employees (in full-time equivalents; square of the number of employees; (12) High-tech manufacturing: chemicals, plastics, electrical and non-electrical machinery, vehicles; electronics/scientific instruments; reference: low-tech manufacturing: food, beverage and tobacco, textiles, clothing and leather, wood processing, paper, printing, glass, stone and clay, metal, metalworking, watches, other manufacturing, energy; time dummies for 1999 and 2002; reference year: 1996; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level respectively; heteroscedasticity-robust standard errors (White procedure);  $\tau$ : share of variance that can be traced back to heterogeneity.



N	1691	1691	1691	1691	1691	1691	1691
R <sup>2</sup>	0.015						
F	12***						
SER	0.395						
R <sup>2</sup> overall	0.096						
Wald ( $\chi^2$ )	235***						
$\tau$	0.590						

Notes: (1) LHK: logarithm of the share of employees with tertiary-level education; (2) RDSKILL\_IMPEDI: shortage of R&D personnel; transformation of a five-level ordinal variable (level 1: „not important”; level 5: „very important”) to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (3) LC: logarithm of capital income pro employee (capital income=value added minus wage costs); (4) INNOPD: introduction of product innovations yes/no; (5): introduction of process innovations; (6) R&D: R&D activities yes/no; (7) PAT: patent applications yes/no; (8) WN: products new for the (world) market; in 1994-1996, 1997-1999 and 2000-2002 respectively; (9): FOREIGN: foreign firm yes/no; dummy variables for 2-digit industries and firm size; reference industry: food, beverage and tobacco; reference firm size class: 5-19 employees; time dummies for 1999 and 2002; reference year: 1996; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level respectively; heteroscedasticity-robust standard errors (White procedure);  $\tau$ : share of variance that can be traced back to heterogeneity.

**Table 4:** Productivity equation; dependent variable: value added per employee; metric innovation indicators

Explanatory variables	2SLS pooled data effects (LRDS instru- mented)	G2SLS Random- data effects (LRDS instru- mented)	2SLS pooled data effects (LNEWS instru- mented)	G2SLS Random- data effects (LNEWS instru- mented)	2SLS pooled data effects (LIMPS instru- mented)	G2SLS Random- data effects (IMPS instru- mented)
LHK <sup>(1)</sup>	0.048*** (0.015)	0.043*** (0.015)	0.059*** (0.014)	0.053*** (0.014)	0.057*** (0.014)	0.055*** (0.014)
RDSKILL_IMPDED <sup>(2)</sup>	-0.056** (0.023)	-0.059** (0.023)	-0.052** (0.023)	-0.048** (0.023)	-0.055** (0.024)	-0.046* (0.023)
LC <sup>(3)</sup>	0.027*** (0.007)	0.026*** (0.004)	0.025*** (0.007)	0.023*** (0.004)	0.027*** (0.007)	0.023*** (0.004)
LRDS <sup>(4)</sup>	0.052*** (0.011)	0.056*** (0.011)	//	//	//	//
LNEWS <sup>(5)</sup>	//	//	0.100*** (0.030)	0.113*** (0.036)	//	//
LIMPS <sup>(6)</sup>	//	//	//	//	0.135*** (0.031)	0.141*** (0.038)
FOREIGN <sup>(7)</sup>	0.119*** (0.034)	0.101*** (0.032)	0.111*** (0.032)	0.089*** (0.031)	0.124*** (0.033)	0.107*** (0.033)
Year 1999	0.013 (0.025)	//	0.053** (0.024)	//	0.056** (0.025)	//
Year 2002	0.051* (0.031)	//	0.114*** (0.026)	//	0.109*** (0.028)	//
Const.	11.784*** (0.087)	11.788*** (0.074)	11.827*** (0.087)	11.853*** (0.081)	11.840*** (0.082)	11.874*** (0.075)
Industry dummies	yes (17)	yes (17)	yes (17)	yes (17)	yes (17)	yes (17)
Firm size dummies	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)
N	1691	1691	1691	1691	1691	1691
R <sup>2</sup>	0.126		0.141		0.045	
F	11***		13***		12***	

SER	0.371	0.372	0.392
R <sup>2</sup> overall	0.148	0.141	0.116
Wald ( $\chi^2$ )	241***	259***	227***
T	0.549	0.525	0.621

Notes: (1) LHK: logarithm of the share of employees with tertiary-level education; (2) RDSKILL\_IMPEDI: shortage of R&D personnel; transformation of a five-level ordinal variable (level 1: ,not important'; level 5: ,very important') to a binary variable (value 1: levels 4 and 5 of the original five-level variable; value 0: levels 1, 2 and 3 of the original variable); (3) LC: logarithm of capital income pro employee (capital income=value added minus wage costs); (4) LRDS: logarithm of R&D expenditures divided by sales; (5) LNEWS: logarithm of sales share of new products; (6) LIMPS: logarithm of sales share of (already existing) considerably modified products; in 1995, 1998 and 2001 respectively; (7): FOREIGN: foreign firm yes/no; dummy variables for 2-digit industries and firm size; reference industry: food, beverage and tobacco; reference firm size class: 5-19 employees; time dummies for 1999 and 2002, reference year: 1996; \*\*\*, \*\*, \* denote statistical significance at the 1%, 5% and 10% test level respectively; heteroscedasticity-robust standard errors (White procedure);  $\tau$ : share of variance that can be traced back to heterogeneity.

## APPENDIX:

**Table A.1:** Composition of the dataset

Industry	N	Percentage of firms
Food, beverage, tobacco	125	7.4
Textiles	54	3.2
Clothing, leather	27	1.6
Wood processing	79	4.7
Paper	41	2.4
Printing	107	6.3
Chemicals	98	5.8
Plastics, rubber	86	5.1
Glass, stone, clay	79	4.7
Metal	39	2.3
Metalworking	252	14.9
Machinery	260	15.4
Electrical machinery	73	4.3
Electronics, instruments	162	9.6
Watches	59	3.5
Vehicles	32	1.9
Other manufacturing	78	4.6
Energy	39	2.3
Firm size		
5 to 19 employees	399	23.6
20-49 employees	370	21.9
50-99 employees	296	17.5
100-199 employees	298	17.6
200-499 employees	213	12.6
500-999 employees	71	4.2
1000 employees and more	44	2.6
Year 1996	512	30.3
Year 1999	512	30.3
Year 2002	666	39.4
Total	1691	100



Table A.2: Correlation between the innovation indicators

	INNO PD	INNO PC	R&D	PAT	WN	LRDS	LNEWS
INNOPC	0.476						
R&D	0.717	0.520					
PAT	0.375	0.243	0.409				
WN	0.389	0.269	0.396	0.427			
LRDS	0.698	0.490	0.924	0.502	0.482		
LNEWS	0.683	0.479	0.617	0.352	0.471	0.649	
LIMPS	0.639	0.491	0.587	0.325	0.327	0.602	0.528

**Table A.3:** Correlation matrix; innovation model

	D	IPC	INPC	16-50 comp.	6-15 comp.	up to 5 comp.	APPR	TPOT	users	suppl.	compet. affil.	univers. discl.	patent discl.	fairs exhib.	FIN_ IMPED	SKILL_ IMPED
IPC	-0.085															
INPC	0.096	-0.009														
16-50 competitors	-0.058	0.042	-0.027													
6-15 competitors	0.037	0.035	0.043	-0.359												
up to 5 competitors	0.070	-0.115	-0.043	-0.225	-0.513											
APPR	0.116	0.009	0.160	-0.041	0.023	0.080										
TPOT	0.110	0.047	0.120	-0.027	0.026	0.021	0.234									
users	0.038	0.038	0.071	-0.024	0.030	0.023	0.152	0.117								
suppliers	-0.003	0.063	0.071	-0.001	0.031	0.056	0.069	0.074	0.127							
competitors	0.003	0.066	0.091	-0.012	0.014	0.014	0.120	0.097	0.216	0.134						
affiliated firms	0.019	0.052	0.077	-0.022	0.053	0.039	0.124	0.080	0.128	0.043	0.187					
universities	0.063	0.053	0.097	-0.036	0.033	0.028	0.161	0.261	0.076	0.039	0.113	0.151				
patent disclosures	0.113	0.025	0.066	-0.030	0.032	0.060	0.270	0.170	0.104	0.022	0.101	0.102	0.240			
fairs, exhibitions	0.005	0.058	0.094	0.018	0.014	0.011	0.162	0.109	0.239	0.161	0.185	0.059	0.101	0.176		
FIN_IMPED	-0.035	0.072	0.001	0.270	0.015	0.054	-0.002	0.050	0.044	0.044	0.028	-0.058	0.019	-0.026	0.078	
SKILL_IMPED	-0.022	0.051	0.020	0.021	-0.010	-0.046	-0.007	0.037	0.044	0.094	0.056	-0.008	0.026	0.002	0.071	0.129
L	0.076	0.148	0.065	-0.031	0.131	0.034	0.158	0.125	0.114	0.037	0.093	0.267	0.163	0.182	-0.191	-0.044

**Table A.4:** Correlation matrix; productivity model

	LC	LHK	RDSKILL IMPED	FOREIGN
LHK	-0.030			
RDSKILL_IMP	0.022	-0.004		
FOREIGN	0.010	0.022	0.045	
INNOLD	0.011	-0.013	0.018	0.107
INNOLD	0.009	-0.092	0.048	0.002
R&D	0.009	-0.018	0.046	0.085
PAT	-0.015	-0.058	0.074	0.097
WN	0.001	0.075	0.054	0.097
LRDS	-0.023	0.071	0.068	0.117
LNEWS	0.025	0.013	0.017	0.101
LIMPS	-0.024	-0.007	0.015	0.071