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Keskusteluaiheita - Discussion papers

No. 562

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EDUCATION AND INNOVATIVE CAPABILITIES

This research has been financially supported by TEKES, the Technology Development Centre. I thank Statistics Finland for making the data available.

ISSN 0781-6847 16.08.1996

LEIPONEN, Aija, **EDUCATION AND INNOVATIVE CAPABILITIES**. Helsinki: ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 1996, 20 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; no. 562).

ABSTRACT: This study investigates the role of competencies acquired in education and through work experience, in innovation. It is argued that education enhances learning and innovation because it provides employees with communication and interaction skills, and, more importantly, with abilities to receive, understand and utilize relevant knowledge and solve problems. These dynamic competencies are the source of innovativeness, which results in economic performance.

A data-set of Finnish industrial firms is used in estimating the factors that influence the probability of making product and process innovations, and product improvements. Different types of innovation turn out to be determined by different factors. General level of education is important for product innovation, technical skills are relevant for both product innovation and improvement, whereas firm-specific work experience comes into play with gradual improvement of products and processes. However, process innovation seems to be determined mainly by the size of the firm. This refers to the product life cycle affecting the type of innovation carried out. Probability of innovation is also studied with principal components approach. The results underline the importance of technical skills for product innovation. According to all the estimations there are considerable lags involved with the effects of competencies on innovation. Longer time series would be needed to evaluate the underlying dynamics properly. Nevertheless, the estimations suggest that competencies acquired through education and work experience have an important role in the accumulation of organizational knowledge and innovation.

KEY WORDS: Innovation, education, competencies

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TIIVISTELMÄ: Raportissa tutkitaan koulutuksessa ja työssä hankitun osaamisen vaikutuksia yritysten innovatiivisuuteen. Koulutus edistää innovaatioiden tekemistä, jos se lisää työntekijöiden kommunikaatio- ja vuorovaikutustaitoja, sekä kykyjä oppia, hyödyntää ja ennen kaikkea luoda uutta tietoa ratkaisemalla ongelmia. Tämä "dynaaminen osaaminen" lisää innovaatioiden ja taloudellisen menestymisen todennäköisyyttä.

Tutkimuksessa hyödynnetään suomalaista yritysaineistoa arvioitaessa tekijöitä, jotka vaikuttavat tuote- ja prosessi-innovaatioiden sekä tuoteparannusten tekemiseen. Eri innovaatiotyyppien todennäköisyyteen vaikuttavat eri osaamismuuttujat. Yleinen koulutustaso on tärkeä tuoteinnovoinnille, tekniset taidot sekä tuoteinnovaatioille että -parannuksille, kun taas yrityskohtainen työkokemus on yhteydessä vähittäisiin tuotteiden ja prosessien parannuksiin. Prosessi-innovaatioiden tekemiseen vaikuttaa kuitenkin eniten yrityksen koko, mikä viittaa tuotteen elinkaaren tärkeään rooliin innovaatiotoiminnan suuntautumisessa. Myös pääkomponenttianalyysiä hyödynnetään innovaatioiden todennäköisyyden arvioinnissa. Tulokset korostavat teknisen osaamisen tärkeyttä tuoteinnovaatioille.

Osaamisen vaikutukset innovatiivisuuteen näkyvät varsin pitkillä viipeillä. Tämän dynamiikan parempi hahmottaminen edellyttäisi pidempiä aikasarjoja. Silti voidaan todeta, että koulutuksella ja työkokemuksella on merkittävä rooli innovaatioiden tekemisessä ja yrityskohtaisen tietämyksen kertymisessä.

ASIASANAT: Innovaatiot, koulutus, osaaminen

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Yhteenveto - Finnish Summary

Tutkimuksessa selvitetään teollisuusyritysten innovatiivisuuteen vaikuttavia tekijöitä. Kysymys on keskeinen taloudellisen kehityksen ymmärtämiseksi, koska innovaatiot ovat tärkeä kehityksen moottori. Erityinen huomio kiinnitetään muodollisen koulutuksen ja työkokemuksen merkitykseen. Lähtökohtana on, että koulutetut työntekijät ovat tehokkaampia oppimaan, vuorovaikuttamaan ja omaksumaan tietoa niin yrityksen sisällä kuin sen ulkopuolelta. Koulutuksessa saatu tietopohja helpottaa uuden tiedon omaksumista, ja kokemukset oppimisesta ja ongelmien ratkaisemisesta parantavat näiden kykyjen käyttämistä työssä. Koulutus antaa myös vuorovaikutustaitoja sekä laajentaa työntekijöiden yhteistä tietopohjaa, mikä osaltaan helpottaa kommunikaatiota.

Tutkimushypoteesina on, että koulutus ja yrityskohtainen työkokemus lisäävät innovaatiotoiminnan tuottoja ja siten innovaatioalttiutta. Osaavat työntekijät ovat tehokkaampia kehittämään uusia tuotteita ja prosesseja ja toisaalta oppivat nopeammin käyttämään uusia menetelmiä ja myymään uusia tuotteita, mikä alentaa innovaatioiden käyttöönoton kustannuksia. Empiirisen mallin mukaan innovaatioiden todennäköisyys riippuu koulutuksella ja työkokemuksella mitattavasta osaamisesta, sekä yrityskohtaisista ja toimialakohtaisista tekijöistä.

Käytettävän aineiston on koonnut Tilastokeskus, ja se sisältää suomalaisia teollisuusyrityksiä 15:ltä eri toimialalta. Innovaatiotiedot perustuvat kyselytutkimukseen, joka tehtiin 1991, koskien 1989-1991 tehtyjä innovaatioita. Innovaatiomuuttujia on neljä: tuote- ja prosessi-innovaatiot, tuoteparannukset sekä "yleisinnovoijat" - yritykset jotka tekivät sekä tuote- että prosessi-innovaatioita. Nämä mittarit näyttävät määräytyvän jossain määrin eri tekijöiden vaikutuksesta.

Tuoteinnovaatioita tehneissä yrityksissä on korkea yleinen koulutustaso, ja lisäksi ne ovat lisänneet teknistä ja tutkimuksellista osaamista nopeasti. Tuotteitaan parantaneet yritykset puolestaan näyttävät nojautuvan tekniseen ja luonnontieteelliseen korkeakoulutukseen. Myös yrityksessä työskennellessä oppiminen on tärkeää. Liian staattinen työvoima on kuitenkin haitaksi innovatiivisuudelle. Merkitsevästi prosessi-innovatiivisuuteen vaikuttavia tekijöitä on sen sijaan hankala löytää. Tärkeimmäksi nousee yrityksen koko. Tämä viittaa teorioihin, joiden mukaan prosessien kehittämisen osuus T&K-toiminnasta kasvaa yrityksen kasvaessa, koska suuressa yrityksessä prosessi-innovaatioiden hyödyntämismahdollisuudet ovat paremmat, mikä lisää innovaation tuottoa. Myös tutkijoiden määrä ja yrityskohtainen työkokemus liittyvät jossain määrin positiivisesti prosessi-innovaatioihin. Yleisinnovoivissa yrityksissä taas yleinen koulutustaso lisää innovaatioiden todennäköisyyttä. Samoin tutkijakoulutetuilla näyttää olevan positiivinen vaikutus, joskaan ei aivan tilastollisesti merkitsevä.

Lopuksi tarkastellaan yritysten yleisimpiä osaamisstrategioita pääkomponenttianalyysin avulla. Neljä ensimmäistä pääkomponenttia tavoittavat 73 % vaihtelusta osaamismuuttujien suhteen. Komponenttien käyttäminen innovaatioiden todennäköisyyttä estimoitaessa lähinnä vahvistaa teknisen osaamisen roolia tuoteinnovoinnissa. Lisäksi tuoteinnovoivat yritykset näyttävät olevan edelleen hyvin dynaamisessa kehitysvaiheessa. Sektorikohtaiset erot otettiin näissä estimoinneissa huomioon ns. Pavittin taksonomian avulla. Taksonomia luokittelee toimialat neljään ryhmään niiden teknologisen kehityksen luonteen perusteella. Havaitaan, että "erikoistuneet toimittajat" ja "tieteeseen pohjautuvat yritykset" tekevät paljon todennäköisemmin tuoteinnovaatioita ja -parannuksia kuin muut luokat.

Tutkimustulosten perusteella voidaan todeta, että koulutukseen ja työkokemukseen perustuvat osaamismittarit liittyvät tilastollisesti merkitsevästi innovaatioihin. Tuote- ja prosessi-innovaatioita sekä tuoteparannuksia tekevien yritysten osaamispääomat poikkeavat selvästi toisistaan. Toimialakohtaiset erot innovatiivisuudessa ovat huomattavia, ja niiden huomioiminen on tärkeää.

1 Introduction

This paper examines the factors that influence the innovativeness of firms. This question is fundamental for understanding economic development, because innovation is one of its most important driving forces. We aim to shed some light on the role of educational competencies in innovation, and assess, which kind of competencies are the most relevant.

Several determinants of innovativeness have been identified in previous studies, most often firm size, market structure, in addition to technological opportunity and appropriability. The firm's internal factors have not been analyzed very thoroughly, although financial position (i.a. Kamien and Schwartz 1978) and degree of diversification (Nelson 1959, Scherer 1965) have been suggested as potential factors. User-producer relations and linkages between R&D, manufacturing and marketing are emphasized in particular in the national innovation systems approach (Lundvall 1992). Accumulated capabilities have been considered mainly in descriptive case studies (see Cohen 1995 for an overview). Studies by Cohen and Klepper (1992) and Klepper (1996) are an exception. They develop models of firms with randomly distributed innovative expertise. It is argued that expertise, together with the size of the firm, determine the composition of R&D and direction of innovative activities to a large extent.

Cohen (1995) describes the supply of trained engineers as a macroeconomic factor of innovation. However, in this study we maintain that competencies, or human embodied knowledge available in the firm, is not only a macroeconomic factor but a decision variable for the firm. Nor are innovative capabilities randomly allocated among firms. Employment strategy, concerning among other things how many engineers and how well educated workers to employ, has a substantial bearing on the innovative outcome. Human knowledge has implications on how technological opportunities are perceived, and on the efficiency, productivity, and profitability of R&D.

The novelty of the work at hand is to estimate the effects of the employees' acquired competencies on innovation. To our knowledge, this has not been explicitly done previously. A companion paper (Leiponen 1996a) found that innovating firms tend to have more highly educated employees, and especially more of those with a post-graduate degree. Now we want to investigate, whether educational competencies affect the propensity to innovate even when controlling for other determinants of innovation. This is done via probit analysis, where the factors influencing the probability of innovation are estimated.

In the next section we discuss briefly the possible role of education and work experience in accumulating innovative capabilities. Section 3 presents the data, and section 4 the empirical model to be estimated. Estimation results of the basic model are discussed in section 5, while in section 6 the principal components of competencies are used in the estimations. Conclusions are drawn in section 7.

2 Education and Work Experience in the Accumulation of Innovative Capabilities

The ability to exploit external knowledge has in several studies been found to be a critical component of innovation. Cohen and Levinthal (1989, 1990) use the concept *absorptive capacity* to describe the abilities of an organization, or its constituent individuals, to recognize the value of new information, assimilate it, and apply it. Absorptive capacity enables the firm to keep track of the technological or other developments in the market.

The abilities to assimilate and apply external knowledge depend crucially on the capabilities of the individuals acting as an interface between the firm and the environment, but also on other employees' abilities. For example, the interfaces between different subunits of the organization are essential, because they shape the communication flows within the firm.

Communication depends on the degree of commonality of knowledge. There has to be some overlap in knowledge, the communicating parties have to share at least the codes of communication and some knowledge of the substance in order to be able to interact. This means that the capabilities of all the members of the organization are relevant for the accumulation of organizational absorptive capacity.

The different capabilities of individual employees introduce the requisite diversity of knowledge in the organization. Sufficient diversity of knowledge is needed in particular in an uncertain and changing environment, where a very narrow knowledge base may be risky. With limited diversity the firm perceives only a small portion of the available opportunities, and therefore might be trapped on a learning path, which turns out to be unprofitable. Also, if everybody has more or less the same knowledge base, there are no benefits from learning by interacting anymore. Learning by doing alone leads to slackening knowledge accumulation, because there is no novelty brought into the system. The firm has to maintain an intricate balance between the coordination of learning - to enable communication - and the decentralization of learning - to maintain diversity and introduce novelty.

Given a sufficient base of shared knowledge among the employees, which enables communication, the organizational innovative capability arises exactly from the interactions between people with diverse knowledge structures. Hence the organizational capacity for novel linkages and associations, that is, innovations, are beyond the capabilities of any one individual.

The building of such a capacity in the organization is a slow and path-dependent process, because it involves the integration of individuals' capabilities and a gradual evolution of their joint operation routines and ways of cooperating and communicating. Learning by interacting cumulatively builds on the prior knowledge of the employees, and it is easier to learn in directions in which the employees already have prior knowledge. Moreover, capabilities affect the way external opportunities are perceived and expectations formed.

There may exist a trade-off between the inward- and outward-directed capabilities. The larger the degree of shared knowledge among the members of a group, the easier it is for them to communicate. However, this may happen to the detriment of external communication. For instance, it has been observed, that external communication with other project groups decreases with group tenure (Cohen and Levinthal 1990). Therefore, we conjecture that the accumulation of innovative capabilities is a concave function of tenure. This arises also because novelty is necessary for continuous learning. Novelty is needed at the employee level, too: continuous learning by interacting depends to some extent on the new capabilities, skills and insights brought in. Either this happens through training and external communication, or through recruiting altogether new employees. Bringing new tacit knowledge in the process of interaction necessitates the latter.

What are then the available possibilities for firms to invest in innovative capabilities? It has been emphasized, that the bulk of dynamic capabilities are strategic and thus very firm-specific by nature, and therefore they must be internally developed (Teece and Pisano 1994). There are no markets for strategic competencies, notably because they are valuable only in a very limited organizational context. Hence, the integration of new employees takes rather a long time, and the possibilities to acquire dynamic competencies through consulting, joint ventures, mergers etc. are quite limited, although these measures are regularly taken by firms, and should not be completely overlooked, either.

Nevertheless, we propose that hiring highly educated people is beneficial for the rates of learning, interacting, and assimilating both external and internal information. Prior related knowledge facilitates the learning of new knowledge, and the same applies for learning skills: prior experience in learning or solving problems during schooling improves the abilities to do them on the job. Education may also enhance the interaction abilities, both through improved communication skills and a larger common base of knowledge. Educational competencies may thus have an important role in learning and problem-solving, and as a result, innovation.

3 The Empirical Model

The returns to investment in innovative activities arise from the income streams generated by new or improved products and better cost efficiency with upgraded methods of production. The costs of innovation include, in addition to the direct R&D expenditures, indirect switching costs from introduction and adoption of new products and processes, and also marketing costs from launching new products.

The cost of innovation depends on the knowledge accumulated, i.e. past R&D investment and organizational knowledge created through learning. This makes innovation a dynamic and path dependent process. Moreover, the learning rate, a manifestation of dynamic competencies, has an impact on the adoption costs.

The hypothesis we want to test is that competencies acquired via education and work experience increase the net benefit from innovation, leading to better profitability of innovative activities and greater propensity to innovate. First, more competent employees are more efficient in developing new products and processes. Second, they learn faster both to use new technologies, and to produce and sell new products, which diminishes the adoption and introduction costs.

We hypothesize in this study that people with more education are more efficient learners and innovators. This is because the skills and knowledge acquired during schooling help to search for, receive and use new information more easily. Another explanation discussed in the literature is the role of education as a sorting device that separates the "talented" from the "untalented" (cf. Arrow 1973). We regard this not as important as the first reason, but in any case the relative importance does not affect the formulation of our empirical model. The relevant thing is that educated employees have accumulated more of both static and dynamic competencies.

Innovations are realized if the difference in profit $\pi_i^I - \pi_i^N$ in case the firm i innovates (I) or does not innovate (N), exceeds the innovation costs C_i^I involved. The returns and costs are functions of a set of explanatory variables x_i. The net benefit from innovation is then

(1) $$I_i = \pi_i^I - \pi_i^N - C_i^I = \beta' x_i + \varepsilon_i$$

where β is a vector of coefficients, and ε is an IID white noise error term.

Profitability of innovation is unobservable, as we have no data concerning the income streams generated by new products and processes. Therefore, we only observe whether the firm innovates or not. Nevertheless, we do have data on variables that are a priori assessed to influence these income streams.

Assuming normally distributed disturbances this setting gives rise to the probit model. Let us define a dummy variable $\bar{I}_i$:

$$(2) \qquad \bar{I}_i = \begin{cases} 1, \\ 0, \end{cases} \text{iff} \begin{cases} I_i \geq 0 \\ I_i < 0 \end{cases}, \quad i = 1, ..., N$$

Then the conditional probability that $\bar{I}_i = 1$ is

$$(3) \qquad \begin{aligned} &\Pr(\bar{I}_i = 1|x_i) = \Pr(I_i \geq 0|x_i) \\ &= \int_{-\infty}^{\beta' x_i} \phi(t)dt = \Phi(\beta' x_i) \end{aligned}$$

where Φ denotes the standard normal distribution. The expected value of I is then

$$(4) \qquad E(I_i) = \Phi(\beta' x_i)$$

and the marginal effects of changes in explanatory variables on this expectation are

$$(5) \qquad \frac{\partial E(I_i)}{\partial x_i} = \phi(\beta' x_i)\beta$$

The focus in the estimations is naturally on the stock of educational competencies in firms, and with their help we hope to reduce the role of firm-specific unobservable effects. In addition we will control for some of the external factors affecting innovation that have been suggested in the literature. This leads to the following general model of the probability of innovation in a firm:

$$Prob(innovation) = f(competencies, firm, industry)$$

4 The Data

We make use of a firm-level data-set compiled by Statistics Finland, which combines several data sources including labor statistics, innovation survey and business statistics. The innovation survey was carried out in 1991, and it concerns product innovation and improvement, and process innovation. The firms were inquired whether they accomplished process innovations and product improvements during the period 1989-1991. The measure of product innovation is slightly different. Product innovators include firms that launched new products in the markets between 1989-1991 and collected some sales revenue from them. This turned out to be more informative an indicator than the one asking the firms if they had made product innovations or not. In addition we constructed another dummy for firms that innovated both products and processes, in order to find out what these "comprehensive innovators" (cf. Baldwin and Johnson 1996) are like.

Table 1. List of Variables

Vector	Variable	Definition
COMPETENCE	HC	*Human Capital Index*, defined below (available 1987-93)
	HIGH	Share of employees with higher education degree, % (1987-93)
	POST	Number of employees with post-graduate degree (1987-93)
	TECH	Share of employees with technical or natural scientific degree, % (1987-93)
	HITECH	- " - higher technical or natural scientific degree, % (1987-93)
	TEN	Average tenure in the firm, years (1987-93)
	TEN^2	Tenure squared (1987-93)
INNOVATION	PROD	Dummy variable for new products launched successfully in markets between 1989-1991 (1991)
	IMPR	Dummy for significant product improvements realized between 1989-1991 (1991)
	PROC	Dummy for process innovations realized between 1989-1991 (1991)
	INNO	Dummy for "comprehensive innovators," firms realizing both product and process innovations (1991)
FIRM	SALES	Sales turnover, million FIM (1985-1993)
	$SALES^2$	Sales squared
	MS	Market share, % (1987-1993)
	EXPORT	Exports in proportion to sales (1989-1993)
INDUSTRY	Dummies	14 different industry classes, reference group being "other industries"
	Taxonomic groups TAX1 - TAX4	Industrial groups according to Pavitt's taxonomy of technological change

The explanatory variables include indicators of educational levels and fields of the workers in each firm, accumulated firm-specific work experience indicated in the average tenure, and several economic and industry-specific control variables (see table 1). A more detailed description and discussion of the data can be found in Leiponen 1996a.

The general level of education is described by an index (HC), constructed from the shares of employees with different educational levels. These shares are weighted with wage differences, assumed reflecting the differences in their productivity to some extent. The index is constructed in the following way:

$$H = \frac{(h_2 w_2 + h_3 w_3 + h_4 w_4)}{w_1}$$

where h_i denotes the share of employees with the level of education i running from 1 = basic education to 4 = post-graduate (doctoral or licentiate) degree, and w_i denotes the average wage level of the corresponding group in the firm. So the index is the sum of the shares of employees with more than basic education, weighted by the wage difference with respect to the basic wage.

5 Estimation Results

We have thus four different measures for innovation: new products introduced in the market (the firm has recently innovated products which already generate part of the sales), product improvements (the firm has significantly upgraded products), process innovations (the firm has significantly improved production processes) and comprehensive innovation (both product and process innovation). These measures turn out to be determined by somewhat different factors.

5.1 Product Innovations

We use a measure of innovated products that already generate sales, because this guarantees that we are dealing with an economically valuable innovation. The estimation results are in table 2 below. Several combinations of explanatory variables were tried out, and the ones reported turned out to be the most significant.

We observe that the general level of education in 1987 and the *growth* of technical and research competencies 1987-91 (ΔTECH and ΔPOST, respectively) are positively associated with the probability of successfully introducing new products in the market. The importance of the initial level of general education for innovation is in line with our conjecture, that education enhances the rate of learning, which facilitates the introduction and selling of new products. Hence the benefits from hiring educated employees appear with considerable lags.

Table 2. Probability of having new products introduced in the market

	Variable	Estimate	t-statistics	Slope at means (marginal effect
	Constant	-1.193*	-2.46	
COMPETENCIES	**HC87**	0.930*	2.19	0.34
	ΔPOST	0.132*	1.99	0.05
	ΔTECH	3.076*	2.74	1.14
FIRM	**SALES**	-0.001*	-3.28	-0.0003
	MS	0.374*	3.14	0.14
INDUSTRY	**Dummies**			
	Log Likelihood	-189.93		
	Likelihood Ratio	77.94		
	d.f.	19		
	McFadden's R^2	0.17		
*** = significant at the 5% level**				

The importance of technical and research competencies is rather intuitive, but it is interesting that the growth rates are more important than the levels. Bearing in mind the usual long lags in innovation processes, this might reflect that the firms need certain competencies in order to be able to develop marketable products from the original inventions. Another possible explanation is that both innovation and acquisition of technological knowledge and skills reflect some generic dynamism in these firms. Being an innovative firm requires continuously more investment in R&D, knowledge and skills. These enable the firm to perceive market opportunities, the exploiting of which necessitates more investment in internal capabilities. It is thus a self-reinforcing cycle. However, with the short time series available we can only make guesses about the underlying dynamics behind the results.

Of the firm-specific factors, most important are market share and the size of the firm. In addition, differences between industries are accounted for with dummy variables. Interestingly, market share is positively related to innovation while the size of the firm is negatively. Smaller firms but nevertheless with a significant share of the market are more likely to launch new products. Industry dummies are significant only in the cases of oil, machine, motor vehicle and electronics industries, and positively so.

The last two columns present the marginal effects as defined in equation (5). Marginal effect, or the slope, is the marginal change in the expected benefit from innovation due to change in the explanatory variable[1]. Marginal effects are calculated for an average firm, i.e. at the mean values of explanatory variables.

3.2 Product Improvements

With respect to product improvements, the initial level of higher technical competencies (HITECH87) turns out to be an important factor (table 3), together with firm-specific work experience (TEN). However, the square of TEN is significantly negative, which suggests that there are limits to learning on the same job.

Among the firm-specific factors, a large market share and export share seem to provide important incentives for product improvement. Again, firms in oil, electronics and motor vehicle industries are more likely to improve their products.

[1] The estimates of β do not as such have an elasticity interpretation.

Table 3. Probability of product improvements

	Variable	Estimate	t-statistics	Slope at means (marginal effect)
	Constant	-1.300*	-2.50	
COMPETENCIES	HITECH87	4.852*	2.07	1.94
	TEN87	0.186*	2.28	0.07
	$TEN87^2$	-0.011*	-2.25	-0.004
FIRM	MS	0.188*	2.53	0.07
	EXPORT	0.655*	1.99	0.26
INDUSTRY	Dummies			
	Log Likelihood	-171.15		
	Likelihood Ratio	108.11		
	d.f.	19		
	McFadden's R^2	0.24		
* = significant at the 5% level				

5.3 Process Innovations

The determinants of process innovations differ clearly from those of product innovations and improvements, and there are practically no significant explanatory variables found (table 4). The logic behind and thus the determinants of process innovation appear to be quite different from both product innovation and improvement. This is reflected also in the quasi-R^2, which is clearly lower for this dependent variable.

Table 4. Probability of process innovation

	Variable	Estimate	t-statistics	Slope at means (marg. effect)
	Constant	-0.508	-1.10	
COMPETENCIES	POST87	0.105	1.23	0.04
	TEN87	0.101	1.39	0.04
	$TEN87^2$	-0.007	-1.54	-0.003
FIRM	SALES	0.001*	2.18	0.0003
	$SALES^2$	-2.3E-08	-1.53	-8.6E-09
	EXPORT	0.466	1.55	0.18
INDUSTRY	Dummies			
	Log Likelihood	-209.05		
	Likelihood Ratio	41.01		
	d.f.	20		
	McFadden's R^2	0.09		
* = significant at the 5% level				

None of our competence variables turns out to be a robust determinant of process innovation. Employees with a post-graduate degree have a modest positive effect (confidence interval around 80%). Tenure has consistently positive and its square negative coefficients.

The propensity to engage in process innovation appears to be mainly determined by the size of the firm. This is in accordance with the life cycle hypothesis presented among others by Cohen and Klepper (1996). They argue that the share of R&D directed to process innovation tends to rise with the size of the firm. Because process innovations are usually exploited internally, the bigger the firm, the more there are opportunities to benefit from innovation externalities. Therefore process innovation increases with the firm size. In line with this, the SALES variable has a positive coefficient, and its square a negative one. In addition, export share has a positive but not quite significant relationship with it. None of the industry dummies are significant, which suggests that a firm in any industry is equally likely to engage in process innovation after reaching a certain size.

5.4 Comprehensive innovation

Firms innovating both products and processes tend to have a high initial general level of education, indicated by the significant positive coefficient on HC87. Initial number of researchers (POST87) has a positive relation, too, but not significant one. Comprehensive innovators tend to be relatively small, somewhat export oriented firms, and with a significant market share in spite of the size. In this sense they remind more of product than process innovators. Among the different industries, surprisingly firms in food industry, in addition to oil and machine industries, are more likely to be this kind of innovators.

Table 5. **Probability of both product and process innovation**

	Variable	Estimate	t-statistics	Slope at mean (marg. effect)
COMPETENCIES	Constant	-1.827	-3.64	
	HC87	0.913*	2.22	0.21
	POST87	0.051	1.05	0.01
FIRM	SALES	-0.0004*	-2.83	-8.9E-05
	EXPORT	0.470	1.56	0.11
	MS	0.174*	2.32	0.04
INDUSTRY	Dummies			
	Log Likelihood	-185.77		
	Likelihood Ratio	57.26		
	d.f.	19		
* = significant at the 5% level	McFadden's R^2	0.13		

To sum up, the quasi-R^2 suggests that this kind of a model is more suited for studying product innovation and improvement than process innovation, which seems to be determined by somewhat different factors. However, we find that competence-related variables show up as significant determinants of innovation. In particular the initial values are important, which lends support to the conjecture of education having considerable effects on learning, which in turn increases the propensity to innovate.

6 Competence Strategies with Principal Components Approach

This section examines the typical competence strategies among firms, and how they are associated with innovation. First we carry out a principal component analysis, and then we use the components for the probit analysis. The benefits from principal components arise from mitigating the possible multicollinearity of the explanatory variables. In addition we obtain information about which kind of competencies tend to go together.

6.1 Principal Components Analysis

As table 6 reveals, the four first principal components capture 73% of the variation among firms. The first component (PRIN1) weights heavily initial levels of higher education and both general and higher technical skills (highlighted in the table). Firms scoring high in the second component have long tenures, a large number of post-graduate employees, and also increase their employment rapidly. As to the technical skills here, the initial level of general technical education is low, but it has been increasing rapidly in this strategy. The third component is dominated by the initial level of POST, and increases in higher education and post-graduate employees. Also the average tenure is quite strongly negatively weighted. The fourth and last one we consider here is dominated by positive weights on the change in technical skills and negative ones on average tenure.

Table 6. Principal Components of Competencies

Variable	PRIN1 "General technical"	PRIN2 "Experienced research"	PRIN3 "Dynamic research"	PRIN4 "Dynamic technical"
HIGH87	**0.58**	0.11	-0.15	0.12
HITECH87	**0.61**	-0.03	-0.12	0.17
POST87	0.24	**0.40**	**0.50**	-0.18
TECH87	**0.38**	**-0.48**	0.07	-0.09
TEN87	-0.07	**0.54**	-0.31	**-0.43**
ΔHIGH	-0.17	-0.18	**0.64**	0.15
ΔPOST	0.22	0.39	**0.44**	-0.01
ΔTECH	-0.12	0.34	-0.10	**0.84**
Proportion of variance	29%	17%	14%	13%
Cumulative	29%	47%	61%	73%

6.2 Probability of Innovation with Principal Components

We now utilize the principal components in the probit analysis of innovation. Instead of industry dummies we control for the sectoral differences in the modes of technological change and the propensity to innovate with dummies according to the so called Pavitt taxonomy (Pavitt 1984). The taxonomy groups industries according to the pattern of technological change (see table 7 below). It creates thus four dummies for our analysis, "the others" being the reference group again.

Table 7. Pavitt's taxonomy of industries

Group	Type of products	Industries
1. Supplier dominated industries	Traditional manufactures	textiles, clothes, wood paper, printing & publishing, furniture
2. Scale intensive	Bulk materials Assembly (consumer durables, autos)	food, metals, vehicles, glass & stone
3. Specialized suppliers	Machinery	machine
4. Science based	Electronical Chemical	electronic, chemical, oil, coal

The four principal components all show up in a positive association with innovation, but with little statistical significance (table 8). However, the "dynamic technical" component turns out to be a significant explanator of product innovation. "General technical" component gains some significance with respect to comprehensive innovation, but not quite within the 95% confidence interval.

The taxonomic dummies appear to describe reasonably well the differential patterns of technological change among industries. The third and fourth groups, specialized suppliers and science based firms are significantly more likely to make product innovations and improvements, and also to be comprehensive innovators.

It is also worth mentioning that within this setup, the export share becomes more significantly associated with all kinds of innovation. The coefficient is within the 95% confidence interval in comprehensive innovation and product improvement, and within 90% for the product and process innovation.

Table 8. Probability of innovation with principal components

Variable	Product Innovation Estimate (t-value)	Process Innovation Estimate (t-value)	Comprehensive Innovation Estimate (t-value)	Product Improvement Estimate (t-value)
INTERCEPT	-0.600	-0.12	-1.181*	-0.291
	(-1.42)	(-0.31)	(-2.79)	(-0.72)
"General technical"	0.092	0.052	0.128	0.102
	(1.15)	(0.69)	(1.75)	(1.10)
"Experienced research"	0.127	0.080	0.163	-0.005
	(1.20)	(0.74)	(1.62)	(-0.04)
"Dynamic research"	0.096	0.074	0.156	0.009
	(0.76)	(0.59)	(1.31)	(0.07)
"Dynamic technical"	0.196*	0.037	0.044	0.018
	(2.42)	(0.48)	(0.55)	(0.22)
SALES	-0.001*	0.001*	-0.0003*	0.0005
	(-3.27)	(2.14)	(-2.59)	(1.34)
MS	0.290*	-0.016	0.129*	0.115
	(2.97)	(-0.22)	(1.96)	(1.40)
EXPORT	0.502	0.456	0.603*	0.686*
	(1.78)	(1.68)	(2.20)	(2.32)
TAX1	0.105	-0.164	0.253	-0.188
	(0.26)	(-0.44)	(0.62)	(-0.48)
TAX2	0.592	0.075	0.795	0.247
	(1.41)	(0.19)	(1.88)	(0.59)
TAX3	1.039*	0.269	1.095*	1.842*
	(2.13)	(0.60)	(2.32)	(3.03)
TAX4	1.055*	0.137	0.991*	0.975*
	(2.28)	(0.32)	(2.16)	(2.10)
Log Likelihood	-203.87	-216.12	-196.07	-185.37
Likelihood Ratio	53.03	26.86	38.37	79.66
d.f.	11	11	11	11
McFadden's R^2	0.12	0.06	0.09	0.18
* = significant at 5% level				

7 Conclusions

We find that competencies described by measures related to education and firm-specific work experience are significant determinants of different types of innovation. Including competence variables in the equations for the probability of innovation is justified by the tests for both joint and individual significance of the coefficients.

As for the different competence indicators, we found out that the initial level of general education is positively associated especially with product innovation. Technical competencies are important for both innovation and gradual improvement of products but not for upgrading of processes. In addition, experience accumulated in the firm is more needed in gradual improvement of products and processes than in developing completely new products.

The determinants of process innovation, in addition to firm size, remain unclear. It might be the case that capabilities needed therein are internally developed to an even greater extent than those in product innovation.

The importance of lagged variables is in line with our hypothesis about the dynamic process of building innovative capabilities. The significance of the *growth* of technical and research competencies raises the question about a possible underlying factor, which causes both competence accumulation and innovation. However, given the long lags from research through invention to innovation, we cannot assess properly the dynamics behind the results. This would require much longer time series on innovation inputs and outputs, in addition to competence stocks.

Concerning the market related factors, it seems that export oriented firms with at least some market power are the most likely to innovate. Also the technological intensity of the industry increases the probability of product innovation, as indicated by the taxonomic dummy variables. Sectoral differences are considerable, and have to be controlled for.

The principal component analysis revealed some typical combinations of competencies prevailing in the firms of our data-set. Using these components in the estimations of the probability of innovation did not shed much more light on the determinants of innovation, however. Nevertheless, it emphasized the importance of both general and technical competencies for product innovation. The principal components also pointed to the fact, that product innovating firms tend to be still in a very dynamic phase of evolution. This was suggested by the component where tenure is weighted strongly and negatively and the change in the stock of technical competencies positively. This supports the proposition by Klepper (1996) of different types of innovation dominating in different phases of the product life cycle.

Overall, we conclude that educational competencies are significantly involved in the innovation process, and different competence combinations are associated with different types of innovation.

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