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CHARACTERISTICS OF PRODUCT AND PROCESS INNOVATORS AMONG FINNISH MANUFACTURING FIRMS**

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Abstract: Our objective is to identify characteristics of innovating firms in Finnish manufacturing. The study exploits the Community Innovation Survey (CIS) conducted in 1997 by Statistics Finland under the supervision of Eurostat: the data refers to years 1994–6 and covers 1,008 firms. We incorporate main hypotheses and findings of the neo-Schumpeterian literature and test them in a unified framework.

Results of bivariate probit estimations suggest that, while the two types of innovations are related, they are nevertheless driven by different factors. The ability to benefit from inward spillovers is the only variable having a clearly symmetric effect on both types of innovation. Cooperation with non-academic outside partners is the only other variable that becomes significant in both equations.

We do not find solid evidence for the Schumpeterian hypotheses on the important role of entrepreneurial regime or market concentration and firm size. Process innovations benefit from capital embodied technology, whereas product innovations require disembodied forms of technology. We do not find that more educated labor force would contribute to innovativeness.

Keywords: Process innovation, product innovation, technological change, Finnish manufacturing industry, firm size, market structure, concentration, Schumpeter, Schumpeterian hypothesis.

JEL codes: L11, L60, O31, O32, 6110, 6211, 6212.

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Tiivistelmä: Tämä tutkimus kartoittaa suomalaisten tuote- ja prosessi-innovoivien teollisuusyritysten ominaispiirteitä. Tutkimuksessa hyödynnetään Tilastokeskuksen vuonna 1997 tekemää ja Eurostatin koordinoimaa innovaatiotutkimusta (Community Innovation Survey, CIS), jossa kerättiin perustietoja yritysten innovaatiotoiminnasta vuosien 1994–6 aikana. Aineisto käsittää 1008 yritystä. Tutkimus yhdistää neo-Schumpeteriläisen kirjallisuuden havaintoja ja löydöksiä, joiden merkitsevyyttä tarkastellaan yhtenäisessä viitekehyksessä.

Kaksiulotteisten probit-estimointien perusteella voidaan todeta, että vaikkakin tuote- ja prosessi-innovaatiot ovat toisistaan riippuvia, eri tekijät vaikuttavat niiden tekemiseen. Vain kyvyllä hyötyä muualla tehdyn tutkimuksen ulkoisvaikutuksista näyttää olevan symmetrinen vaikutus molempiin innovaatiotyyppeihin. Muista muuttujista vain yhteistyö ulkopuolisten ei akateemisten tahojen kanssa tulee merkitseväksi molemmissa yhtälöissä.

Vedenpitävää näyttöä Schumpeteriläisistä hypoteeseista yrittäjyyden, markkinoiden keskittyneisyyden ja yrityskoon rooleista innovaatiotoiminnasta ei löytynyt. Pääomahyödykkeisiin ja välituotteisiin sitoutunut teknologia tukee prosessi-innovointia. Tuoteinnovaatioiden lähteenä on ihmisiin sitoutunut tietotaito. Koulutustasolla ja innovaatioilla ei näytä olevan selvää yhteyttä.

Avainsanat: Prosessi-innovaatio, tuoteinnovaatio, teknologinen muutus, suomalaiset teollisuusyritykset, yrityskoko, markkinarakenne, keskittyminen, Schumpeter, Schumpeteriläinen hypoteesi.

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Petri Rouvinen
October 11, 1999

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INTRODUCTION

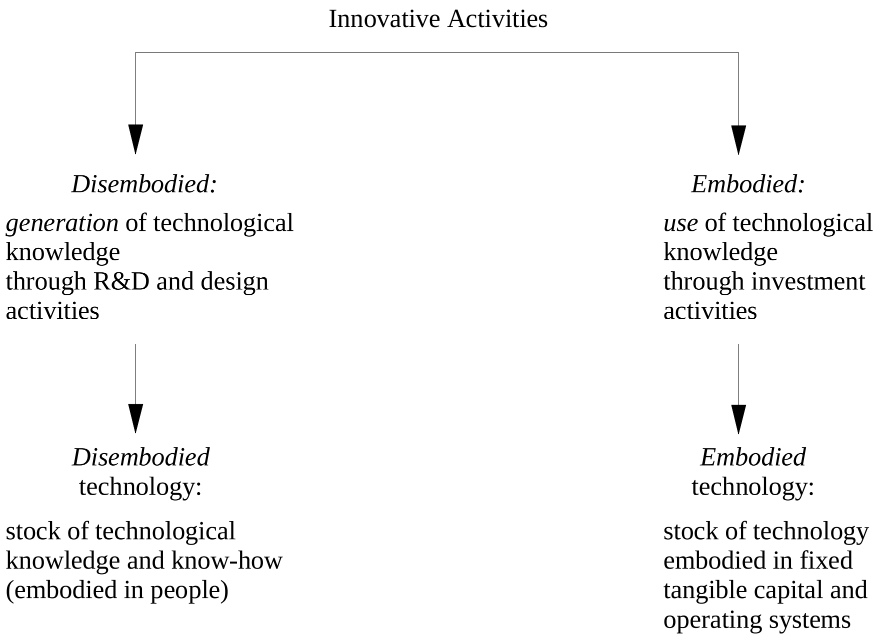
The core of a modern economy is a vivid corporate sector, where emerging and established companies compete against each other. The market shares and profitability of incumbent firms may be undermined by more cost-effective competitors and/or their new products. This innovation-driven ‘creative destruction’ has recently been emphasized as a major source of economic growth (Caballero & Jaffe, 1993; Grossman & Helpman, 1991).

Considering the importance of the matter, it is a little surprising that “… no single coherent theory exists… [for] the analysis of innovative behaviour of firms…” (Leo, 1996, p. 63). Instead, there are a number of approaches emphasizing particular aspects of the issue.

We incorporate hypotheses and findings in various branches of the literature, and tests them in a unified framework with the Community Innovation Survey (CIS) data on product and process innovations among Finnish manufacturing firms.

LITERATURE REVIEW

Technological change is such a complex and multidimensional phenomenon that it difficult to study it under a coherent conceptual framework (Evangelista, 1999, p. xiii). Evangelista (1999) argues that the distinction between **embodied** and **disembodied** technological change is a useful generalization upon discussing the issue. In the proposed terminology, *disembodied technological change* refers to the stock of knowledge or to a set of capabilities whereas *embodied technological change* refers to the stock of productive assets or fixed productive capital.[1] Innovative activities are conceptualized as activities aiming at producing new technological knowledge or using new technologies via investment in fixed capital. Features of embodied and disembodied views of technological change are summarized in Figure 1 below.



Source: Evangelista (1999, p. 69: Figure 5.1).

Figure 1. Embodied and disembodied views on technological change.

In light of the current literature of technological change, Evangelista's organization of the literature is perhaps somewhat unorthodox: the current literature is almost solely on the 'disembodied' path. Both paths are, however, important, and, as briefly discussed below, in the history of thought the 'embodied' path has been quite pronounced.

Classical economists, Smith, Ricardo, and Marx, explicitly incorporated notions of embodied technological change in their analysis. Thoughts on the division of labor is considered one of Smith's (Wealth of Nations, 1776, as in Heilbroner & Malone, 1986) original contributions, which in turn is seen as one of the keys in industrialization and increasing labor productivity. Smith saw causality from the increasing market size to the deepening specialization and new production methods.[2] Ricardo's central goal was to create a theory of value and distribution. Thus, technological change is discussed only in the third edition of his magnum opus, *On the Principles of Political Economy and Taxation*. In Ricardo's writings, technological change is mainly associated with mechanization through investment. Marx clearly saw that mechanization and changes in the organization of labor are related to the capitalistic battle on the market place. Marx also acknowledged the role of science in capitalistic production process. According to the classical economists, physical capital investment is the vehicle of technological change in production and in the economy as a whole, i.e., they were on the embodied technology path of Figure 1.

Schumpeter departed from the classical economists' view of technological change. The introduction of disembodied perspective on technological change is often attributed to him. As suggested in *The Theory of Economic Development* (1934), innovative activities and their outcomes, innovations, enable the innovator to gain temporary monopolistic power, expiring as soon as the innovation is imitated or replaced. The form of innovation could be either an introduction of a new good, a new method of production, an opening of a new market, a discovery of a new input supply, or a change in the organizational structure. Schumpeter's early work emphasized the role of the entrepreneur in the innovative process. In his later work *Capitalism, Socialism, and Democracy* (1942), Schumpeter switched to emphasizing the importance of oligopolistic market structures in promoting innovative activity.

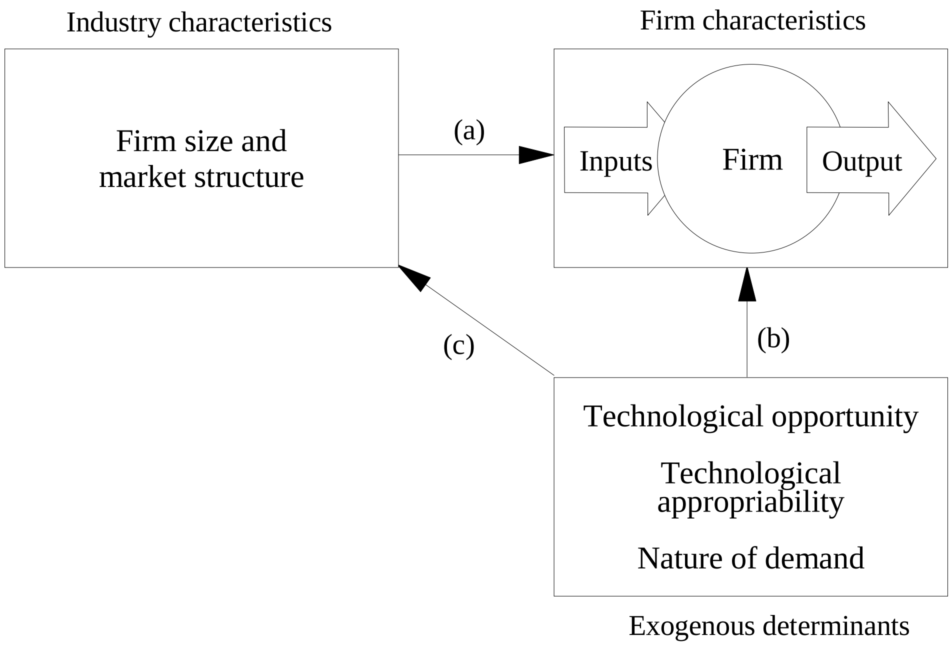
Neoclassical literature has abundant references to technology, but it is typically assumed exogenous. A production function presents a technology that can be used to transfer inputs to output. Different combinations of inputs cause movements along an existing isoquant, implying that the technology is known to the agents and that they are capable of applying it. Technological advance is represented by an upward shift of the production function. In the footsteps of Solow (1957), neoclassical scholars divided economic growth to explained and unexplained parts; the latter was labeled technological change. Arrow (1962) suggested endogenizing technological change in the production function framework. In Arrow's model learning takes place by doing; the production and use of capital goods is argued to be a proxy for the accumulated experience. Thus, Arrow's model incorporates both embodied and disembodied technological change through the dual role of physical capital. The literature has since shifted to emphasizing the disembodied form. Romer (1986; 1990) was the first to associate technological change with the society's accumulated knowledge stock. This stock is largely an outcome of innovative activities by private enterprise.

In early Keynesian contributions, technological change had virtually no role. Later contributions emphasized the role of physical investment in explaining long-term economic growth.

As far as technology is concerned, these contributions lean towards the classical economists and the embodied form of technology.

In classical, neoclassical, and Keynesian traditions, technological change is often studied at the aggregate level and the firm is treated as a 'black box'. Only the Schumpeterian tradition has its origins in the micro- and firm-level characteristics of innovation. Thus, it has provided a natural starting point for micro-level analysis of the phenomena, generating the second largest body of empirical literature in industrial organization (Cohen & Levin, 1989).

Figure 2 can be used to classify studies in the neo-Schumpeterian tradition. Most of these studies have discussed link (a), i.e., the effects of market structure and firm size on disembodied innovative activities as measured by R&D, patenting, or innovation counts. The role of other industry characteristics have been studied relatively little. Some recent contributions have discussed the role of technological regimes, appropriability conditions, and knowledge in determining the level and nature of innovative activity (link (b)) and industry structure (link (c)).



Note: A modified version of Evangelista (1999, p. 71: Figure 5.2 – Technological change and industrial structure: the neo-Schumpeterian links). We have added labels to the three boxes. Contents of the upper left box are unchanged. We have added "nature of demand" to the bottom box. We have omitted the text "New determinant factors of innovative activities and industrial structure characteristics" from the left side of the bottom box. The upper right box was originally titled "Disembodied innovation activities" and included the following text: "Generation of technological knowledge and innovations measured by R&D and patenting indicators".

Figure 2. Determinants and links of innovative activities.

The upper right box of Figure 2 includes a rough sketch of a firm's value chain. The neo-Schumpeterian tradition is mainly interested in disembodied forms of technology; embodied forms of technology, e.g., capital inputs, are potentially interesting as well. Furthermore, the internal organization of the firm has consequences on innovative activities.

An innovation has major economic consequences outside the firm only after it has been introduced on the market place. Yet, most studies focus on the innovative activity, i.e., on attempts to come up with an innovation, rather than on innovations themselves.

Above we have discussed the historical underpinnings of the innovation literature and given some idea of the scope in the current literature. There is an enormous body of theoretical and empirical literature dealing directly or indirectly with various aspects of innovative activity. We include below only a few notes primarily on the empirical studies (for reviews see, e.g., Cohen, 1995; Cohen & Levin, 1989; Evangelista, 1999; Kamien & Schwartz, 1982; Scherer, 1980).

There are literary hundreds of studies considering link (a), the relationship between market concentration or firm size and innovative effort. In a sense, these studies modify the structure-conduct-performance (S-C-P) paradigm, by replacing the 'C' with innovative efforts and 'P' with outputs of innovative activity. As with S-C-P, the chain also indicates causality. According to Cohen (1995), the empirically robust findings of studies testing the Schumpeterian hypothesis can be summarized as follows:

1. there is a positive monotonic relationship between firm size and R&D investment,
2. innovative output increases less than proportionally with firm size, and
3. R&D productivity declines with firm size.

Findings (1.) through (3.) can be interpreted in either of two ways. It can be argued that larger firms have no particular advantage in performing R&D, in fact, they may have a disadvantage. More recent literature, however, suggests that these findings signal the 'cost-spreading' advantage of larger firms. Since information market imperfections force firms to exploit innovative output through their own production, larger firms capture more of the benefits by spreading them over a larger number of production units.

Despite the potential advantage of large firms, more concentrated industries are not necessarily more innovative, since diversity may decline with the number of firms. Most studies examining the concentration and R&D relationship find positive effects, but these results seem to be driven by inadequate control of other industry-level variables. The findings on the effects of concentration on innovation are inconclusive.

There is some indication that the relationship between size and R&D may be nonlinear. Pavitt, Robson, and Townsend (1987) would seem to suggest that the relationship of size and R&D productivity is U-shaped: small and large firms are relatively more productive than medium-sized firms. It may also be a mistake to assume that R&D would be homogenous across firms: the intuition that large firms tend to conduct more incremental and process R&D is empirically supported (see, e.g., Mansfield, 1981; Scherer, 1991).

Unfortunately emphasis on firm size and market structure has lead many researchers to ignore other, perhaps more fundamental, industry characteristics. By these 'other characteristics' we refer to the bottom box in Figure 2.

Two schools of thought have been arguing over the ultimate driving force of innovation almost since the seminal works of Schumpeter (1942) and Schmookler (1966). Schmooklerians argue that demand conditions determine the direction and rate of technological change ("demand pull"), whereas Schumpeterians argue that scientific advances and isolated R&D efforts are the main factors contributing to innovations ("technology push"). The truth is, of course, somewhere in between and is highly dependent on the situation at hand.

It is often taken for granted that in some industries technological advances are easier to achieve for a given innovative input. There is no consensus on how to quantify this 'easiness' empirically. The most commonly followed path in empirical studies was initiated by Scherer (1965), who crudely classified firms on the basis of their technological and scientific fields.

Appropriability is one of the keys in determining the profitability of innovative activity. If new knowledge 'spills over' easily, i.e., other firms can readily exploit it without compensating the original source, the rewards of an innovation may be reduced to the extent that the associated costs are not justified. Appropriability is obviously related to the issue of R&D spillovers (see below).

While industry-level determinants certainly have an effect on innovative activity, the decisions on conducting R&D as well as the exploitation of the potential results take place at the firm level. Discussion of the firm-level determinants have largely revolved around financial and organizational issues.

Internal financial capability (see, e.g., Antonelli, 1989; Kraft, 1989), typically measured by cash flow, has potential effects on innovative activity, if firms favor internal to external funds in financing R&D and/or if some, e.g., larger firms have better opportunities to attract funding. Both arguments imply some kind of market imperfection, and the latter argument has Schumpeterian underpinnings as it may refer to the advantages of size. Some studies indeed confirm that there is some relationship between cash flow and R&D intensity, although the evidence is far from conclusive.

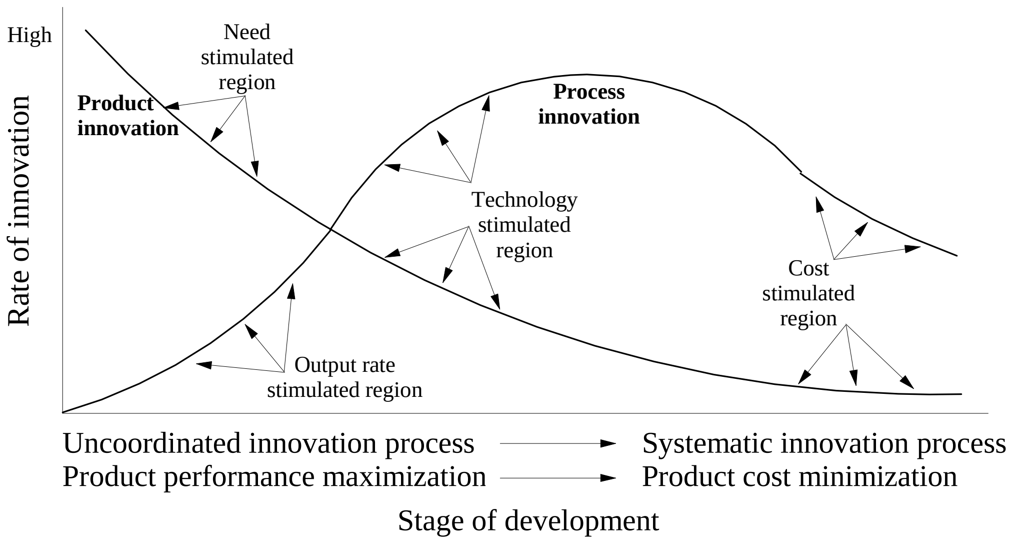
Nelson (1959) argued that diversified firms have better opportunities to exploit unpredictable R&D results than others. An additional argument for the relationship between innovation and diversification is the complementarity of innovative activities, which are possibly better captured under the same corporate umbrella. The evidence on the diversification-innovation link is mixed. Complementarity among assets is perhaps a more interesting, and more complicated, issue than diversification in itself. It has been suggested (e.g., Mowery & Rosenberg, 1989) that links across marketing, manufacturing and R&D activities are important for innovative success. In addition, organization of R&D, technological diversity, managerial control, organizational and procedural capabilities, and related stocks of knowledge are among the topics discussed.

Obviously, the quality of a firm's labor force and the pool of human capital should bear relation to innovative activity. Leiponen (1996b) has found some evidence for this. Innovative activity in, e.g., electronics requires some knowledge of the basic concepts. Furthermore, Cohen and Levinthal (1989) argue that in order to benefit from discoveries made elsewhere, firms have to do some research themselves. It also often argued that after a while people get better in doing things, i.e., learning-by-doing takes place (Krouse, 1994).

As far as innovative activity is concerned, the role of spillovers is two-sided. First, firms do not innovate in isolation, so the ability to exploit advances made elsewhere obviously contributes to the level of innovation. The second issue relates to the imperfect appropriability of any innovation the firm may make: spillovers emitted by the firm reduce the incentive to innovate since competitors capture some of the benefits.

One of the ways to overcome the disincentive issue associated with spillovers is cooperation among competitors. Since the classic work of d'Aspremont & Jacquemin (1988), the relationship between spillovers and cooperation has been widely debated in the theoretical literature. Asset complementarities may be another motive for cooperation in innovative activity.

The Schumpeterian notion of ‘creative destruction’ is a dynamic concept. Industry and firm structures are a consequence of historical developments. Utterback and Abernathy (1975) have presented a classic ‘product-cycle’ model of dynamic interaction between technological change and industrial structure. The essence of this model is summarized in Figure 3.



Source: Utterback and Abernathy (1975, p. 645: Fig. 1).

Figure 3. Innovation and stage of development.

In the early stages of industrial evolution in Figure 3, innovative efforts of the firms in the emerging industry are aimed at matching high technological opportunities with also high market uncertainty. As the industry matures, the emphasis of innovation shifts to developing more capital intensive mass production methods. Ultimately the focus of innovation is on cost reduction. Changes in innovative patterns are accompanied by changes in industry structure.

Leo (1996) is one of the few studies analyzing firm-level determinants of process and product innovations in an econometric framework. There are, of course, a number of related works with their own agendas (Audretsch, 1995; Audretsch & Acs, 1991; Baldwin & Johnson, 1997; Bertschek, 1995; Bertschek & Entorf, 1996; Brouwer & Kleinknecht, 1996; Cassiman & Veugelers, 1998; Cesaratto & Stirati, 1996; Crépon, Duguet, & Mairesse, 1998; Evangelista, Perani, & Archibugi, 1997; Flaig & Stadler, 1994; Hansen, 1992; Johnson & Evenson, 1997; Koeller, 1995; Kraft, 1989; Leiponen, 2000; Leiponen, 1996a; Leiponen, 1996b; Leiponen, 1996c; Leppälahti & Åkerblom, 1991; Nås, 1996; Nås & Leppälahti, 1997; Scholz, 1990; Sirilli & Evangelista, 1998; SVT, 1998; Veugelers & Cassiman, 1998; Veugelers & Cassiman, 1999; Wagner & von der Schulenburg, 1992), some of which are rather descriptive.[3] In what follows we discuss a few details of Leo's paper.

Although Leo acknowledges and promotes the usual polarized view of process and product innovations,[4] he nevertheless emphasizes that the two are interrelated:

> "… if a new product is created the production process has also to be altered; if the production process is altered, this can not be reduced to the installation of new machines in the production plant, but rather may also require its own R&D efforts, small scale prototypes, modification of the product characteristics, etc.; even process innovations themselves may lead to new product concepts…" (Leo, 1996, p. 62 – footnote 1).

Against this background it is perhaps a little surprising that the author chooses to estimate separate Logit models for process and product innovations, rather than something like the bivariate probit model implemented in this study. A 234 firm subsample of the Austrian WIFO Innovation Survey, covering 600 industrial establishments, is being used. The results would seem to suggest that product and process innovations are determined by essentially the same factors, namely: relations with customers, government R&D promotion programs, and cooperation with other firms.

Model

While our empirical implementation is not a direct application of any given theoretical model, it is perhaps useful to introduce some theoretical structure to the problem at hand. In recent years a number of game theoretic models incorporating both process and product innovations have emerged. While all models have their virtues, let us consider a two-period model introduced in Athey and Schmutzler (1994; 1995). In the first period, the firm invests in product and process flexibility as well as in product and process research. An investment in flexibility reduces the cost of implementing the innovation; an investment in research increases the likelihood of an innovative opportunity. In the second period, opportunities for process and product innovations emerge, and the firm chooses whether to implement each type of innovation or not. Below a few details of the model – please see the original papers for further details.

In the second period the firm observes opportunities for process (D, 'design') and product (T ,'technology') innovations, $\eta \in \{D,T\}$, and chooses whether to ignore one or both of the opportunities (0) or to make the adjustment(s) (1), $a_\eta \in \{0,1\}$. The adjustment decisions depend on the associated net returns, $r_D, r_T \in \mathbb{R}^+$; r_D increases marginal revenue and r_T reduces marginal cost. Together with adjustment decisions, the firm chooses its production quantity Q. The firm faces a downward sloping demand curve with inverse demand $P(Q, a_D, r_D)$ and an average cost function $C(Q, a_T, r_T)$. Furthermore, there is a cost associated with the implementation of each innovation type, $A_\eta(a_\eta, f_\eta)$, where f_η represents the flexibility of the firm in dimension η. The second period payoffs of the firm can be written as follows:

$$\Pi_2(a_D, a_T, Q, f_D, f_T, r_D, r_T) = \left[P(Q, a_D, r_D) - C(Q, a_T, r_T)\right]Q - A_D(a_D, f_D) - A_T(a_T, f_T) \qquad (1)$$

Variables (a_D, a_T, Q) are chosen from the set $\Gamma_2 \equiv \{0,1\} \times \{0,1\} \times \{\mathbb{R}^+\}$. Thus, the solution to the second period problem is

$$(a_D^*, a_T^*, Q^*) \equiv \underset{(a_D, a_T, Q) \in \Gamma_2}{\arg\max} \; \Pi_2(...). \qquad (2)$$

Let us make the reasonable assumptions that product innovation raises price and that process innovation reduces cost, i.e., in the absence of adjustment cost, innovations are beneficial. Analysis of the pairwise relations between the variables (a_D, a_T, Q) reveals that there is a force supporting the co-existence of process and product innovations. Under reasonable assumptions, the game is supermodular,[5] which enables the authors to make comparative statistics predictions on the firm's choices regarding innovative activity. The authors show, among other things, that

1. second period optimal choices of implementing a product innovation, implementing a process innovation, and setting the quantity of output increase with the returns and flexibility associated with each type of innovation,
2. firms tend to choose higher levels of process flexibility with higher levels of product flexibility and *vice versa*,
3. if marginal cost of **either** type of flexibility decreases, higher levels of both types of flexibility are chosen, and
4. investments in process and product flexibility and research are mutually reinforcing.[6]

Although the model does not yield predictions of inter-firm differences in research expenditures *per se*, it nevertheless shows how prior decisions regarding flexibility and research are affected by future innovation opportunities and costs of adjusting operations as a consequence of implemented innovation(s).

To some extent, exogenous factors, such as technological opportunities within the industry, determine the nature and intensity of firm-level innovative activity. At least in the short run, firms may be locked into unattractive technological environments as a consequence of their prior decisions and institutional histories.

In what follows we implement an empirical model analyzing the inter-industry and firm-level determinants affecting the joint decision of implementing a process and/or product innovation.

APPROACH

Firms have two main reasons to innovate: first, to introduce new or improved product(s) to the market (=product innovation), and, second, to develop better method(s) to produce their output (=process innovation). While innovations may come about costlessly, i.e., they may be ingenious inventions or free side products of some other activity, firms frequently commit some resources to innovative activity, the most obvious example being R&D expenditure. Furthermore, implementing the innovation can also be quite costly: some current production may have to be forgone in order to improve production, machines have to be acquired, new products have to be marketed, etc.

Firms earn returns on the innovative efforts via income generated by new/improved product(s) and/or better cost efficiency brought about by new/improved production method(s).

In what follows, we will study variables that contribute to firms' likelihood to innovate. We hope to uncover what variables are important overall, and how process and product innovators differ in their dominant characteristics.

We assume that firms innovate because it is profitable for them to do so. Our goal is to determine what firm-level variables seem to contribute to this ability to increase profits via innovation. Thus, profits of an innovating firm i must be higher with (π_i^I) than without (π_i^N) innovation, i.e.,

$$y_i^* = \pi_i^I - \pi_i^N > 0 . \quad (3)$$

Unfortunately, we do not observe a firm's profits with and without innovation. We merely observe whether it in fact innovates. The observed counterpart to y_i^* is y_i, which takes a value of either zero (does not innovate) or one (innovates) as follows:

$$y_i = \begin{cases} 1 \text{ if and only if } y_i^* > 0 \\ 0 \text{ otherwise} \end{cases} . \quad (4)$$

A latent regression can be specified as

$$y_i = \boldsymbol{\beta}' \boldsymbol{x_i} + \varepsilon_i , \quad (5)$$

where $\boldsymbol{\beta}$ is a vector of coefficients, $\boldsymbol{x_i}$ is a vector of explanatory variables, and ε_i is an error term following some distribution. Once we assume some distribution for ε_i, we can define the conditional probabilities, expected values, and marginal effects of y_i being one.

The situation at hand is complicated by the fact that for each firm we observe whether it does process and product innovations or not. Thus, for each i we observe a pair of y_i s. Thus, a bivariate probit model is a natural candidate for the empirical modeling in our case. We estimate such a model with a set of explanatory variables suggested in the previous literature.

IMPLEMENTATION[7]

As discussed above, there are actually two Schumpeterian hypotheses. First, Schumpeter argues that competition among entrepreneurs drives innovation. Second, somewhat conflictingly, he emphasizes the importance of oligopolistic market structures in promoting innovation. We measure the first by the relative share of small (less than 100 employees) firms in the industry and the latter by the three firm concentration ratio (kindly provided by Aija Leiponen).

Schumpeter is also associated with the 'technology push' view on the ultimate driving force of innovation, competing with the Schmooklerian 'demand pull' view. We derive measures for both based on industry average answers to the questions regarding the importance of universities and non-profit research organizations, on the one hand, and customers, on the other, as sources of innovation.

The Finnish innovation survey does not include direct questions on the appropriability of technology within the industry. It does ask, however, how important sources of innovation(s) competitors are. We infer that if competitors are on average important sources of technology across the industry, appropriability is low.[8]

Our analysis is based on a cross-section of firms, so we have rather limited possibilities to study industry dynamics. We proxy the state of development of the industry by the average age of the employees across the industry, arguing that people entering industries are roughly the same age and due to their educational backgrounds and prior work experiences they are locked to the industry in question even though they may be mobile across firms.

The neo-Schumpeterian tradition has not been very concerned with embodied forms of technology. We include a measure for the importance of embodied forms of technology (industry average of the answer to the question on the importance of equipment suppliers as a technology source). We also include the industry average capital intensity, which proxies the accumulated stock of embodied technology.

At the firm level, the discussion in the Schumpeterian tradition has revolved around the issue of firm size and R&D. We measure size by the number of employees[9] and R&D effort by R&D intensities (internal R&D/sales and external R&D/sales).

After R&D intensity and firm size, the role of financial factors and corporate structure have been the most studied issues in the previous literature. We construct a dummy for firms that are financially constraint as suggested by Ali-Yrkkö (1998) and include a dummy for firms with multiple plants.

We attempt to measure disembodied human capital by including three measures of educational level of employees: (a) the ratio of employees with master or similar degrees, (b) the ratio of employees with research degrees (Ph.D. or licenciate), and the ratio of employees with engineering or natural science degrees. Furthermore, we include the average age of employees and the average tenure within the firm as explanatory variables. We also measure directly firms' ability to benefit from disembodied inward spillovers, which is obviously related to the qualities of the labor force.

We include three measures of cooperation: (a) a dummy for cooperation within the group, (b) a dummy for cooperation with non-academic outside partners, and (c) a dummy for cooperation with universities or non-profit research organizations.

We performed separate likelihood ratio tests for multiplicative heteroskedasticity with respect to sales, value added, physical capital stock, labor productivity, and the three measures of formal education and found no evidence for it. We also studied effects of dropping unsignificant variables:[10] the coefficients that were significant in the estimation of the full model remained largely unchanged as variables were being dropped.

At the industry level, we also studied the inclusion of a number of other variables, including industry import penetration (in order to better capture the 'effective' industry concentration in a small open economy), industry export orientation (to capture that fact that domestic production does not necessarily effect the competition and concentration at the home market), industry

OECD export market share (to study the effect of the Finnish market power in the world market), average establisment size within the industry (to study whether the size effect is an industry rather than a firm phenomenon), and industry R&D intensity (a potential proxy for technological opportunity within the industry).

We also studied the inclusion of industry dummies with two alternative industry definitions, one proposed by Veugelers and Cassiman (1999) and a more detailed classification of our own. Industry dummies were individually and jointly insignificant and thus we could conclude that our industry-level variables capture cross-industry differences sufficiently well.

At the firm level, we considered including the actual number of plants (to better proxy the diversification or spreading advantages), physical capital intensity (to capture the role of embodied technology at the firm level), labor productivity (a possible measure for labor quality), the export intensity of the firm, dummies for ’make’ and ’buy’ R&D strategies, a dummy for foreign ownership, as well as firms’ Finnish and OECD export market shares (proxies for firm-level market power in the home and international markets).

Previous literature has suggested that the effect of size on innovative output may be nonlinear. We studied this by adding the square and cubic terms of firm size as well as with dummies for different firm sizes and found no evidence for this.

We also performed likelihood ratio tests (with the null of coefficients being equal) on whether coefficients are equal across equations.[11] In less than half of the cases we conclude that the coefficients are **not** equal. These results are, however, driven by the fact that most coefficients are not significant in both equations. Of the few coefficients that were significant in both, only the ability to benefit from inward spillovers clearly had a symmetric effect on both types of innovation.[12]

Table 1 presents the bivariate probit estimation results of what may be titled the ’maximal’ (or full) and ’minimal’ (or reduced) models: the former includes all the variables mentioned above and the latter includes only the variables that were statistically significant in the ’maximal’ model (with the expection of constant and firm size which were included by default) and also imposes the aforementioned cross-equation parameter restriction.

Table 1. Maximum likelihood estimation results of bivariate probit models.

Variable (x)	Est.	St. dev.	M. effect of x	$E(y_i) \mid y_j$	Est.	St. dev.
Process (y_1) innovation equation						
Constant	.47	1.60	.99 $\mid y_2=1$	.39 $\mid y_2=0$	.70	.63
Ind.: Entrepreneurial regime	-.26	.70	-.39 $\mid y_2=1$	-.16 $\mid y_2=0$		
Ind.: Concentration	.91	.82	.37 $\mid y_2=1$	.19 $\mid y_2=0$		
Ind.: Technology push	-1.47	2.61	-.30 $\mid y_2=1$	-.20 $\mid y_2=0$		
Ind.: Demand pull	1.74	1.90	-.35 $\mid y_2=1$	-.02 $\mid y_2=0$		
Ind.: Appropriability	-5.31	3.15 *	-1.78 $\mid y_2=1$	-.97 $\mid y_2=0$	-1.84	.64 ***
Ind.: Dynamic stage	.54	4.26	-.46 $\mid y_2=1$	-.14 $\mid y_2=0$		
Ind:: Embodied technology	2.63	2.15	1.37 $\mid y_2=1$	.66 $\mid y_2=0$		
Ind.: Capital intensity	.92	.33 ***	.37 $\mid y_2=1$	.19 $\mid y_2=0$	.62	.27 **
Firm: size	.21	.19	.01 $\mid y_2=1$	.02 $\mid y_2=0$	.21	.18
Firm: Internal R&D-int.	-.48	1.64	-1.12 $\mid y_2=1$	-.44 $\mid y_2=0$		
Firm: External R&D-int.	-.04	4.54	-2.23 $\mid y_2=1$	-.82 $\mid y_2=0$		
Firm: financially constr.	-.13	.18	-.02 $\mid y_2=1$	-.02 $\mid y_2=0$		
Firm: multiple plants	.27	.14 *	.09 $\mid y_2=1$	.05 $\mid y_2=0$	.25	.13 *
Firm: master degrees	-.90	.62	-.32 $\mid y_2=1$	-.17 $\mid y_2=0$		
Firm: Research degrees	-1.69	6.30	-2.88 $\mid y_2=1$	-1.16 $\mid y_2=0$		
Firm: Technical degrees	-.22	.38	-.01 $\mid y_2=1$	-.02 $\mid y_2=0$		
Firm: avg. employee age	-5.68	2.43 **	-2.33 $\mid y_2=1$	-1.20 $\mid y_2=0$	-5.47	1.50 ***
Firm: avg. empl. Tenure	.09	1.51	.32 $\mid y_2=1$	.12 $\mid y_2=0$		
Firm: inward spillovers	2.88	.31 ***	.75 $\mid y_2=1$	.45 $\mid y_2=0$	2.76	.22 ***
Firm: Coop. in the group	-.08	.15	-.07 $\mid y_2=1$	-.03 $\mid y_2=0$		
Firm: Non-acad. coop.	1.09	.16 ***	.35 $\mid y_2=1$	.19 $\mid y_2=0$	.96	.12 ***
Firm: Academic coop.	-.08	.16	-.12 $\mid y_2=1$	-.05 $\mid y_2=0$		
Product (y_2) innovation equation						
Constant	-4.55	1.95 **	-2.14 $\mid y_1=1$	-1.30 $\mid y_1=0$	-4.00	.53 ***
Ind.: Entrepreneurial regime	1.58	.77 **	.76 $\mid y_1=1$	.46 $\mid y_1=0$	2.06	.64 ***
Ind.: Concentration	.14	.85	-.10 $\mid y_1=1$	-.02 $\mid y_1=0$		
Ind.: Technology push	-1.95	2.59	-.60 $\mid y_1=1$	-.44 $\mid y_1=0$		
Ind.: Demand pull	6.40	2.13 ***	2.56 $\mid y_1=1$	1.65 $\mid y_1=0$	2.56	.53 ***
Ind.: Appropriability	-3.13	3.74	-.42 $\mid y_1=1$	-.49 $\mid y_1=0$		
Ind.: Dynamic stage	4.03	4.87	1.71 $\mid y_1=1$	1.08 $\mid y_1=0$		
Ind:: Embodied technology	-1.27	2.22	-1.06 $\mid y_1=1$	-.54 $\mid y_1=0$		
Ind.: Capital intensity	.16	.37	-.10 $\mid y_1=1$	-.02 $\mid y_1=0$		
Firm: size	.47	.28	.17 $\mid y_1=1$	.11 $\mid y_1=0$	.53	.22 **
Firm: Internal R&D-int.	5.28	1.60 ***	2.47 $\mid y_1=1$	1.50 $\mid y_1=0$	4.92	1.56 ***
Firm: External R&D-int.	12.73	7.11 *	5.75 $\mid y_1=1$	3.54 $\mid y_1=0$	13.71	6.20 **
Firm: financially constr.	-.21	.17	-.07 $\mid y_1=1$	-.05 $\mid y_1=0$		
Firm: multiple plants	.16	.16	.02 $\mid y_1=1$	.03 $\mid y_1=0$		
Firm: master degrees	-.40	.67	-.01 $\mid y_1=1$	-.05 $\mid y_1=0$		
Firm: Research degrees	12.31	16.35	5.86 $\mid y_1=1$	3.54 $\mid y_1=0$		
Firm: Technical degrees	-.50	.40	-.18 $\mid y_1=1$	-.12 $\mid y_1=0$		
Firm: avg. employee age	-.88	2.65	.67 $\mid y_1=1$	.16 $\mid y_1=0$		
Firm: avg. empl. Tenure	-1.61	2.17	-.74 $\mid y_1=1$	-.45 $\mid y_1=0$		
Firm: inward spillovers	2.92	.33 ***	.78 $\mid y_1=1$	.61 $\mid y_1=0$	(restricted: as above)	
Firm: Coop. in the group	.22	.18	.11 $\mid y_1=1$	.07 $\mid y_1=0$		
Firm: Non-acad. coop.	.73	.17 ***	.12 $\mid y_1=1$	.12 $\mid y_1=0$	.78	.15 ***
Firm: Academic coop.	.51	.17 ***	.25 $\mid y_1=1$	.15 $\mid y_1=0$	.56	.15 ***
Cross equation corr.	.52	.07 ***			.52	.07 ***
Log-likelihood			-643.59		-658.03	
Likelihood ratio index			.40		.39	
Obs. / No. of parameters			1008 / 46+1		1008 / 16+1	

Note: ***, **, and * indicate significance at 1, 5, and 10% level. Sample averages of individual marginal effects.

The results confirm Leo's (1996, footnote 1 – see above) suggestion that the two types of innovations are indeed related, manifested by the rather high and statistically significant cross-equation correlation. Thus, the estimation of two separate probit models would lead to significant loss of efficiency and possibly misleading results. The likelihood ratio index, roughly comparable to R^2 of conventional regression models (see, e.g., Greene, 1993), suggest that the model fit data reasonably well. With the exceptions of one industry-level variable in each of the two equations, the coefficients change only marginally between the 'maximal' and 'minimal' models; while the absolute sizes of appropriability conditions in the process equation and demand pull in the product equation reduce, the signs of the coefficients do not change and the variables remain significant. Let us discuss individual explanatory variables in some detail.

We find some evidence for the first Schumpeterian hypothesis on the role of entrepreneurs in innovative activity: the industry-level entrepreneurial regime variables is positive and significant in the product equation. There is no clear evidence on the second hypothesis on the benefits of concentration and firm size – coefficients have expected signs but they are not significant in the full model. As mentioned above, we also tried three additional measures in order to capture the international aspects of concentration and size, but there where no indication that these variables should be included in the model.

Demand pull becomes significant in the product equation – note that product innovations may, e.g., be differentiated products requested by particularly demanding clientele. We fail to get the expected signs for the technology push indicator.[13]

Surprisingly enough, appropriability conditions are significant only in the process equations: this would seem to suggest that process equations spill over more easily and/or that product innovations can be more readily protected via patents, trademarks, etc.

Our admittedly rather poor proxy for the dynamic stage of the industry does not become significant.

The measure for embodied technology in insignificant. Whereas this variable captures the current flow effects of this form of technology, capital stock captures the stock of cumulated embodied technology up to date. This seems to be a significant explanatory factor of process innovations. Note that this an industry-level phenomenon – as mentioned above, experiments to also include firm-level capital stocks were unsuccessful.

Investments in R&D, whether conducted internally or externally, only contribute to product innovation according to our results. We also experimented with the inclusion of a cross term, but test statistics did not suggest that it should be included.

The effects of the firm being financially constraint has the expected sign, but does not become significant. We also experimented with some continuous measures of financial constraints with no improvements in t-values.

Diversification advantages, as proxied by the firm be a single- or multi-plant operation, seem to be present in the case of process innovations. This may also relate to the appropriability issues – if product innovations are more appropriable, they can be sold more readily on the market place and the 'spreading' advantage, now relating to the number of plants rather than size, is not present since internal exploitation of innovations does not have to take place.

Our skill measure are the only really puzzling set of variables in the estimations – with one exception, none of the schooling or experience measures become significant in either of the equations. Furthermore, the signs are potentially controversial. First potential argument regarding the (non)findings on schooling is that we do not observe the skill-level and experience of personnel actually involved in the innovative activities. For roughly one fifth of the sample, we had some information on the educational level of the R&D personnel, but experiments with these variables did not give clear indication of more positive results. To further develop the idea, one could argue that the numbers we actually observe are only a proxy for the role of bureaucrats in the organization. We did, however, experiment with the inclusion of the relative share of administrative personnel, so this argument does not seem plausible. Second, one could argue that there are some kind of nonlinearities in the innovation–schooling relationship. We studied this by including square and cubic terms of schooling variables. None of the coefficients became significant, but the absolute values seemed to suggest that the relationship is indeed J-shaped; moderate relative shares of more educated personnel reduce innovativeness slightly and the positive effects come only at rather high concentrations. Third, it could be argued that formal education reduces flexibility discussed in the theoretical model above. In the case of the average employee age, which becomes negative and significant in the process equation, this is quite plausible explanation. Fourth, other variables, e.g., measure of R&D, may better capture the role of human capital in innovative activity. The personnel with research degrees has a large and positive absolute coefficient and marginal effect in the product equation, but also a sizable standard deviation.

Ability benefit from inward spillovers was the only clearly symmetric effect we found. Thus, we sharply contradict the findings of Leo (1996), who basically argues the determinants of the two kinds of innovation are essentially the same.

Surprisingly enough, within group cooperation in innovative activities does not become significant. Non-academic outside cooperation seem to contribute to both types of innovation, but cooperation with universities and non-profit research organizations only to product innovation.

The significance levels and marginal effects tell us about the relative importance of various explanatory variables. The ultimate test of binary dependent variable models is, however, how well they are able to predict the observed outcomes. Table 2 evaluates the predictive per-

Table 2. Predictive performance: joint frequencies and shares of correct predictions.

Joint frequences of the full model

Fitted count in parenth.	No prod. innov.	Product innov.	Tot. prod. Innov.
No proc. innov.	611 (699)	117 (45)	728 (744)
Process innov.	70 (12)	210 (252)	280 (264)
Tot. proc. innov.	681 (711)	327 (297)	1,008

Joint frequences of the reduced model

Fitted count in parenth.	No prod. innov.	Product innov.	Tot. prod. Innov.
No proc. innov.	611 (706)	117 (35)	728 (741)
Process innov.	70 (5)	210 (262)	280 (267)
Tot. proc. innov.	681 (711)	327 (297)	1,008

Percentage share of correct predictions

	Process innov.	Product innov.	Both types of innov.
Correct predictions with the full model	82.3%	85.9%	74.3%
Correct predictions with the reduced m.	82.0%	85.3%	74.0%
Correct predictions of the naïve m. (y_i=0)	72.2%	67.6%	60.6%

Note: Refers to the models in Table 1.

formance of the two models above. The joint frequency tables suggest that the models predict relatively well non-innovators and *comprehensive* innovators, i.e., those that make both process and product innovations. In the bivariate case, the frequency tables do not directly reveal how many of the predictions are correct. Therefore, we have calculated the percentage shares of correct predictions in the bottom of Table 2. Due to the relative imbalance of innovators versus non-innovators in both dimensions, the naïve prediction of setting both dimensions equal to zero actually performs quite well (bottom row). Despite this, both the full and reduced models offer considerable improvements over the naïve model.

ANALYSIS

While the introduction of process and product innovations are certainly positively related, they are largely driven different industry- and firm-level factors. In the above estimations, the ability to benefit from inward spillovers is the only variable that clearly has a symmetric effect on both innovations. Of the rest, outside cooperation with non-academic partners turns out be the only statistically significant explanatory factor in both equations.

We do not reach conclusive results on the 'later' Schumpeterian hypothesis of market concentration and firm size. As far as product innovations are concerned, the role of size is rather interesting. We find some indication of the 'earlier' Schumpeterian hypothesis, i.e., that competition among entrepreneurs (as proxied by the relative share of small and medium-sized firms in the industry) promotes innovations. Conditional on this finding, there is some indication that large firms are more innovative (this can be seen only in the reduced version).

The industry-level 'embodied' technology seems to be relevant for process innovations, whereas product innovations are related to 'disembodied' forms of technology both in- and outside the firm.

Low appropriability reduces the probability of process innovations. This, combined with the fact that multi-plant firms seem to be more likely process innovators, would seem to suggest that process innovations spill over more easily and are thus exploited internally, i.e., there is 'spreading' advantage across plants in process innovations.

We argue that the fact that the likelihood of making process innovations reduces with the average age of employees, indicates that older employees are on average less flexible in adjusting to new processes which makes their implementation more costly.

Conventionally we have thought that product innovations are driven by scientific break-throughs and advances in basic and applied research. In our analysis only ‘demand pull’ seem to contribute to the likelihood of introducing product innovations. Note, however, that new product is defined as being new to the **firm**, it may or may not be new to the **market**. Thus, for instance ‘mass customization’ or differentiation of products to different clientele would be examples of ‘product innovations’ possibly driven by ‘demand pull’.

CONCLUSION

By and large, the literature on innovative activity has discussed determinants of innovation in isolation, and is thus subject to omitted variable bias. While these studies have obviously address their specific issues in much more detail than we have, it is quite useful the evaluate how important these issues are relative to each other.

The Finnish community innovation survey provides a reasonable starting point for econometric analysis, but it could benefit, among other things, from the explicit treatment of appropriability conditions, from a more detailed descriptions innovations, from a finer classification of innovations, as well as from the actual innovation counts rather than only binary information. On the other hand, expanding the survey will surely reduce the firm’s motivation to provided accurate answers. Despite the fact that self reported data on firm-level innovations is rather noisy, we are able to get some conclusive and reasonable results.

The proposed approach could be extended to a number of dimensions. In our own further research, we will address some technology policy issues, which, to our knowledge, have not received much attention in prior innovation studies.

Our findings suggest that treating innovations are homogenous would be a mistake. Although the interrelations between the two types of innovations should be acknowledged, they are largely driven by a different set of factors. Some prior findings of high nonlinearities in innovation with respect to, e.g., firm size, may be driven by inadequate treatment of heterogeneity among innovations.

ENDNOTES

[1] It should be noted that technology may also be *embodied* in intermediate inputs.

[2] "This great increase of the quantity of work, which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first, to the increase of dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many." (Adam Smith, 1776, Wealth of Nations, as in Heilbroner & Malone, 1986, p. 164).

[3] See also http://www.cordis.lu/eims/src/cis.htm.

[4] That is, '…efforts to shift the technological frontier…" (product innovation, p. 62) and "…focus on investments and introduce ("embodied") technological progress through purchase of capital goods…" (product innovation, p. 62).

[5] Increasing one of the two variables increases returns to increasing the other.

[6] Investments in learning about the innovative opportunities have the highest returns when the firm is more likely to implement the possible discoveries.

[7] Please see Appendix A for descriptive statistics and other details of the data set.

[8] I am grateful for Aija Leiponen for pointing this out.

[9] We also experimented with sales and total assets as a proxy for size – there were no major changes in results.

[10] We first dropped variables that were not significant at 15% level **in either of the equations** and re-estimated the model. From this model, we then dropped variables not significant at 10% level.

[11] For these tests, we used a reduced model with only the variables that were significant in at least one of the equations.

[12] The effect of 'cooperation with outside partners' may also be symmetric.

[13] Note, however, that the model includes variables that may actually capture better the essence of 'technology push', e.g., the cooperation with the academia.

APPENDIX A. DATA DOCUMENTATION.[i]

Most industrialized countries have been collecting R&D statistics since the 1960s. Expenditure on R&D is, however, essentially an input measure and in some contexts it is necessary to measure the output of R&D and related innovative activities. Many output measures, including bibliometrics (article, citation, and co-citation counts), technological balance of payments (technology-related payments and receipts), trade in technology intensive goods, and patents/patent applications have been suggested (Åkerblom, Virtaharju, & Leppälahti, 1996).

The 'Oslo manual' (OECD, 1992) set forth the agenda and guidelines for studying innovations through surveys. Many European countries, led by the Community's central statistical office Eurostat, have implemented Community Innovation Surveys (CIS) in more than one occasion in the 1990s. We draw from the 1996 version of the Finnish Community Innovation Survey (CIS-2) conducted by Statistics Finland and coordinated by Eurostat. Statistics Finland has conducted two innovation surveys in the past, but they are not directly comparable.

CIS-2 collects information at the firm-level, i.e., it can be characterized as being subject oriented. One could also attempt to collect information on individual innovations, i.e., take an object-oriented approach. Some basic definitions of CIS-2 are as follows:

> The *innovating firm* has, in a period of three years (1994–6), introduced a product innovation, made use of a process innovation, or has been engaged in activities the specific purpose of which has been to come up with such innovations.
>
> *Technological innovation* is a new or improved product or process, the characteristics of which are significantly different from previous ones from the implementing firm's point of view.

Separate innovation surveys were conducted for industrial and service branches. We will concentrate on the former. The EU part of the Finnish CIS-2 includes firms with 10 or more employees. Statistics Finland has also collected some information on smaller firms.

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[i] We have used two lengthy programs, one in SAS and one in STATA, to construct our data set. These procedures are self documented and provide further information on the construction of the data set. They are available upon request.

Our sample includes the 1,008 manufacturing firms having usable observations of in the survey. This information is matched to other sources available at Statistics Finland, e.g., industrial statistics, R&D surveys, financial statement figures, and educational statistics.

The innovation survey specifically asks whether the firm has innovated during the years of 1994–6.[ii] Thus, for other variables, we took the means of 1994–6 figures whenever possible.[iii] The actual data was collected in 1997. Of the 3,521 firms in Finnish manufacturing 1,687 were in the sample, of which 71.9% answered.[iv] Our final sample accounts for roughly half of manufacturing employment in 1994–6.

Table 3 presents brief descriptions of the variables used in the above analysis. For computational reasons, we have attempted to keep the variables roughly in the same scale, and thus the units of measurement may seem a little odd.

[ii] Details of the sampling are documented in SVT (1998).

[iii] Nominal variables are deflated by the implicit GDP deflator (1995=1.00). If the variable of interest was not observed for some years, we took the mean of the year(s) available.

[iv] Roughly hundred observations were lost due to inconsistent or incomplete answers or other problems.

Table 3. Descriptive statistics.

Variable	Mean	St.dev.	Min.	Max.	Description
Ind.: entrepreneurial reg.	.636	.094	.000	.786	A proxy for the degree of 'entrepreneurial regime' within the industry: the ratio of firms with less than hundred employees to the total number of firms (financial statement statistics).
Ind.: concentration	.270	.101	.086	.957	Industry concentration: the ratio of sales of the three biggest firms to the total industry sales (Leiponen).
Ind.: technology push	.175	.067	.051	.317	The industry average answers to the importance of universities and non-profit research organizations as sources of innovation (innovation survey).
Ind.: demand pull	.352	.124	.179	.588	The industry average answer to the importance of customers as a source of innovation (innovation survey).
Ind.: appropriability	.249	.082	.145	.556	The industry average answer to the importance of competitors as a source of innovation (innovation survey).
Ind.: dynamic stage	.389	.016	.334	.420	The average age of employees within the industry, in hundreds of years (labor survey).
Ind.: embodied techn.	.241	.066	.143	.444	The industry average answer to the importance of mach. & eq. suppliers as a source of innovation (innovation survey).
Ind.: capital intensity	.253	.210	.066	1.166	The industry average capital intensity – capital stock / gross output (industrial statistics and Maliranta)
Firm: process innovation	.278	.448	0	1	A dummy for making process innovation(s) in the period of 1994–6 (innovation survey).
Firm: product innovation	.324	.468	0	1	A dummy for making product innovation(s) in the period of 1994–6 (innovation survey).
Firm: size	.190	.485	.006	6.928	The average number of employees from 1994 to 1996, in thousands (financial statement statistics).
Firm: internal R&D	.015	.050	.000	.828	The ratio of internally conducted R&D and sales, 1994–6 average (innovation survey; if n/a, R&D survey(s)).
Firm: external R&D	.003	.014	.000	.310	The ratio of 'contracted' R&D conducted outside the firm and sales, 1994–6 average (innovation survey; if n/a, R&D survey(s)).
Firm: financially constr.	.147	.354	0	1	A dummy for the firm being financially constraint (as defined in Ali-Yrkkö, 1998) on average in 1994–6, i.e., operating income did not cover interest expenses and half depreciation (financial statement statistics).
Firm: multiple plants	.216	.412	0	1	A dummy for the firm having multiple plants in any year from 1994 to 1996 (industrial statistics).
Firm: master degrees	.109	.113	.000	.689	The firm's average share of employees with master or similar degrees, 1994–6 average (labor survey).
Firm: research degrees	.002	.009	.000	.133	The firm's average share of employees with research (Ph.D. or licenciate) degrees, 1994–6 average (labor survey).
Firm: technical degrees	.454	.200	.000	.956	The firm's average share of employees with engineering or natural science degrees, 1994–6 average (labor survey).
Firm: avg. employee age	.389	.037	.255	.509	The average age of employees with the firm, 1994–6 average, in hundreds of years (labor survey).
Firm: avg. empl. tenure	.096	.048	.005	.344	The average employee tenure within the company, 1994–6 average, in hundreds of years (labor survey).
Firm: inward spillovers	.174	.223	.000	.917	A proxy for the ability the benefit from inward spillovers. The company average answer to the importance of patents, conferences, the internet, fairs and exhibitions as a sources of innovation (innovation survey).
Firm: coop. in the group	.159	.366	0	1	A dummy for cooperation within the group (innovation survey).
Firm: non-acad. coop.	.309	.462	0	1	A dummy for cooperation with non-academic outside partners (innovation survey).
Firm: academic coop.	.261	.439	0	1	A dummy for cooperation with universities and non-profit research organizations (innovation survey).

Note: Survey questions were originally answered on a 0–3 scale from unimportant to very important. We use a 0–1 scale instead, i.e., answers were divided by 3.

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