ETLA
**ELINKEINOELÄMÄN TUTKIMUSLAITOS**
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY
Lönnrotinkatu 4 B 00120 Helsinki Finland Tel. 358-9-609 900
Telefax 358-9-601 753 World Wide Web: http://www.etla.fi/

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Aija Leiponen

# COMPETENCIES, R&D COLLABORATION, AND INNOVATION UNDER DIFFERENT TECHNOLOGICAL REGIMES

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**ABSTRACT:** This study focuses on the determinants of organisation of innovation, particularly firms' internal competencies and technological environments (regime) in which they operate. Competencies are hypothesised to complement collaborative innovation. Different types of collaboration are expected to be associated with different competencies. Competencies are measured by levels and fields of employees' education. Dimensions of technological regimes include appropriability, demand-pull, supplier-domination, science-push, and entrepreneurial vs. routinised innovation regime. Innovation is modelled as a system of equations, where R&D, collaborative arrangements, and product innovation are simultaneously determined.
Results indicate, first, that technical and research competencies are significant factors in firms' 'systems of innovation.' This reflects the need for absorptive capacity: to be able to internalise knowledge from external relationships the firm needs sufficient internal capabilities. For instance, research competencies are important for collaboration with universities. Second, collaboration with competitors is less common than that with other types of partners. To understand innovation, other types of collaborative agreements need to be investigated as well. Third, technological regimes have a considerable impact on firm organisation. Understanding how firms' innovation behaviour depends on technological regime supports more efficient technology policy.

**KEY WORDS**: R&D collaboration, innovation, competencies, technological regimes

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**TIIVISTELMÄ:** Tutkimuksessa tarkastellaan innovaatiotoiminnan organisointiin vaikuttavia tekijöitä, erityisesti yritysten osaamista ja teknologista ympäristöä. Hypoteesinä on, että yrityksen osaaminen täydentää innovaatioyhteistyötä, ja että yhteistyösuhteet erilaisten kumppanien kanssa edellyttävät erilaista osaamispääomaa. Osaamista mitataan henkilöstön koulutustasoilla ja –aloilla. Teknologisen ympäristön ulottuvuuksia ovat tiedon omistettavuus, innovaatioiden kysyntä, laitetoimittajien merkitys, tieteen edistyminen sekä yrittäjyyden rooli innovaatiotoiminnassa. Innovaatiotoiminta mallinnetaan yhtälösysteeminä, jossa T&K, innovaatioyhteistyö ja tuoteinnovointi määräytyvät simultaanisesti.
Tulosten mukaan ensinnäkin yrityksen osaaminen on merkittävä tekijä sen "innovaatiojärjestelmässä". Tämä heijastaa omaksumiskyvyn merkitystä: pystyäkseen omaksumaan tietoa yhteistyösuhteista yritys tarvitsee riittävästi sisäistä tietämystä. Esimerkiksi tutkimusosaaminen on keskeistä tehtäessä yhteistyötä yliopistojen kanssa. Toiseksi, yritykset tekevät yhteistyötä kilpailijoiden kanssa harvemmin kuin muiden tahojen kanssa. Innovaatiotoiminnan ymmärtämiseksi muunlaisten yhteistyösuhteiden tutkimus on vähintään yhtä tärkeää. Kolmanneksi, teknologisilla regiimeillä on huomattava vaikutus yritysten innovaatiotoiminnan organisointiin. Yritysten innovaatiokäyttäytyminen riippuu siis teknologisesta ympäristöstä. Tämän parempi ymmärtäminen mahdollistaisi tehokkaamman teknologiapolitiikan.

**ASIASANAT**: T&K-yhteistyö, innovaatio, osaaminen, teknologinen ympäristö

# YHTEENVETO

Tässä tutkimuksessa selvitetään innovaatiotoimintaan vaikuttavia tekijöitä, erityisesti innovaatioyhteistyön edellytyksiä. Hypoteesina on, että onnistunut yhteistyö vaatii yritykseltä omaa sisäistä osaamista – sisäistä tutkimus- ja kehitystoimintaa (T&K) ja henkilöstön osaamista ei voida kokonaan korvata ulkoa hankittavalla tietämyksellä, vaan nämä täydentävät toisiaan. Lisäksi yhteistyö erilaisten kumppanien kanssa edellyttää yritykseltä erilaista osaamista. Siksi esimerkiksi innovaatioyhteistyötä yliopistojen kanssa tekevien yritysten osaamispääoman odotetaan olevan erilainen kuin laitetoimittajien kanssa yhteistyötä tekevien yritysten.

Toisaalta tutkimus fokusoi toimialojen välisiin eroihin teknologian kehityksessä. Teknologisen ympäristön eli regiimin on empiirisissä tutkimuksissa havaittu vaikuttavan yritysten T&K-investointeihin ja innovatiivisuuteen. Teoreettisen kirjallisuuden mukaan niillä on yhteys myös toimialan rakenteeseen. Tässä tutkimuksessa selvitetään, kuinka teknologinen ympäristö vaikuttaa yritysten innovaatiostrategiaan, erityisesti innovaatiotoiminnan organisointiin. Tutkimuksella on politiikkaimplikaatioita, koska teknologiapolitiikassa korostetaan yhä enemmän laajaa "verkottumista" ja innovaatioyhteistyötä. Teknologisen ympäristön tässä tarkasteltavia ulottuvuuksia ovat tiedon omistettavuus (tietovuodot), innovaatioiden kysyntä, laitetoimittajien rooli innovaatiotoiminnassa, tieteen edistymisen ripeys ja merkitys sekä aggressiivista yrittäjyyttä tai rutinoitunutta innovointia suosiva ympäristö.

Edellä esitettyjä ajatuksia testataan suomalaisella yritysaineistolla. Aineiston perustana on Tilastokeskuksen innovaatiokysely 1996, joka koskee yritysten innovaatiotoimintaa vuosina 1994-96. Tähän on yhdistetty henkilöstöä koskevia tietoja työssäkäyntitilastosta. Poikkileikkausaineistossa on noin tietoja noin 1000 teollisuusyrityksestä. Estimoinneissa käytetään painoja, jotka edelleen parantavat aineiston edustavuutta.

Tulokset osoittavat, että yritysten osaaminen vaikuttaa paitsi innovaatiotoiminnan organisointiin myös T&K-toimintaan ja innovaatioiden todennäköisyyteen. Yritykset tarvitsevat paitsi sisäistä osaamista oman innovaatiotoimintansa tueksi, myös kykyä omaksua tietoa ulkopuolisilta tahoilta. Tätä tukee tulos, jonka mukaan innovaatioyhteistyö yliopistojen kanssa vaatii yritykseltä erityisen paljon tutkimusosaamista. Toisaalta tutkimusosaaminen ei merkitsevästi tue yhteistyötä laitetoimittajien kanssa, vaan tekninen osaaminen on siinä tärkeämpää.

Taloustieteellisessä kirjallisuudessa on tutkittu eniten kilpailijoiden välistä T&K-yhteistyötä. Tämän tutkimuksen mukaan kuitenkin yritykset tekevät useammin yhteistyötä asiakkaiden, toimittajien ja yliopistojen kanssa kuin kilpailijoiden. Lisäksi edellä mainittujen yhteys tuoteinnovaatioihin on läheisempi. Toisaalta yhteistyösuhteet erilaisten kumppanien kanssa vaativat erilaista osaamista ja ne tapahtuvat todennäköisimmin erilaisissa teknologisissa ympäristöissä. Onkin tärkeää, että T&K-yhteistyötä tutkittaessa otetaan huomioon yrityksen yhteistyökumppanin ominaisuudet ja suhde yritykseen (asiakas, toimittaja vai kilpailija).

Teknologisen ympäristön mittarit tuottavat hyödyllistä tietoa toimialojen eroista. Tulosten mukaan aloilla, joissa tiedon omistettavuus on heikko tai yritykset ovat riippuvaisia laitetoimittajien teknologisesta osaamisesta, yritykset investoivat vähemmän innovaatiotoimintaan. Tietovuodot vähentävät lisäksi yhteistyötä erityisesti toimittajien kanssa, kun taas toimittajista riippuvaisilla aloilla yritysten todennäköisyys tehdä yhteistyötä asiakkaiden ja yliopistojen kanssa on pienempi. Voimakas innovaatioiden kysyntä tai tieteen suuri merkitys alalla sen sijaan lisäävät yritysten todennäköisyyttä investoida T&K-toimintaan ja innovoida. Innovaatiokysyntä saa yritykset tekemään yhteistyötä erityisesti asiakkaiden kanssa. Tieteestä innovaatiomahdollisuuksia löytävillä aloilla yritykset löytävät innovaatiokumppaneita yliopistoista ja ulkoistavat T&K-toimintaa todennäköisemmin. Mielenkiintoista on myös, että tutkimusosaaminen lisää ulkoistettujen T&K-investointien todennäköisyyttä. T&K-projektien ulkoistaminen ei siis ole sisäisen osaamisen vaihtoehto, vaan edellyttää korkeaa osaamista ja omaksumiskykyä.

Teknologinen ympäristö siis vaikuttaa paitsi yritysten T&K-investointeihin ja innovaatioiden todennäköisyyteen, kuten aiemmassa tutkimuksessa on havaittu, myös innovaatiotoiminnan organisointiin erilaisten yhteistyösuhteiden ja T&K-investointien ulkoistamisen kautta. Toimialoittaisten erojen ja innovaatioyhteistyön osaamisvaatimusten ymmärtäminen voi parantaa teknologiapolitiikan osuvuutta. Tuetuista yhteistyösuhteista eivät hyödy yritykset, joilla ei ole riittävästi omaksumiskykyä. Toisaalta jos esimerkiksi tiedon omistettavuus on heikko, yritykset eivät ole halukkaita avoimeen yhteistyöhön, jolloin yhteistyön hyödyt voivat jäädä vähäisiksi.

## 1. Introduction

Determinants and effects of innovation are topics of intense research interest, particularly since the fundamental relationship between economic and technological change has become widely acknowledged. As a result, contributions of research and development activities (R&D) to innovation and industrial evolution, especially in manufacturing industries, are well appreciated. However, in economic models and also in many empirical studies, R&D is often conceptualised as an innovation production function. Such treatment may be a useful first approximation of the innovation process within a linear model of innovation. However, in qualitative empirical studies over the past 20 years it has been observed that the *organisation* of the firm, and R&D in particular, are critical determinants of both innovation (e.g. Mowery, 1983) and economic performance (e.g. Teece, 1986). Informal models of innovation emphasise feed-backs and complementarities among a firm's activities and knowledge bases (Kline and Rosenberg, 1986, Rothwell, 1994). Organisational choices, for instance whether to organise knowledge creation activities (e.g., R&D, training, employing qualified workers) internally or outsource them, have a considerable impact on the strength of the interactions between various sources of knowledge.

In this paper innovation is supported by a system of activities; internal R&D, R&D collaboration with outside partners, and outsourcing of R&D. I argue that this system is complemented by competencies and skills of the firm. Competencies are hypothesised to be prerequisites for success in the three forms of R&D activities.

It is well known that industries are characterised by different patterns of technological change (e.g. Pavitt, 1984). The effects of these sectoral differences on R&D investment (Cohen and Levinthal, 1989) and industrial structure (Winter, 1984 has a theoretical model) have been studied. In this paper I assess how sectoral differences affect firms' organisational choices applied to R&D and, ultimately, innovation.

Recent innovation survey data from Finland are used to analyse the determinants of external R&D arrangements in firms, i.e., collaboration with various partners and outsourcing. The main research questions are: (1) How do competencies affect the organisation of innovation activities? (2) How does the technological environment affect the organisation of innovation?

## 2. Related Literature and Conceptual Framework

### Firm capabilities

In recent years a literature on the capabilities of firms has emerged emphasising the role of knowledge accumulation in firm performance and evolution. Original contributions include the work of Penrose's (1959), and the evolutionary approach to industrial dynamics (Nelson and Winter, 1982; Wernerfelt, 1984; Teece et al. 1997). In this perspective, a firm's knowledge resources are critical determinants of competitiveness. At the same time, firm specificities arising from the organisational nature of productive knowledge make firms idiosyncratic, due to which they may perform very differently in markets over the long run. This literature holds great promise as to our understanding of firm behaviour and industrial dynamics, but it has proven quite difficult to extend the analysis from case studies of individual firms to cross-sectional empirical studies and to produce theoretical models of firm organisation.

Important contributions to the innovation literature by Rothwell et al. (1974), Rosenberg (1982), Freeman (1982), von Hippel (1988) among others has emphasised the complex interactions among various internal and external sources of knowledge and capabilities. Cohen and Levinthal (1990), in line with the empirical work of many scholars in the 1980s, coined the term *absorptive capacity*, which refers to the firm's capability to assimilate information from the environment. The idea is that a firm carries out R&D not only to improve its own products and technologies, but also to keep up with the technological advance by other firms in the industry and to be able to use that knowledge internally. In other words, external and internal knowledge sources are complementary in the firm's innovation activities.

### R&D collaboration

As technological change has become more rapid and complex, and dissemination and sourcing of information have become easier due to new technologies, many firms decide not to create all knowledge internally. Some information can be acquired in the 'markets'. However, there are no markets for some important kinds of knowledge. In particular, a significant part of firms' productive knowledge is tacit or collective and therefore not easily transferable, and other parts are firm-specific or strategic, and thus not for sale. Nevertheless, through intensive collaboration within an R&D alliance, even some of this 'stickier' knowledge can be shared and jointly utilised. Collaborative R&D can be viewed as a transaction in organisational knowledge. Indeed, collaborative arrangements like R&D alliances, joint ventures, and research consortia are becoming increasingly common in modern economies. However, in order to make use of another firm's knowledge, a firm needs to possess sufficient internal competencies, in other words, absorptive capacity.

As collaborative arrangements between firms have proliferated over the past two decades, various explanations for their occurrence have been offered in the academic literature (see e.g. Contractor and Lorange, 1988). The benefits of collaboration are usually emphasised in these studies, partly due to the sampling bias: generally only collaborating firms are examined (e.g. Hagedoorn and Schakenraad, 1992; Powell, Koput and Smith-Doerr, 1996)[1]. It is very unusual to find a study where the reasons for *not* collaborating are assessed. The cross-sectional approach with random sampling in this paper reduces this bias.

One of the few more critical views on collaborative arrangements comes from the transaction cost approach, which suggests that R&D collaboration can lead to unintended leakage of strategic information to the firm's competitors (Pisano, 1989; Oxley, 1997). Other studies argue that external organisation of R&D may reduce the possibilities to innovate profitably as externally sourced knowledge may be more difficult to integrate tightly with the other activities of the firm. In such a situation, the potential complementarities related to innovation may remain only partially exploited (Mowery and Rosenberg, 1989; Leiponen, 1999). External organisation of R&D may be associated with a trade-off between lower costs of developing new internal capabilities and the transactional hazards stemming from leakage of knowledge-based assets (i.e.,

[1] However, Contractor and Lorange (1988) in their introductory chapter discuss both benefits and costs of cooperative ventures.

appropriation by competitors) and from missed opportunities for complementarity among knowledge resources.

According to Hagedoorn (1993), the main reasons behind strategic R&D alliances include i) technological complexity and complementarities, ii) reduction of the uncertainty and costs of R&D, iii) interest in capturing partners' knowledge, and iv) reduction of product development times. However, to my knowledge, what kinds of partners firms do and do not cooperate with has not been empirically examined. The literature generally focuses on collaboration with competitors, perhaps as an outgrowth of economists' interest with organisational changes related to degradation of competitive structure. Is it possible that motivations for forming alliances with customers differ from those associated with partnering with competitors or universities? The transaction point of view emphasising policing of opportunism implies that the logic and cost structures supporting 'vertical' alliances might be different from those of 'horizontal' ones.

Beyond analysing patterns of collaboration, this study seeks to examine possible interactions between collaboration and internal competence accumulation. Using the Finnish survey data, we can compare the skill characteristics of firms entering collaborative arrangements with those of non-collaborating firms.

**Technological regimes**

A stream of research on technical change argues that it is possible to identify the underlying dimensions according to which industries differ from one another (*i.a.* Winter, 1984; Levin et al. 1987). One approach to classification suggests characterising the technological and innovation environment according to the *opportunities* for and degree of *appropriability* of the returns to innovation (Levin et al. 1987; Klevorick et al. 1995). It is argued that high opportunities encourage investment in R&D, but appropriability can have two opposed effects due to the dual role of R&D: on the one hand, higher appropriability increases the returns to innovation, but on the other, lower appropriability increases the returns to imitation. Both can encourage R&D activities (Cohen and Levinthal, 1989).

Scholars in the Schumpeterian tradition (e.g., Audretsch, 1995, Malerba and Orsenigo, 1993) have characterised the technological environment through reference to the degree of technological turbulence (see also Tushman and Anderson, 1986). In an *entrepreneurial regime*, small and flexible firms will find it easier to innovate, while in a *routinised regime*, big firms with large scale R&D may be in a better position to innovate due to increasing returns to knowledge accumulation. Basically this is a question of whether or not there are returns to scale in innovation.

Pavitt (1984) suggested another approach to technological regimes. His taxonomy of the patterns of technological change identified three principle types of industries: (1) supplier dominated, (2) production intensive, and (3) science based. Pavitt argued that patterns of technological change differ markedly between these groups and must be understood and taken into account in explaining the behaviour and evolution of industries.

Finally, Schmookler (1966) among others has emphasised the importance of demand in creating incentives for innovation. Demand-induced innovation is economically less risky compared to 'science-' or 'technology-push' innovation in the sense that a market already exists, provided firms can match innovations with technological opportunities.

The effects of the technological regime on *innovation outcomes* have been less frequently studied, with the exception of Levin, Cohen and Mowery (1985). Furthermore, the effects of the technological environment on the choice of organisation of R&D have not been examined. This is the novelty of the paper at hand.

**Conceptual framework**

This study examines the joint determination of R&D investment, R&D collaboration decisions, and product innovation. These decisions are viewed as highly intertwined. When the firm decides to pursue innovation, it will also choose whether to carry out formal R&D, and how to organise such a project (internally, outsource, and/or collaborate)..

The main hypotheses are, first, that skill and competence investments, measured with fields and levels of education of employees and firms' investments in internal R&D, complement collaboration in innovation, and thus the two are positively associated. Second, different types of skills complement collaboration with different types of partners. For instance, research cooperation with universities and other research organisations necessitates relatively high internal research skills due to the absorptive capacity requirement.. Collaboration with universities is thus expected to be associated with high research competencies. In contrast, collaboration with suppliers is expected to be associated with relatively low research competence requirements. Third, the technological regime affects the innovation behaviour of firms as measured by their propensity to engage in R&D, collaborate in innovation, and innovate.

The proxies for technological regime include industry averages of the importance of various external sources of knowledge to the firm's innovation process. The Finnish innovation survey does not contain direct information about the appropriability of innovation returns. However, data on competitors as knowledge sources can serve as an indication of appropriability: when competitors are important sources of knowledge in an industry, it is likely that secrets are difficult to maintain, and thus appropriability is fairly low. On this basis, low appropriability is expected to discourage collaboration and outsourcing of R&D due to the transaction hazards. Its effect on R&D investment is ambiguous, however, as R&D supports both internal innovation and absorption of spillover knowledge. The effect of low appropriability on innovation is hypothesised to be negative because of the disincentives to innovate created by spillovers.

Industry averages of importance of the other external knowledge sources – customers, suppliers, and universities – are also treated as indicators of particular technological environments. Where universities are important knowledge sources, the regime is considered to be relatively science-intensive. According to Klevorick et al. (1995), science-intensive regimes are higher in innovation opportunities. Thus, firms in industries where universities are important knowledge sources are expected to be more likely to invest in R&D, collaborate with universities, and innovate. The importance of customers as a knowledge source represents the demand for innovation and the need to be in touch with users, both of which bode well for profitable innovation. Therefore, firms operating in an environment in which customers frequently provide ideas and opportunities for innovation both invest more in innovative activities and succeed in innovation more often. They are also highly likely to collaborate with customers in R&D. Finally, industries in which suppliers represent important sources of knowledge are treated as supplier dominated regimes (Pavitt, 1984). Supplier domination implies that a considerable part of technological development is delegated upstream for example to equipment suppliers. Consequently, innovations become embodied in production equipment, machinery, and service technicians. Firms in supplier dominated regimes are often oriented toward process improvement through incremental learning in their operations and do not necessarily introduce new products frequently. On this basis, outside of their close relations with suppliers, they are not expected to collaborate in innovation.

The 'Schumpeterian' regime is hypothesised to affect the propensity of firms to externalise R&D. Firms can share innovation risks by collaborating instead of developing the complementary capabilities internally. In a rapidly changing environment, expected returns to internally developed capabilities are lower, *ceteris paribus*, because of the higher risk that the capabilities will soon become obsolete due to some other firm's radical innovation. Therefore it is expected that a more turbulent, or *entrepreneurial*, environment is associated with more frequent outsourcing of and collaboration in R&D.

In addition, the level of competition in the industry characterises the firms' economic operating environment. Because of particularities of the Finnish economy, namely its small size, we use measures of international competition: the firm's export share and import intensity of their industry.[2] Export and import competition are expected to encourage innovative activities.

## 3. Econometric Set-up and the Data

To assess the hypotheses put forth in the previous section, we want to estimate a system of equations, because R&D investment, R&D collaboration and innovation are simultaneously determined:

$$(1)\quad \begin{cases} R\&D_i = f(COMPETENCIES_{1,i}, FIRM_{1,i}, REGIME_{1,i}, COMPETITION_i) \\ COLLAB_i = g(COMPETENCIES_{2,i}, FIRM_{2,i}, REGIME_{2,i}, COMPETITION_i) \\ INNO_i = h(COMPETENCIES_{3,i}, FIRM_{3,i}, REGIME_{3,i}, COMPETITION_i) \end{cases}$$

[2] The traditional variables of industry concentration and market share were originally included as well, but they did not capture statistically significantly the aspects of competition in Finnish manufacturing, perhaps due to the too high level of aggregation and the small open economy environment.

where $i = 1,\ldots,N$ refers to the individual firms. *R&D* is the share of R&D investment in sales, *COMPETENCIES* is a vector of skill indicators, *FIRM* is a vector of firm-specific variables, *REGIME* refers to a set of measures for the technological regime, and *COMPETITION* consists of the measures for the competitive environment. The other dependent variables are binary, and they refer to R&D collaboration with different partners (*COLLAB*) and product innovation (*INNO*).

However, since a system with two binary dependent variables and one continuous but censored dependent variable cannot be subjected to a standard estimation procedure, it is modified into a system of three probit equations: R&Ddum =1 if R&D>0, otherwise R&Ddum=0.

$$(2)\quad \begin{cases} R\&Ddum_i = f^*(COMPETENCIES_{1,i}, FIRM_{1,i}, REGIME_{1,i}, COMPETITION_i) \\ COLLAB_i = g(COMPETENCIES_{2,i}, FIRM_{2,i}, REGIME_{2,i}, COMPETITION_i) \\ INNO_i = h(COMPETENCIES_{3,i}, FIRM_{3,i}, REGIME_{3,i}, COMPETITION_i) \end{cases}$$

This approach allows us to account for the simultaneities and perform estimation with a standard procedure. Other approaches include the kind of two-stage methods suggested by Maddala (1983). However, this possibility is not pursued here due to the complexities involved in deriving the covariance matrix.

The estimation method is thus trivariate probit, where the decisions to engage in R&D, to collaborate in R&D with other organisations, and to innovate are simultaneously estimated. Collaboration data is binary but has several 'dimensions': did the firm collaborate with rivals, customers, or suppliers etc., or not. The choices are of course not mutually exclusive. Ideally, one would estimate the simultaneous determination of all types of collaboration. But due to lack of reasonable methods we settle for the trivariate approach.

Statistics Finland compiled the data from the innovation survey of 1996 and labour survey of 1995. The sampling frame of the innovation survey was the Statistics Finland enterprise register. All firms with more than 100 employees were included, together with a random sample stratified by size of smaller firms. The response rate was 71%. The Eurostat Community Innovation Survey methodology was applied. The list of variables is in Table 1 below and basic descriptive statistics are presented in Table 2. These data are weighted to represent the Finnish manufacturing sector.

**Table 1. Variables**

| Dependent variables | | | |
|---|---|---|---|
| RD_dum | | Dummy for R&D_inv > 0 | |
| COL_com | | Dummy for R&D collaboration with competitors | |
| COL_cus | | Dummy for R&D collaboration with customers | |
| COL_sup | | Dummy for R&D collaboration with suppliers | |
| COL_uni | | Dummy for R&D collaboration with universities | |
| OUTRD | | Dummy for outsourced R&D investment > 0 | |
| INNO | | Dummy for successful product innovation (sales revenue from the commercialised new product >0) | |
| **Independent variables** | | | **Expected effect on collaboration** |
| COMPETENCIES | RESEARCH | Share of employees with a post-graduate degree (doctoral or licentiate) | + |
| | TECHNIC | Share of employees with a higher technical or natural scientific degree (e.g. university engineer, Master of science in chemistry) | + |
| | RD_inv | Internal Research and Development investments/sales | + |
| FIRM | EMPL | Number of employees | + |
| TECHNOLOGICAL REGIME | REG_com | Industry average for the importance of competitors as sources of knowledge | +/- |
| | REG_cus | Industry average for the importance of customers as sources of knowledge | + |
| | REG_sup | Industry average for the importance of suppliers as sources of knowledge | - |
| | REG_uni | Industry average for the importance of universities as sources of knowledge | + |
| | SCHUMP | Share of small firms (EMPL<100) among innovating firms in the industry | + |
| COMPETITION | EXPORT | Firm's exports/sales | + |
| | IMPORT | Total imports in the product category/domestic industry sales | |

**Table 2. Descriptive statistics (weighted)**

| | Mean | Std.Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|
| COL_com | 0.057 | 0.232 | 0 | 1 | 1029 |
| COL_cus | 0.153 | 0.360 | 0 | 1 | 1029 |
| COL_sup | 0.150 | 0.357 | 0 | 1 | 1029 |
| COL_uni | 0.136 | 0.343 | 0 | 1 | 1029 |
| INNO | 0.194 | 0.396 | 0 | 1 | 1029 |
| RD_inv (%) | 0.7 | 2.4 | 0 | 31.6 | 1029 |
| RD_inv > 0 (%) | 2.3 | 3.9 | 0.0002 | 31.6 | 400 |
| RD_dum | 0.304 | 0.460 | 0 | 1 | 1029 |
| OUTRD | 0.228 | 0.420 | 0 | 1 | 1029 |
| RESEARCH | 0.001 | 0.005 | 0 | 0.082 | 1029 |
| TECHNIC | 0.064 | 0.088 | 0 | 0.636 | 1029 |
| EMPL | 97.8 | 361.2 | 10 | 9602 | 1029 |
| REG_com | 1.500 | 0.136 | 1.27 | 2.67 | 1029 |
| REG_cus | 2.124 | 0.250 | 1.7 | 3 | 1029 |
| REG_sup | 1.514 | 0.264 | 1.04 | 2 | 1029 |
| REG_uni | 1.109 | 0.197 | 0.6 | 1.67 | 1029 |
| SCHUMP | 0.557 | 0.133 | 0 | 1 | 1029 |
| EXPORT | 0.187 | 0.273 | 0 | 1 | 1029 |
| IMPORT | 0.337 | 0.283 | 0.033 | 0.947 | 1029 |

The descriptive statistics for the collaboration variables show that more firms collaborate with customers (15%), and suppliers (15%) or universities (14%) than with competitors (6%). Obviously, collaborating firms can have more than one type of partner. 19 percent of the firms reported product innovations between 1994-96, and 30 percent invested in R&D. Average R&D investment is 0.7 percent of sales for the whole sample. There are 400 R&D firms (RD_inv>0) in the dataset, and their average R&D investment is 2.3 percent of sales revenue. Employees with advanced formal educational degrees (RESEARCH) are few, only 0.1 percent on average, while higher technical and natural scientific skills (*TECHNIC*) are quite common. Six percent of the firms' employees have a higher (tertiary) degree in these fields. Among the knowledge *REGIME* variables, customers are the most important knowledge sources. Competitors and suppliers are recognized as next most important. Universities are the least commonly cited sources of knowledge among the sources considered here. Table 3 displays the 1029 firms broken down by industrial classification. Metal industries are slightly over-represented in the sample, but sampling weights correct for most of this bias.

**Table 3. Industry distribution in the sample**

| Industry | N | Share |
|---|---|---|
| Food | 107 | 10.4 % |
| Textile | 79 | 7.7 % |
| Wood | 76 | 7.4 % |
| Paper | 26 | 2.5 % |
| Printing, publishing | 98 | 9.5 % |
| Oil, Chemical | 43 | 4.2 % |
| Plastic, Rubber | 47 | 4.6 % |
| Non-metallic minerals | 44 | 4.3 % |
| Primary metals | 26 | 2.5 % |
| Metal products | 97 | 9.4 % |
| Machines, equipment | 146 | 14.2 % |
| Electronics | 133 | 12.9 % |
| Cars, vehicles | 54 | 5.2 % |
| Furniture | 53 | 5.2 % |
| Total | 1029 | 100.0 % |

## 4. Estimation Results

### R&D Collaboration

Estimation of the simultaneous equations in (2) for the joint determination of R&D-investment, R&D collaboration, and product innovation decisions is done by trivariate probit. To provide a baseline for comparison, each of the equations is estimated with simple one equation probit. The results are in the appendix (Tables A1-A7). The multivariate model accounts for some of the endogeneities between the different innovation activities by separating the effects of being an R&D firm, and the level of investment in R&D. Table 4 contains the results when collaboration with competitors is the dependent variable of the second equation.

**Table 4. Collaboration with competitors (N=1029), 3-variate probit system, weighted**

| Dependent variable | RD_dum | | COL_com | | INNO | |
|---|---|---|---|---|---|---|
| | coeff. | t-stat | coeff. | t-stat | coeff. | t-stat |
| Constant | -0.71 | -1.10 | -1.69 | -1.63 | -1.40** | -1.99 |
| RESEARCH | 20.48** | 2.02 | 12.76 | 1.44 | 22.17** | 2.12 |
| TECHNIC | 2.18** | 4.17 | 0.12 | 0.18 | 1.85** | 3.14 |
| RD_inv | | | 2.46 | 1.25 | 3.45** | 2.17 |
| EMPL | 0.0014** | 10.61 | 0.0003** | 5.49 | 0.0011** | 4.98 |
| EXPORT | 0.97** | 5.66 | 0.42 | 1.56 | 0.60** | 3.24 |
| REG_com | -1.27** | -3.27 | 0.33 | 0.52 | -0.84* | -1.95 |
| REG_cus | 0.72** | 2.88 | -0.24 | -0.53 | 0.57* | 1.84 |
| REG_sup | -0.56** | -2.72 | -0.59* | -1.69 | -0.47** | -1.97 |
| REG_uni | 0.82** | 3.21 | 0.40 | 0.98 | 0.56** | 1.97 |
| SCHUMP | | | 0.57 | 1.01 | | |
| IMPORT | | | | | 0.53** | 2.88 |
| Correlation coefficients | | | | | | |
| R(01,02) | 0.66** | 8.05 | | | | |
| R(01,03) | 0.84** | 26.87 | | | | |
| R(02,03) | 0.53** | 6.56 | | | | |
| Log Likelihood | -976.533 | | | | | |

Note: ** indicates 95% level significance, * indicates 90% level.

The probability of investing in internal R&D is associated with high research and technical competencies, and seems to be strongly driven by industry-specific factors measured here with the technological regime variables. In accordance with the hypotheses, firms in regimes where customers and universities are important sources of knowledge are more likely to carry out R&D internally, while firms in environments that rely on spillovers from competitors or suppliers are less likely to perform R&D in-house. However, this model does not very well explain the variance in firms' engagement in collaborative arrangements with competitors. Only firm size plays an important role. Competence and R&D investments appear to be closely associated with successful new product introduction. In line with the demand and innovation opportunities hypotheses, firms in the high spillover regimes, that is supplier or competitor dominated regimes, are somewhat less innovative, while firms in the customer-driven and science-intensive regimes are more likely to innovate. As expected, international competition in terms of export intensity and import penetration is a positive driver of innovation.

**Table 5. Collaboration with customers (N=1029), 3-variate probit, weighted**

| Dependent variable | RD_dum. | t-stat | COL_cus | t-stat | INNO | t-stat |
|---|---|---|---|---|---|---|
| Constant | -0.60 | -0.95 | -1.96** | -2.44 | -1.41** | -2.01 |
| RESEARCH | 20.98** | 2.21 | 20.92** | 2.26 | 24.41** | 2.25 |
| TECHNIC | 2.21** | 4.20 | 2.42** | 4.15 | 1.92** | 3.20 |
| RD_inv | | | -1.04 | -0.55 | 3.35** | 2.16 |
| EMPL | 0.0013** | 8.83 | 0.0008** | 8.96 | 0.001** | 4.93 |
| EXPORT | 1.02** | 6.02 | 0.85** | 4.61 | 0.64** | 3.50 |
| REG_com | -1.31** | -3.31 | -0.57 | -1.24 | -0.86* | -1.93 |
| REG_cus | 0.72** | 2.86 | 0.71** | 2.06 | 0.59* | 1.92 |
| REG_sup | -0.56** | -2.73 | -0.55** | -2.18 | -0.43* | -1.78 |
| REG_uni | 0.78** | 3.08 | 0.48* | 1.70 | 0.49* | 1.74 |
| SCHUMP | | | 0.09 | 0.18 | | |
| IMPORT | | | | | 0.50** | 2.74 |
| Correlation coefficients | | | | | | |
| R(01,02) | 0.77** | 17.11 | | | | |
| R(01,03) | 0.84** | 26.30 | | | | |
| R(02,03) | 0.69** | 14.30 | | | | |
| Log Likelihood | -1069.61 | | | | | |

Collaboration with customers is much more closely associated with competence investments than collaboration with competitors (see Table 5). In this model, *RESEARCH* and *TECHNIC* become statistically significant coefficients. However, collaboration does not seem to be complementary with the *level* of R&D investment. More R&D does not increase the likelihood of engaging in collaborative innovation. Nevertheless, the high correlation between the first two equations (76%) suggests a very close association between the activities. In the case of collaboration with customers,the technological environment is seen to come more significantly into play. Firms in regimes where 'demand pull' is strong and innovation opportunities frequent are more likely to collaborate, while those in supplier dominated regimes are less so.

**Table 6. Collaboration with suppliers (N=1029), 3-variate probit, weighted**

| Dependent variable | RD_dum | t-stat | COL_sup | t-stat | INNO | t-stat |
|---|---|---|---|---|---|---|
| Constant | -0.70 | -1.09 | -0.43 | -0.55 | -1.38** | -1.96 |
| RESEARCH | 21.05** | 1.99 | 13.61 | 1.64 | 20.78* | 1.66 |
| TECHNIC | | | 1.99** | 3.32 | 1.97** | 3.28 |
| RD_inv | 2.08** | 3.93 | -2.61 | -1.40 | 3.16** | 2.03 |
| EMPL | 0.0016** | 11.26 | 0.0013** | 5.99 | 0.0013** | 5.81 |
| EXPORT | 0.96** | 5.69 | 0.81** | 4.13 | 0.60** | 3.26 |
| REG_com | -1.26** | -3.10 | -1.12** | -2.65 | -0.82* | -1.81 |
| REG_cus | 0.72** | 2.87 | 0.42 | 1.34 | 0.58* | 1.84 |
| REG_sup | -0.56** | -2.74 | -0.31 | -1.33 | -0.47* | -1.95 |
| REG_uni | 0.78** | 3.07 | 0.34 | 1.17 | 0.48* | 1.66 |
| SCHUMP | | | -0.36 | -0.78 | | |
| IMPORT | | | | | 0.53** | 2.92 |
| Correlation coefficients | | | | | | |
| R(01,02) | 0.80** | 21.58 | | | | |
| R(01,03) | 0.84** | 27.37 | | | | |
| R(02,03) | 0.63** | 12.14 | | | | |
| Log Likelihood | -1074.83 | | | | | |

Collaboration with suppliers requires internal competencies, especially in the form of technical skills (Table 6). The technological regime variables do not capture variation in this type of collaboration very well. Only the competitor dominated, that is low appropriability regime is significantly negatively associated with supplier collaboration. The hazard of leaking strategic information to rivals may be aggravated by collaborating with suppliers, a potential spillover channel.

Collaboration with universities is associated with very high internal research competencies, relatively high technical competencies, and a large export share (Table 7). Firms in supplier dominated regimes are clearly not likely to collaborate with universities, but, quite intuitively, firms in science-intensive regimes are.

**Table 7. Collaboration with universities (N=1029), 3-variate probit, weighted**

| Dependent variable | RD_dum | t-stat | COL_uni | t-stat | INNO | t-stat |
|---|---|---|---|---|---|---|
| Constant | -0.72 | -1.13 | -3.00** | -3.33 | -1.26* | -1.81 |
| RESEARCH | 23.72** | 2.20 | 34.75** | 2.48 | 22.68 | 1.22 |
| TECHNIC | 2.18** | 4.13 | 2.06** | 3.47 | 1.96** | 3.29 |
| RD_inv | | | -1.80 | -0.81 | 3.36** | 2.22 |
| EMPL | 0.0015** | 9.60 | 0.0015** | 6.51 | 0.0012** | 5.59 |
| EXPORT | 1.02** | 5.95 | 0.92** | 4.91 | 0.65** | 3.44 |
| REG_com | -1.32** | -3.40 | -0.05 | -0.09 | -0.89** | -2.06 |
| REG_cus | 0.78** | 3.10 | 0.32 | 0.87 | 0.55* | 1.77 |
| REG_sup | -0.57** | -2.76 | -0.70** | -2.41 | -0.46* | -1.92 |
| REG_uni | 0.77** | 3.06 | 1.19** | 3.49 | 0.49* | 1.75 |
| SCHUMP | | | 0.65 | 1.25 | | |
| IMPORT | | | | | 0.57** | 3.15 |
| Correlation coefficients | | | | | | |
| R(01,02) | 0.78** | 15.66 | | | | |
| R(01,03) | 0.85** | 26.70 | | | | |
| R(02,03) | 0.72** | 13.60 | | | | |
| Log Likelihood | -1022.52 | | | | | |

The last type of external R&D arrangement is contract R&D. In Table 8, the likelihood of outsourced R&D is positively associated with internal competencies, high export orientation and science-intensity in the environment. The connection between R&D outsourcing and science-intensity is interesting. Except for high innovation opportunities, science-intensity may reflect the potential for codification. It may be easier to both define the research project and explain the results in a science-intensive environment, as opposed to environments with highly tacit and ill-defined underlying knowledge.

**Table 8. R&D outsourcing (N=1029), 3-variate probit, weighted**

| Dependent variable | RD_dum | t-stat | OUTRD | t-stat | INNO | t-stat |
|---|---|---|---|---|---|---|
| Constant | -0.57 | -0.89 | -1.98** | -2.60 | -1.31* | -1.85 |
| RESEARCH | 15.53 | 1.62 | 16.96** | 2.41 | 17.50* | 1.74 |
| TECHNIC | 1.99** | 3.69 | 1.16** | 2.18 | 1.88** | 3.10 |
| RD_inv | | | 2.12 | 1.36 | 3.50** | 2.23 |
| EMPL | 1.53** | 11.51 | 1.28** | 5.82 | 1.23** | 5.52 |
| EXPORT | 0.98** | 5.76 | 0.96** | 5.58 | 0.58** | 3.17 |
| REG_com | -1.32** | -3.44 | -0.11 | -0.23 | -0.87** | -1.96 |
| REG_cus | 0.75** | 2.98 | 0.28 | 1.03 | 0.57* | 1.89 |
| REG_sup | -0.59** | -2.85 | -0.35* | -1.69 | -0.44* | -1.83 |
| REG_uni | 0.75** | 2.94 | 0.55** | 2.13 | 0.47* | 1.68 |
| SCHUMP | | | 0.42 | 1.28 | | |
| IMPORT | | | | | 0.54** | 2.97 |
| Correlation coefficients | | | | | | |
| R(01,02) | 0.89** | 40.09 | | | | |
| R(01,03) | 0.83** | 25.96 | | | | |
| R(02,03) | 0.75** | 19.21 | | | | |
| Log Likelihood | -1075.0 | | | | | |

Qualitatively the multivariate results do not differ too drastically from the single equation probit results reported in the appendix. The coefficients on competence measures are larger and more significant in explaining the probability of collaboration when the endogeneity of being an R&D firm is accounted for. Only the coefficient of the level of R&D investment has a different sign. Nevertheless the firm needs to do internal R&D to be able to benefit from external R&D arrangements, as indicated by the high correlations between the first and second equations. However, provided that the firm does some R&D, a higher level of investment does not necessarily increase the probability of collaboration any further.[3]

As expected, in most cases, the coefficient of the measure of the Schumpeterian regime (SCHUMP) is positive, but it is never significant. The variable was retained in the

[3] The insignificance of the level of R&D holds even if one removes the RESEARCH variable, which is potentially endogenous, from the collaboration equation.

estimation nevertheless in order to ensure identification, which was difficult in some cases. Its presence does not much impact the other coefficients.

To check the ability of the regime variables to account for the knowledge accumulation patterns within industries, the trivariate systems were estimated with a full set of industry dummies as control variables in the collaboration equation. The system for collaboration with universities is provided in the appendix (Table A8) to demonstrate that the results on competencies do not depend on the control variables used. Research competencies and technical skills remain strong and significant determinants of university collaboration with industry dummies.

To summarise, the multivariate model seems to work quite well in explaining how the three innovation related activities are jointly determined. The high correlations between the three equations indicate that assuming a joint distribution for the dependent variables is warranted. Thus, it makes sense to estimate their determination simultaneously. Skills play a significant and positive role in innovation. They may be complementary with R&D activities, independent of how R&D is organised. Moreover, internal competencies enable the benefits of external R&D efforts to be internalised. In particular, research skills are necessary for benefiting from collaboration with universities and customers, and higher technical skills are important in all types of collaboration except that with competing firms.

## 4. Discussion

This study took as its starting point the idea that organisational decisions related to R&D are simultaneous with the decisions to invest in innovation. The strong positive associations identified among internal competencies, R&D investment, R&D collaboration, outsourcing of R&D, and product innovation indeed are in line with the notion that they are complementary, although partial correlation does not constitute a rigorous test.

Collaboration can be thought of as a vehicle to transact in tacit knowledge. The firm would probably choose to buy the necessary capabilities or information in the spot markets, if such resources were available. However, exchanging sticky or tacit knowledge may require more intensive and prolonged interaction, creating a need for a governance structure as constituted by the collaboration agreement. Collaboration involves exchanging knowledge for knowledge, while in R&D outsourcing, knowledge is exchanged for money. Evidently, outsourced research involves less sticky and less firm-specific information, and is often embodied in blueprints or artifacts.

Skills and competencies are important covariates in the firm's 'system of innovation' as defined by the various innovation activities (R&D, collaboration, outsourcing). This finding highlights the important role of absorptive capacity. Without internal capabilities the firm is not likely to be an attractive partner in collaborative arrangements or to benefit fully from externally sourced knowledge. Estimation results here support the interpretation that high internal skills and competencies, in addition to internal R&D, help build absorptive capacity and enhance firms' ability to engage in collaborative innovation. Naturally, competencies and internal R&D have a very important role in innovation itself.

It is important to distinguish patterns of collaboration among different kinds of partners. First, this paper demonstrates that competence requirements vary somewhat with the type of collaboration: research competencies are identified as much more important for university collaboration than for the other types of collaboration. Second, collaboration with competitor firms is not so prevalent as the extant literature on research joint ventures between rivals would seem to imply. From market structure or a competition point of view, it is highly relevant to study the implications of and reasons for cooperation among rivals. However, to understand innovation, technological change, and the evolution of firms and industries, , it is equally important that we assess the knowledge transactions firms carry out with differently positioned actors in production systems.

The analysis accounted for industry differences with a set of proxies for the technological environment. It seems that using and further developing measures for technological regimes is a worthwhile endeavour. Current measures perform quite well, and we are able to see <u>how</u> industries differ in addition to controlling for these differences. Understanding industry-specificities is highly relevant from the perspective of policy analysis. For instance, technological regimes may have a bearing on issues of antitrust and intellectual property rights. If patterns of cooperation in knowledge creation among firms depend on the technological environment, competition policies concerned with collusive behaviour need to take this into account – cooperation may be beneficial in some environments, in others it may be an indication of collusion. Relatedly, firms' willingness to collaborate and thus the rate and nature of innovation may depend on intellectual property rights legislation and enforcement. Fruitful cooperation may be hindered by spillover hazards..

Limitations of this research include the structure of the data: innovation records are at the firm level, not R&D project level, potentially blurring some results. Also, the statistical association between competencies and collaboration is not sufficient evidence of complementarity – the two could be confounded. This question could be addressed, at least to some extent, with longitudinal data on innovation, collaboration, and related investments, enabling us to better control for endogeneities. Such data exist for patents, but as is well known, these are a relevant measure of innovation for only a few industries.

The econometric method used in this study could be improved to make use of all available data. Instead of three probit equations, the existing data could be used to estimate a system with a truncated regression of R&D investment, probit estimations of R&D collaboration, and an interval regression of innovation output (share of new products in current sales). As the econometric methods for limited dependent variable systems develop, this type of a system can be estimated. These shortcomings represent avenues for future work.

## 5. Conclusion

The principle results of this study are that competencies of firms are closely associated with organisational choices for innovation activities. High levels of internal capabilities make R&D investments, collaborative R&D arrangements, contract R&D, and innovation more likely. There are indications that skills contribute to absorptive capacity. In choosing partners for R&D, research competencies appear to be important determinants of collaboration with universities and customers, but not of collaboration with suppliers or competitors. Furthermore, firms with high research competencies often engage in R&D outsourcing. The skills associated with absorptive capacity are likely to be useful in monitoring external technical activities.

We observe that technological regimes affect firms' innovation behaviour. Firms in regimes of low appropriability are not likely to collaborate with suppliers, and are also less likely to do R&D or innovate. Regimes of strong 'demand pull' are associated with high probabilities of R&D, collaboration with customers, and product innovation. Supplier dominated firms are less likely to innovate or collaborate with customers or universities. Lastly, science-intensive regimes with high innovation opportunities are associated with frequent contract R&D, collaboration with universities, internal R&D, and product innovation. These results indicate that the technological regime and competencies of firms impact not only patterns of R&D investment and industrial structure, but also boundaries of the firm as effected by their knowledge procurement strategies.

# Appendix

**Table A1. Single equation probit estimation (N=1029). Dependent variable: RD_dum**

| | Coeff | t-stat | Slope |
|---|---|---|---|
| Constant | -0.83 | -1.31 | -0.29 |
| RESEARCH | 23.03** | 2.23 | 7.92 |
| TECHNIC | 2.22** | 4.00 | 0.76 |
| EMPL | 0.0016** | 5.82 | 0.0005 |
| EXPORT | 1.05** | 6.31 | 0.36 |
| REG_com | -1.22** | -2.90 | -0.42 |
| REG_cus | 0.75** | 3.05 | 0.26 |
| REG_sup | -0.58** | -3.02 | -0.20 |
| REG_uni | 0.81** | 3.27 | 0.28 |
| Log Likelihood | -520.94 | | |
| % correct | 75 | | |

Note: ** indicates 95% level significance, * indicates 90% level.

**Table A2. Dependent variable: COL_com**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | -1.57 | -1.49 | -0.15 |
| RESEARCH | 7.16 | 0.74 | 0.70 |
| TECHNIC | -0.36 | -0.46 | -0.04 |
| RD_inv | 7.14** | 3.20 | 0.70 |
| EMPL | 0.0003** | 2.99 | 0.00003 |
| EXPORT | 0.28 | 1.18 | 0.03 |
| REG_com | 0.48 | 0.76 | 0.05 |
| REG_cus | -0.27 | -0.65 | -0.03 |
| REL_sup | -0.58* | -1.86 | -0.06 |
| REG_uni | 0.27 | 0.71 | 0.03 |
| SCHUMP | 0.36 | 0.60 | 0.04 |
| Log Likelihood | -203.21 | | |
| % correct | 92 | | |

**Table A3. Dependent variable: COL_cus**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | -1.62* | -1.94 | -0.33 |
| RESEARCH | 14.76 | 1.47 | 2.99 |
| TECHNIC | 1.58** | 2.61 | 0.32 |
| RD_inv | 7.91** | 3.76 | 1.60 |
| EMPL | 0.0008** | 4.56 | 0.0002 |
| EXPORT | 0.74** | 4.07 | 0.15 |
| REG_com | -0.46 | -0.93 | -0.09 |
| REG_cus | 0.65** | 2.06 | 0.13 |
| REG_sup | -0.60** | -2.56 | -0.12 |
| REG_uni | 0.39 | 1.32 | 0.08 |
| SCHUMP | -0.28 | -0.55 | -0.06 |
| Log Likelihood | -358.92 | | |
| % correct | 79 | | |

**Table A4. Dependent variable: COL_sup**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | 0.03 | 0.04 | 0.01 |
| RESEARCH | 4.88 | 0.57 | 1.02 |
| TECHNIC | 1.08* | 1.79 | 0.23 |
| RD_inv | 5.83** | 2.83 | 1.22 |
| EMPL | 0.0013** | 5.72 | 0.0003 |
| EXPORT | 0.72** | 3.90 | 0.15 |
| REG_com | -1.09** | -2.21 | -0.23 |
| REG_cus | 0.38 | 1.26 | 0.08 |
| REG_sup | -0.37 | -1.63 | -0.08 |
| REG_uni | 0.26 | 0.84 | 0.05 |
| SCHUMP | -0.77 | -1.52 | -0.16 |
| Log Likelihood | -371.65 | | |
| % correct | 79 | | |

**Table A5. Dependent variable: COL_uni**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | -2.88** | -3.24 | -0.50 |
| RESEARCH | 31.52** | 3.04 | 5.47 |
| TECHNIC | 1.17* | 1.85 | 0.20 |
| RD_inv | 6.75** | 3.21 | 1.17 |
| EMPL | 0.0015** | 6.23 | 0.0003 |
| EXPORT | 0.83** | 4.28 | 0.14 |
| REG_com | 0.06 | 0.10 | 0.01 |
| REG_cus | 0.37 | 1.08 | 0.07 |
| REG_sup | -0.65** | -2.46 | -0.11 |
| REG_uni | 1.06** | 3.29 | 0.18 |
| SCHUMP | 0.11 | 0.19 | 0.02 |
| Log Likelihood | -304.39 | | |
| % correct | 83 | | |

**Table A6. Dependent variable: OUTRD**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | -1.91** | -2.52 | -0.55 |
| RESEARCH | -0.51 | -0.06 | -0.15 |
| TECHNIC | -0.04 | -0.06 | -0.01 |
| RD_inv | 18.29** | 6.82 | 5.21 |
| EMPL | 0.0012** | 5.00 | 0.0003 |
| EXPORT | 0.94** | 5.40 | 0.27 |
| REG_com | 0.20 | 0.44 | 0.06 |
| REG_cus | 0.14 | 0.49 | 0.04 |
| REG_sup | -0.39* | -1.83 | -0.11 |
| REG_uni | 0.53** | 1.98 | 0.15 |
| SCHUMP | 0.15 | 0.34 | 0.04 |
| Log Likelihood | -437.32 | | |
| % correct | 79 | | |

**Table A7. Dependent variable: INNO**

| | Coeff. | t-stat | Slope |
|---|---|---|---|
| Constant | -1.34* | -1.80 | -0.34 |
| RESEARCH | 18.08* | 1.63 | 4.51 |
| TECHNIC | 1.06* | 1.71 | 0.26 |
| RD_inv | 17.90** | 7.33 | 4.47 |
| EMPL | 0.0012** | 5.18 | 0.0003 |
| EXPORT | 0.42** | 2.30 | 0.11 |
| REG_com | -0.65 | -1.38 | -0.16 |
| REG_cus | 0.47 | 1.50 | 0.12 |
| REL_sup | -0.44** | -1.97 | -0.11 |
| REG_uni | 0.42 | 1.56 | 0.10 |
| IMPORT | 0.44* | 1.91 | 0.11 |
| Log Likelihood | -392.92 | | |
| % correct | 80 | | |

**Table A8. Multivariate probit with industry dummies for R&D and collaboration equations**

| | RD_dum | t-stat | COL_uni | t-stat | INNO | t-stat |
|---|---|---|---|---|---|---|
| Constant | -1.28** | -15.24 | -2.38** | -5.38 | -1.00 | -1.59 |
| RESEARCH | 23.93** | 2.17 | 34.22** | 2.33 | 21.85 | 1.22 |
| TECHNIC | 3.01** | 6.01 | 2.35** | 3.85 | 2.09** | 3.20 |
| RD_inv | | | -1.37 | -0.60 | 3.53** | 2.27 |
| EMPL | 1.43** | 7.67 | 1.51** | 7.65 | 1.22** | 6.43 |
| EXPORT | 1.05** | 6.01 | 1.03** | 5.31 | 0.70** | 3.81 |
| REG_com | | | | | -0.73* | -1.68 |
| REG_cus | | | | | 0.36 | 1.19 |
| REG_sup | | | | | -0.23 | -1.01 |
| REG_uni | | | | | 0.09 | 0.35 |
| IMPORT | | | | | 0.49** | 2.39 |
| D1 | 0.29* | 1.92 | 0.59 | 1.25 | | |
| D2 | | | 0.56 | 1.18 | | |
| D3 | | | 0.40 | 0.84 | | |
| D4 | 0.78** | 2.07 | 0.94* | 1.81 | | |
| D5 | | | 0.20 | 0.39 | | |
| D6 | 0.45** | 2.11 | 0.84 | 1.57 | | |
| D7 | 0.76** | 4.40 | 0.72 | 1.49 | | |
| D8 | 0.00 | 0.00 | 0.47 | 0.92 | | |
| D9 | | | 1.10* | 1.92 | | |
| D10 | 0.29** | 2.32 | 0.70 | 1.51 | | |
| D11 | 0.27** | 2.15 | 0.74* | 1.66 | | |
| D12 | | | 0.69 | 1.52 | | |
| D13 | 0.03 | 0.14 | 0.51 | 1.04 | | |
| | | | | | | |
| Log L | -1032.85 | | | | | |
| R(01,02) | 0.77** | 15.58 | | | | |
| R(01,03) | 0.83** | 26.84 | | | | |
| R(02,03) | 0.71** | 14.21 | | | | |

Note: A full set of dummies could not be used for all equations due to identification problems.

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**ELINKEINOELÄMÄN TUTKIMUSLAITOS (ETLA)**
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY
LÖNNROTINKATU 4 B, FIN-00120 HELSINKI

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