R&D Cooperation and Innovation Activities of Firms
- Evidence for the German Manufacturing Industry -

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Abstract

The aim of the paper is to investigate in a simultaneous equation framework the role of R&D cooperation in the innovation process under two specific aspects. First, the analysis is concentrated on the impact of R&D cooperation - in line with other factors - on firm's innovation input and output. Second, it will be analyzed how the number of cooperation partners affects the development of new products.

Starting with the discussion of theoretically expected effects of successfully R&D cooperation on the innovation activities of firms, the importance of inter-organizational arrangements in R&D is empirically investigated for firms in the German manufacturing industry. The estimation results can be summarized as follows: In the German manufacturing industry, R&D cooperations are used complementary in the innovation process, enhancing the innovation input and output of firms measured by the intensity of inhouse R&D respectively the realization of product innovations. On the input side, the intensity of inhouse R&D also stimulates the probability and the number of R&D cooperations with other firms and institutions.

Key words: *R&D Cooperation, Innovation Behaviour, Technological Opportunities, Manufacturing Industry*

JEL classification: *O31, L10, I20, L60*

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1. Introduction

In principle, innovations are not based on activities of a single firm only. Most innovation activities involve multiple actors. The development of new and improved products rather requires an active search-process involving several firms and institutions to tap new sources of knowledge and technology (De Bresson, 1996; Nooteboom, 1999; von Hippel, 1988). Exchange of information and resources with different partners are important factors in the innovation process. By this, firms become more and more dependent on the know-how of other companies and institutions.

Firms that engage in innovation activities are aware of the necessity to establish *R&D cooperation* to obtain expertise which can not be generated inhouse. Such cooperations are defined as collaborations to achieve a common goal that is to develop new and improved products (technologies).[1] Within a more or less durable constellation of agreements between two or more partners, assets and activities are pooled, and combined. Thus, technological capabilities to develop product and process innovations can be improved.[2]

The importance of R&D cooperation has risen steadily as a consequence of growing complexity, risks and costs of innovation (Coombs et al., 1996; Dogson, 1993; Hagedoorn and Schakenraad, 1992). Inter-firm collaborations occur especially within technology based industries. Arora and Gambardella (1994) demonstrate the high importance of R&D collaborations for large US chemical and pharmaceutical companies in the biotechnology sector. Colombo (1995) provides empirical evidence of complementary relationship between inter-firm cooperative arrangements and R&D intensity for a representative sample of international firms in the information technology industries (semi-conductor, data processing and telecommunications). Veugelers (1997) identifies significant positive effects of R&D cooperation in the Flemish manufacturing industry on the level of R&D investments but only if firms have established absorptive capacities as a full-time staffed R&D department. By this, R&D active Flemish firms are found to be more frequently engaged in technological cooperations, the more they spend on inhouse R&D.

For Germany, the influence of R&D cooperation on the intensity of firms' innovation activities is less investigated. Recent studies have focussed on the role of inter-organizational arrangements

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1 Various definitions of R&D (technological) cooperation exist. For an overview see: Child and Faulkner, 1998; Hagedoorn, 1993; Mariti and Smiley, 1983.

2 *Technological capabilities* are defined as the ability to allocate the resources available within the firm in such a way that competitive products will be developed and produced (Cantwell, 1994; Teece and Pisano, 1994).

in *single industries* and the importance of *specific types* of R&D cooperation. For example, Peters and Becker (1999) have investigated the role of R&D cooperation with universities in the German automobile industry. Formal R&D arrangements with universities are preferred because automobile suppliers can enhance their inhouse capacities and use their automobile-specific potentials more efficiently. By establishing cooperative R&D arrangements, suppliers rather save R&D costs than realize quality improvements of products.

Becker and Peters (2000) found empirical evidence in the German manufacturing industry that R&D cooperation with universities enhance the probability of R&D and increase the R&D investment of firms. This underlines the complementary effect of joint R&D with such research partners. Firms cooperating with universities invest more in the development and improvement of products than companies that do not cooperate with universities. Fritsch and Lukas (1999) identify similar patterns for manufacturing enterprises in three German regions. They found differences in firms' R&D cooperation behaviour concerning the prospensity to collaborate with others in R&D and the kind of cooperation partners.

This paper picks up these specific results and investigates the role of R&D cooperation for firms in the German manufacturing industry from a *broader perspective*. In doing so, the issue in this paper is novel in two points. The analysis is concentrated on the impact of R&D cooperation - in line with other factors - on firm's *innovation input and output*. Furthermore, it will be investigated how the *number of cooperation partners* affects the development of new and improved products.

The paper is organized as follows: In section 2, the innovation effects of R&D cooperation are discussed from a theoretical point of view. A formal analysis is neglected since the focus is put on the elaboration of expected effects of R&D cooperation on firm's innovation behaviour. The discussion is emphasized on the formulation of core arguments and their interdependencies.

Section 3 describes data set, variables used and estimation methods for the empirical analysis. Section 4 presents estimation results on the importance of R&D cooperation as an explanatory factor of the innovation input and output for firms in the German manufacturing industry. Section 5 contains a summary of the main findings.

2. R&D Cooperation and Innovation Activities of Firms – Theoretical Aspects

Firms are engaged in R&D cooperations because they allow the utilization of external resources - technological opportunities - for own purposes *directly and efficiently*. Technological opportunities define the total amount of the currently existing and exploitable external resources firms are faced with (Cohen, 1995; Dosi, 1988; Klevorick et al., 1995). Such opportunities are diverse, varying in kind and usefulness not only between industries but also between firms. "Due to variations in the degree of availability of these technological opportunities, innovations are "cheaper" to realize ... This factor stands - in combination with others - behind the empirically observable inter-industrial differences in the rates of technical progress, of total factor productivity and of economic growth" (Harabi, 1995, p. 67). Strength and sources of technological opportunities are important factors explaining firm-specific and cross-industry variations in R&D intensity and R&D productivity (Arvanitis and Hollenstein, 1994; Nelson and Wolff, 1997; Sterlacchini, 1994).

R&D cooperations are an efficient strategy for adapting external resources only if the *cost-benefit-relationship ('trade-off')* of joint R&D is positive or at least can be expected to be positive. The benefits of joint R&D (Becker and Peters, 1998; Camagni, 1993; Robertson and Langlois, 1995) can be described as follows:

- joint financing of R&D,
- avoiding multiple and wasteful duplication of R&D,
- reducting uncertainty,
- realizing cost-savings,
- realizing economies of scale and scope,
- shortening development times.

The disadvantages of joint R&D are caused by transaction costs (Coase, 1937; Pisano, 1990; Williamson, 1989) especially to coordinate, manage and control the R&D activities of different actors. Transaction costs are mainly related to the following topics:

- unification of heterogeneous structures, decision-making processes, etc.,
- coordination of distinct organizational routines, styles, etc.,
- combination of complementary assets, resources, etc.,
- fixation of transfer prices of intangible goods, for example information or know-how,
- regulation of the exploitation (appropriation) of the results (rates of return) of joint R&D.

Further, R&D cooperations are faced with hidden and unexpected risks, such as insufficient quality of assets, delays in development time, failure of research success, change in the relative contractual (market) power of the partners, etc. In addition, opportunistic behaviour, such as moral hazard problems can occur. Because single R&D efforts are not directly observable, partners tend to focus on their own profit when choosing their level of R&D investment.

Governance modes to organize technological cooperations, such as cross-licencing agreements or R&D joint ventures can help to avoid moral hazard (Gandal and Scotchmer, 1993; Hagedoorn, 1990; Morasch, 1995).

If the adaptation of external resources is *cheaper* than inhouse R&D, inter-organizational arrangements in R&D are an efficient way to expand and optimize firms' innovation activities with positive effects on research efficiency, profitability and ability to compete. R&D cooperations offer possibilities of efficient knowledge transfer, resource exchange and organizational learning.[3] Durable, but limited collaborations in well-defined research fields, leaving aside the possibility of competition in the market *('pre-competitive stage')*, allow the stable and comprehensive adaptation of resources needed. Complementary assets, technological capabilities can be combined and merged, generating synergies and cross-fertilization effects.

In recent years, numerous analytical contributions have emerged trying to formalize the incentives of firms to engage in R&D cooperation using oligopoly models with strategic interactions between firms (D'Aspremont and Jacquemin, 1988; de Bondt and Veuglers, 1991; Katz, 1986; Motta, 1992; Steurs, 1995; Suzumura, 1992). Following the game-theoretic approach the effects of cooperation on the innovation process have been examined predominantly by two-stage models of oligopolistic/duopoly competition. Accordingly, private incentives for R&D agreements are high, if external resources (technological opportunities) are sufficiently large, usable with positive effects on the level of R&D investment, output and social welfare.

To judge the innovation effects of R&D cooperation precisely, it is critical to distinguish whether external resources are used either as substitutes or complements.[4] R&D cooperation - given a certain initial state A[5] - leads to a reduction of R&D efforts, if ceteris paribus a *substitution* effect of inhouse R&D occurs.[6] If external R&D resources are used *complementary*, then, ceteris

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[3] To the concept of organizational (mutual) learning see: Brown and Duguid, 1991; Powell, Koput and Smith-Doerr, 1996; Simonin, 1997.

[4] For the role of substitutive and complementive effects in the innovation process see: Arora and Gambardella, 1990; David, Hall and Toole, 2000.

[5] The conditions of establishing R&D cooperation are seen as given.

[6] This suggests that the production of new or improved products requires idiosyncratic and generic R&D efforts. Whereas *idiosyncratic* R&D focuses on generating firm-specific knowledge, *generic* R&D produces knowledge that is easy to access also by other actors (R&D spillovers). Given a certain degree of efficiency in the production of generic knowledge, cooperations with other firms and organizations turn out to be profitable if the costs of searching and processing are lower than the costs of internal knowledge production. A substitution of the generic part of internally produced knowledge reduces total R&D expenditure. Concerning the generic production of knowledge costs are driven down, whereas in the idiosyncratic knowledge production costs can not be higher then status quo ante. For a formal analysis see: Becker and Peters, 1999; Harhoff, 1996.

paribus an increase (decrease) of inhouse R&D leads to an enhancement (reduction) of firms' R&D expenditures.

Further, the innovation effects of R&D cooperation depend on the *number of partners*. It can be expected that networking effects of inter-organizational arrangements in R&D rise with the number of partners cooperating efficiently with each other. Hereby, firms can establish inter-industry agreements (Katz and Ordover, 1990; Mowery, 1989; Vonortas, 1997a)[7] and/or collaborate with institutions outside the industrial sector; especially universities and public research institutes (Faulkner and Senker, 1994; Lee, 1996; Leyden and Link, 1999).

For the empirical analysis the *theoretically expected* effects of successfully R&D cooperation on the innovation activities of firms can be summarized as follows: First, the adaptation of external resources within such collaborations leads to an extension of firms' technological capabilities to develop new and improved products. This becomes evident in an increase of technological know-how and improved skills. Second, assets, resources and information transferred in R&D cooperation improve the research efficiency of firms. Such effects can be observed by higher rates of return of R&D with positive impacts on firms' innovation input and output. Third, the number of partners cooperating efficiently with each other affects the efforts of firms to develop new products positively.

3. Data Set, Variables and Estimation Methods

3.1. Data Set and Variables

For the empirical analysis data from the *first wave of the Mannheim Innovation Panel (MIP-93)* conducted in the German manufacturing[8] industry are used. About 2,900 firms participated in the survey and filled in a questionnaire about their innovation activities in the period 1990-1992. A total of 2,048 firms were included in the empirical investigations.

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[7] A particular type of industrial collaborations are strategic alliances (Beamish, 1998; Gerybadze, 1995; Lorange and Roos, 1992). Strategic alliances are very often a typical feature of a network of firms that show multiple relationships (Jarillo, 1995; Thorelli, 1986). According to Harrigan (1988), these networks can be called *'spider-web cooperations'*. Other forms of inter-firm arrangements are R&D joint ventures (Gandal and Scotchmer, 1993; Link, 1996; Vonortas, 1997b). In the following, no differences are made between these specific types of R&D cooperation.

[8] The empirical investigations are focussed on the German manufacturing industry because more than 90 per cent of the entire R&D expenditures of private firms are conducted in the secondary sector (Bundesministerium für Bildung und Forschung, 1999).

The *MIP-93* data set defines the frame for the specifications of the variables in the econometrical investigations.[9] Unless otherwise noted, all data relate to the year 1992. The *dependent variables* reflecting the innovation input and output of firms in the German manufacturing industry are listed in Table 1, including descriptive statistics.

INSERT TABLE 1 HERE

The innovation input variable R&D_INT - defined as R&D expenditures to sales ratio - measures firms' intensity to develop new and improved products. The log of this intensity is computed because of the problems with non-normal distributions. Firms' *innovation output* are measured by a dummy variable IN_RE_PRD indicating the realization of product innovations in the period 1990-1992.

In Table 1, *independent variables* explaining the innovation behaviour of firms in the German manufacturing industry are also listed. To capture innovation effects of *R&D cooperation*, two variables are integrated in the econometrical estimations. The variable COOP is used to identify firms within R&D cooperations. Members of inter-organizational arrangements in R&D are defined as firms taking part in joint R&D projects with others in the year 1992. Bivariate analysis indicates a close correlation between regularity of inhouse R&D and membership in R&D cooperation. Therefore, it can be assumed that firms cooperating with other firms and institutions in 1992 have been members in R&D cooperation in the years before.

We generate the variable COOP_CLA to measure the *networking effect* of inter-organizational arrangements in R&D. By doing so, it can be investigated how the number of partners cooperating efficiently with each other affects the intensity of R&D/innovation activities.

In the econometrical models, variables reflecting firms' restrictions in the innovation process *('barriers of innovation activities')* are taken into consideration. By this, conditions affecting the willingness to cooperate with others - in section 2 described as the benefits (advantages) of joint R&D - are investigated. We use factor scores of five variables BAR_ generated by a factor analysis of seventeen potential barriers of innovation (see Appendix A1).

To capture the influence of other firm-specific and environmental factors, different variables are integrated in the estimations.[10] Variables related to *appropriability conditions (AP_)* are

9 A detailed description of the *MIP-1993* data set is given by: Harhoff and Licht, 1994.

10 In empirical studies working with the *MIP 1993* data set, generally a variable EAST is implemented in the regressions to control for location effects in East Germany (e.g., Felder et al., 1996; König and Licht, 1995). East German firms have received many tax incentives and subsidies from the government in order to support their

employed because the extent to which firms can protect their knowledge from others affects the innovation activities of firms (Cohen and Levinthal, 1989; König and Licht, 1995; Levin et al., 1987). The better firms can secure their knowledge against others and retain the returns of their R&D, the higher the incentives for inhouse R&D are.[11] In the estimations, scores of factor analysis on firm-specific and law-specific mechanism of protecting internal knowledge (AP_FIRM, AP_LAW) are used (see Appendix A2). Additionally, factor scores of different *aims of innovation activities (AIM_)* reflecting firms' motivation to be engaged in the development of new and improved products are implemented (see Appendix A3). Because of their heterogeneous character, the expected effects of the different aims on firms' innovation activities can hardly be defined.

To capture the influence of *market-related factors*, the variables firm size (SIZE_SALE), intensity of international sales (INTERNAT) and degree of diversification (DIVERS) are integrated in the estimations. These factors reflect the importance of order and demand in the innovation process. The role of *firm size* in the innovation process is a priori difficult to assess because this variable "... can be used as a proxy for various economic effects" (Arvanitis and Hollenstein, 1996, p. 18). It is a proxy for scale effects in the knowledge production, the capacities to specialize innovation activities and the ability to perform (applied) research efficiently. Following Schumpeter (1942), a positive correlation between *absolute* size of a firm and innovation expenditures can be expected. Large firms can benefit from economies of scale in R&D and production. Otherwise, empirical evidence could be found that the *share* of R&D in sales of large firms is lower than that of small firms (Acs, 1999; Acs and Audretsch, 1991; Kleinknecht, 1996). The innovation effects of demand factors are less ambiguous. It can be assumed that high *export shares of sales* (Felder et al., 1996; Wakelin, 1998) and *degree of diversification* (Kamien and Schwartz, 1982; Nelson, 1959) stimulate firms' innovation activities.

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development. In regression with EAST as independent variable, not reported here, we found mostly similiar patterns as reported in section 4.

[11] Appropriability conditions and R&D spillovers are closely related (Cohen, 1995; Griliches, 1992). R&D spillovers are externalities beyond their primary definition, where not alone the innovator has the benefit, but also other actors can apply them for own purposes (Encaoua et al., 2000; Levin and Reiss, 1988). Appropriability problems caused by R&D spillovers may firms motivate to underinvest in R&D because they can not completely internalize the benefit from their private engagement in the development of innovations. In general, the higher (lower) the appropriability conditions of firms are, the less (more) R&D spillovers will occur.

To measure the importance of *technological opportunities*,[12] we distinguish technological opportunities stemming from suppliers (TEC_SUPP), customers and competitors (TEC_CUCO) and scientific institutions (TEC_SCIE). Scores generated by a factor analysis of nine external scources of technological information are used in the estimations (see Appendix A4). In general, the higher the importance of external (knowledge) resources, the higher firms' inhouse capabilities to develop new and improved products are (Arvanitis and Hollenstein, 1994; Gambardella, 1992; Levin and Reiss, 1988). Along this line, the higher the level of technological opportunities, the higher the motivation of a firm will be to become engaged in the innovation process.

To capture the influence of *industry-specific conditions*, a variable on the *degree of market concentration* (COMP_INT) is integrated in the estimations. The influence of market structure on firms' innovation behaviour is ambiguous. On the one hand, empirical studies indicate positive effects of market (industrial) concentration on R&D intensity (Geroski, 1994; Martin, 1994; Vossen, 1999). On the other hand, the degree of competition in the firms' market has an impact of comparable small order of magnitude on the innovation activities of firms, if the estimations are controlled by variables of technological opportunities (Arvanitis and Hollenstein, 1996; Crépon, Duget and Kabla, 1996). Because firm size is not equally distributed within an industry, the market share of a company is an additional indicator of market structure. As with the market concentration, R&D intensity can be expected to increase with market share but level off and may fall when a firm captures the whole market as monopolist.[13]

Further, *industrial technology levels* are used as independent variables. In the *MIP-93* data set, the manufacturing industry encloses eleven sectors. According to common OECD classification (OECD, 1994, p. 94), these sectors are divided in three technology groups (LOW, MEDIUM, HIGH). The variable HIGH is defined as basis group.

A firms' innovation behaviour is closely linked to the development of an industry along with technology and demand. At a given time, the technological regime (Audretsch, 1997; Nelson and Winter, 1982) represents the specific environment of firms at the sectoral level. The features of technological regimes, such as opportunity conditions, degree of cumulativeness of technological knowledge and characteristics of the relevant knowledge base define "... the nature of the

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[12] We assume that the variables of technological opportunities can be used to measure especially the evidence of R&D spillovers in the innovation process.

[13] For the effects of buyer and supplier market concentration on the innovative behaviour of firms see: Farber, 1981; Geroski, 1995; Peters, 2000.

problems that firms have to solve in their innovation activities, the incentives and constraints to particular behaviours and the basic dynamics mechanism of evolution of firms, technologies and industries" (Malerba and Orsenigo, 1993, p. 46). These circumstances lead to specific patterns of innovation activities in industries. In particular, firms in technology-based industries are forced to be steadily active in the innovation process and secure their market competitiveness (Malerba, Orsenigo and Peretto, 1997; Pavitt, 1984).

3.2. Estimation Methods and Econometric Specifications

To estimate the relationship between innovation activities of firms and R&D cooperation, *simultaneous equation systems* are often used (Colombo, 1995; Colombo and Garrone, 1996; Veugelers, 1997). Two main reasons for this can be mentioned. First, internal capacities are necessary to exploit external resources within R&D cooperation. Second, the use of external resources affects the intensity of the firms' innovation engagement. Because of this included endogenous variables in each equation are correlated with the disturbances (*u's* see below), so that Ordinary Least Square (OLS) disregarding simultanity would lead to inconsistent estimators. Further, estimation problems arise from the different scales of the dependent variables R&D_INT, COOP and COOP_CLA (see Table 1).

To get *unbiased* estimation results adequate econometric models have to be used. To avoid identification of single firms the available information for R&D_INT in the data set are censored at point 0.35 (before logs are taken). Therefore, we use a *Tobit model* to capture this upper-censoring. For COOP and COOP_CLA only discrete information is available so that a Probit or Ordered Probit model are the appropriate estimation methods.

To take into account all these estimation problems we use a simultaneous equation model with limited and/or qualitative dependent variables.[14] The estimated models are illustrated below for R&D_INT and COOP:

$$R\&D\_INT^* = \gamma_C \cdot COOP^* + X_R\beta_R + u_R$$

$$COOP^* = \gamma_R \cdot R\&D\_INT^* + X_C\beta_C + u_C$$

$$COOP = 0 \qquad if \quad COOP^* \leq 0 ,$$

$$COOP = 1 \qquad if \quad COOP^* > 0 \qquad .$$

$$R\&D\_INT = R\&D\_INT^* \qquad if \quad R\&D\_INT^* < m,$$

$$R\&D\_INT = m \qquad if \quad R\&D\_INT^* \geq m.$$

where *m* represents the upper-censoring point at 0.35, X_R and X_C indicate the exogenous variables in the corresponding equation, *R&D_INT**, *COOP**, u_R and u_C are unobservable random variables. The actual value *R&D_INT* can be watched, if *R&D_INT*<m*. In the cases *R&D_INT *≥m*, the only available information is that *R&D_INT** lies in the range between *m* and ∞. For *COOP** only the sign is observable.

In the first step, the reduced form parameters are estimated for the COOP equation with the Probit method and for the R&D_INT equation with the upper-censored Tobit model including all exogenous variables. In the second step, these estimations are inserted in the structural form. Following Amemiya's principle, the structural parameters can be estimated efficiently by Generalized Least Square (GLS) using the defined relation between the reduced and structural form.[15] The asymptotic covariance matrix is calculated using Lee's (1992) estimation procedure, which is more flexible to the scale of the dependent variable (see also Wilde, 1999).

For innovation output, the findings of the two-step equation method as described above indicate *no simultaneous relationship* between the innovation output (IN_RE_PR) and cooperative behaviour (COOP and COOP_CLA) (see section 4.2.2.). Therefore, a single equation model builds the adequate analytical framework. We use a Probit respectively a Ordered Probit model (see e.g. Greene, 1997; Ronning, 1991).

4. Results of the Empirical Analysis

In the following, the findings of the empirical investigations with special attention to the importance of R&D cooperations as an innovation factor are described and discussed. Before we point out the econometrical results, descriptive information about the evidence of R&D cooperation in the German manufacturing industry is given.

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[14] For more details to this kind of simultaneous equation systems see: Blundell and Smith, 1993; Lee, 1981; Maddala, 1983.

[15] For more details see: Amemiya, 1978; 1979.

4.1. Evidence of R&D Cooperation in the German Manufacturing Industry

In 1992, about 37 per cent of firms had formed inter-organizational arrangements in R&D with one or more partners to develop new products jointly (see Table 1). Obviously, R&D cooperation is a crucial instrument for firms to gain and implement external resources efficiently. As expected, the part of cooperating firms in the German manufacturing industry varies considerably over sectors. The range reaches from approximately 17 per cent in the wood sector up to about 53 per cent in the vehicle/automobile sector.

Further, regarding the number of cooperation partners considerable differences between firms exist. Approximately 61 per cent of cooperating firms work together with up to three partners. About 29 per cent have R&D agreements with four up to six partners, and 10 per cent collaborate with seven or more other firms or institutions.

4.2. Innovation Effects of R&D Cooperation

We now focus on the econometrical analysis of the effects of joint R&D on the innovation *input and output* of firms. The estimation strategy is as follows: In Model 1, we measure the innovation effects of R&D cooperation in general (COOP) among other exogenous variables. In Model 2, we use additional information on R&D cooperations of firms and investigate how the number of cooperation partners (COOP_CLA) affects the firms' innovation behaviour. Both model specifications are tested with and without the variables of technological opportunities to check the robustness of the estimations, because cooperation is closely connected with technological opportunities and may measure similar effects at least to a certain degree.

4.2.1. Effects on Innovation Input

Using a simultaneous equation system, the estimation results for the effects of R&D cooperation on the *firms' inhouse intensities* (R&D_INT) are listed in Table 2.[16] By this, we investigate whether external resources within such collaborations are used as substitutes or complements to inhouse activities.

INSERT TABLE 2 HERE

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[16] In regressions, not reported here, we find similiar results for INNO_INT (innovation expenditures to sales ratio). Besides R&D, innovation expenditures include also the firms' investment in product design, trial production, purchase of patents and licenses, etc.

Collaborations with other firms and institutions enhance the innovation engagement of firms in the German manufacturing industry. In both specifications of Model 1, the coefficient for COOP is highly significant (at the 0.01 level), pointing out a *complementary relationship* between cooperative agreements in R&D and the level of the firms' innovation input. These findings are in line with work done in other countries (Colombo, 1995; Leyden and Link, 1991; Sakakibara, 1997; Veugelers, 1997). R&D cooperations motivate firms to invest more in the development of innovations. Inter-organizational arrangements in R&D expand technological capabilities with stimulating impacts on the firms' research intensity.

The estimations for Model 2 underline impressively the *networking effects* of inter-organizational R&D arrangements. The number of partners (COOP_CLA) cooperating efficiently with each other affects the intensity of firms' R&D activities positively. The mix of heterogeneous actors in R&D cooperation enfolds synergetics and enhance research productivity in a specific way. This underlines the importance of networking effects in the innovation process (Autio 1997; Love and Roper, 1999; Malerba and Torrisi, 1992; OECD, 2001).

The results for the other exogenous variables in Model 1 and 2 correspond mostly to the theoretically expected signs. A high degree of *appropriability conditions* motivates firms in the German manufacturing industry to invest in the development of new and improved products. Firm-specific strategies to protect knowledge from other companies (AP_FIRM) increase the level of innovation engagement. Mechanisms of protecting innovations by law (AP_LAW) have significant effects on the intensity of R&D investments (at the 0.01 level).

Looking at the five variables AIM_ generated by a factor analysis of twenty potential *aims of innovation activities*, the expansion of demand abroad (AIM_DEMA) and the enlargement of production program (AIM_PROD) have positive effects on R&D_INT (significant at the 0.01 level). Contrary, the improvement of environmental issues (AIM_ENVI) leads to an reduction of the firms' R&D expenditures.

The effect of *firm size* (SIZE_SALE) on the level of firms' R&D expenditures are negative and significant (at the 0.05 level). Large firms in the German manufacturing industry spend less money in order to develop innovations - compared to their sales - than small firms. These findings correspond with studies from other countries (Acs and Audretsch, 1990; Arvanitis, 1997; Evangelista et al., 1997). Obviously, the intensity of the firms' R&D rises less than proportional with size. "Perhaps it is the kind of specialisation underlying the innovative behaviour of small and big firms which allows small firms to innovate without noticeable disadvantages" (Arvanitis 1997, p. 487).

In addition, the regressions indicate highly significant effects of the market-related variable INTERNAT. Firms' R&D intensities rise with the *share of international sales.* The coefficients for the variable DIVERS - *degree of diversification* – are also positive, but lack statistical significance. Both findings support the demand-pull hypothesis (Felder et al., 1996; Kleinknecht and Verspagen, 1990; Wakelin, 1998).

The results for the variables of *technological opportunities* are different. In both model specifications (Model 1a and 2a), the coefficients for suppliers as external knowledge source (TEC_SUPP) are negative and highly significant (at the 0.01 level). This can be explained by the fact that suppliers' information tend to be a substitute for inhouse activities, as also found in studies for the US (Cohen and Levinthal, 1989; Nelson and Wolff, 1997). Further, the regressions indicate positive impacts of a high assessment of customers and competitors (TEC_CUCO) and universities and research institutes (TEC_SCIE) as external knowledge sources on firms' R&D intensity. These results are consistent with other findings (Becker and Peters, 2000; Henderson, Jaffe and Trajtenberg, 1998; Mansfield and Lee, 1996). The strong significance (at the 0.01 level) of TEC_CUCO is remarkable. Contrary, the coefficients for TEC_SCIE lack significance.

The effects of industry-specific variables are ambiguous. The coefficient for *market* c*oncentration* (COMP_INT) is positive and significant (at the 0.05 level). This coincides with the theoretically expected sign. Further, the estimations indicate expected (highly significant) effects of *industrial technology levels* (LOW, MEDIUM). The lower (higher) this level, the less (more) intensive firms' investments in R&D are.

In Table 2 also, the findings for COOP and COOP_CLA as *dependent variable* in the simultaneous equation system are reported.[17] In general, intensity of inhouse R&D (R&D_INT) has stimulating, complementary effects (significant at the 0.01 level) on the probability that firms in the German manufacturing industry are engaged in R&D cooperation. By this, the existence of innovation barriers (BAR_) raises the engagement of firms to cooperate with others in R&D to overcome these restrictions. In particular, firms in the German manufacturing industry are

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[17] To estimate the determinants of R&D cooperation in the simultaneous equation model, the set of explanatory factors for firms' R&D intensity is used with slight modifications. In line with theoretical and empirical studies (Colombo, 1995; Fritsch and Lukas, 2001; Katz and Ordover, 1990; Kleinknecht and Reijnen, 1992; Motta, 1992; Vonortas, 1997a), firm characteristics, market (demand) structure and industrial peculiarities are used as explanatory variables. Contrary to the estimations for R&D_INT, we insert variables of firms' innovation barriers (BAR_) in the estimations for COOP and COOP_CLA as dependent variables and left out factors capturing the firms' motivations of being engaged in the innovation process (AIM_).

interested in such cooperations when costs and riskness of innovation activities (BAR_COST), and financial restrictions (BAR_FIN) are high. As shown in other studies (Peters and Becker, 1999; Veugelers, 1997; Vonortas, 1997a), the adaptation of external resources within R&D cooperation leads to an extension of firms' capabilities of developing new products. Firms are aware that they must establish R&D cooperations to obtain expertise which cannot be generated inhouse.

Positive, highly significant coefficients for BAR_MARK (significant at the 0.01 level) indicate that unsufficient market impulses and demand conditions stimulate the firms' willingness to cooperate. The (insignificant) results for BAR_TEC are ambiguous: Restrictions in internal technological resources vary in the estimations with and without variables of technological opportunities (TEC_). Further research has to be done to investigate this point in detail.

Differences to the estimations for R&D_INT as dependent variables are founded especially for the market-related variables SIZE_SALE and INTERNAT. The likelihood to cooperate in R&D rises with firm size measured by the level of sales (see also Fritsch and Lukas, 2001). Contrary, it decreases with the share of international sales. This may reflect the fact that less cooperative firms do basic innovations for international markets than non-cooperative firms for domestic markets. In this context, Roper and Love (2001) found that German innovative and non-innovative firms do not differ with respect to their export performance and they doing more incremental innovations.

Further, the regressions underline the role of technological opportunities as determinants of R&D cooperation. The higher the importance of external (knowledge) resources from suppliers (TEC_SUPP) and scientific institutions (TEC_SCIE) are, the higher the firms' motivation of being engaged in joint R&D are (at the 0.01 level). Two arguments can be given for this: First, by using their *market power* firms are able to shift R&D expenditures by cooperation agreements towards their suppliers (see R&D equation Model 1a and 2a). Second, if firms rate scientific institutions as important sources of information, they establish formal R&D agreements because there exists no permanent *market relation*, e.g. a product exchange through which firms are able to acquire information.

In contrast, the effects of technological opportunities from customers and competitors (TEC_CUCO) are negative and highly significant. Information stemming from customers and competitors are associated with higher R&D expenditures. This lowers the probability (readiness) to cooperate in R&D. Obviously, the cost-benefit-relationship of joint R&D (as described in section 2) is expected to be negative.

The effect of industrial technology levels on the participation in R&D cooperation is also contrary to the estimations for R&D_INT. The lower the industrial technology level, the higher the likelihood of joint R&D. In sectors with low R&D intensity there are only few possibilities for firms to mark off from competition. With the help of cooperation partners firms – especially small ones - are able to overcome this shortcoming and master the development of complex and risky technologies (Acs, 1999; Malerba and Orsenigo, 1993; Pfirrmann 1998).

4.2.2. Effects on the Innovation Output

We use the set of explanatory factors as on the input level but with slight modifications to estimate the effects of R&D cooperation on the innovation *output* of firms in the German manufacturing industry. The impacts are analyzed for the realization of new products (IN_RE_PRD).

In a first step, we use the same estimation techniques and models as in section 4.2.1. for R&D_INT, but *no* simultaneous relationship between innovation output and R&D cooperation could be detected. This may be due to the fact that only relatively few (nominal) information on the realization of new products is available. 88 per cent of the non-cooperating firms in the data set are innovative so that there is little difference to cooperating firms. Because of this we use a single equation Probit model. Table 3 presents the results of these estimations.[18] Because only few empirical studies exist on the innovation output effects of R&D cooperation, we cannot discuss our results to the extent as done for the input side in section 4.2.1.

INSERT TABLE 3 HERE

Looking at *R&D cooperation* as a whole (COOP), positive output effects can be generally recognized. Collaborations with other firms and institutions enhance the probability of realizing new products (at the 0.01 level). Joint R&D has stimulating impacts on the realization of product innovations. Similar to the innovation input side, the *complementary* effect of using external resources within such inter-organizational arrangements dominates.

Further, the estimations indicate positive output effects of the *number of partners* (COOP_CLA) cooperating efficiently with each other. The realization of new products rises with the number of actors in R&D cooperation. This underlines the networking effects of inter-organizational R&D arrangements.

The estimation results for the other exogenous variables are also listed in Table 3. Not suprising, the *intensity of firms' R&D expenditures* (R&D_INT) has stimulating, highly significant effects on the probability to develop product innovations. Additionally, *appropriability conditions* (AP_) affect the realization of new products positively.

Further, the effect of *firm size* (SIZE_SALE) on the innovation output in the German manufacturing industry is positive with highly significance. The likelihood of realizing product innovations rises with the level of sales. These findings strengthen the presumption that larger firms work more efficiently on the realization of new products as smaller firms, although they invest less in their R&D activities as shown in section 4.2.1. In addition, the demand-related variables *degree of diversification* (DIVERS) and *level of international sales* (INTERNAT) indicate positive impacts on firms' innovation output.

Sources of *technological opportunities* (TEC_) have different effects on IN_RE_PRD. The higher firms rank the importance of external knowledge from customers and competitors (TEC_CUCO), the higher the probability to develop new products is (at the 0.01 level). In addition, for technological opportunities stemming from scientific institutions (TEC_SCIE) the estimations indicate negative effects (at the 0.10 level). This result corresponds with the findings of Arvanitis/Hollenstein (1996). They also found negative (but insignificant) effects of technological opportunities stemming from scientific knowledge sources on the sales shares of new products in the case of Swiss manufacturing firms. One reason that explains these findings can be seen in the fact that knowledge from universities and research institutes affect the development of new products more *indirectly* and improve the quality of products more *indirectly* by increasing firms' R&D efficiency and enhancing inhouse technological capacities rather than by generating technical advance *directly*. "What university research most often does today is to stimulate and enhance the power of R&D done in industry .... By far the largest share of the work involved in creating and bringing to practice new industrial technology is carried out in industry, not in universities" (Rosenberg/Nelson 1994, 340). Nevertheless, the technological opportunities proxy TEC_SUPP has negative impacts on IN_RE_PRD. The higher firms rank the importance of external knowledge from suppliers, the lower the probability of realizing new products. One explanation for this remains to the point that suppliers are often specialized in the

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[18] Including variables reflecting firms' aims and barriers in the estimations, the reported results do not change, therefore they are left out.

development of *process* innovations (Arvanitis/Hollenstein, 1996; Malerba, 1992; von Hippel, 1988).

The estimation results for the industry-specific variables are similar to the effects on firms' innovation input as reported in 4.1.2., but with much less significance. The coefficients for the *market concentration* variable (COMP_INT) is positive. Further, the probability of realizing new products decreases with the *industrial technology level* (LOW, MEDIUM).

5. Summary

Firms engaged in the innovation process are aware of the necessity of establishing R&D cooperation to obtain expertise which cannot be generated inhouse. Thus, internal capabilities to develop new products are improvable. Collaborations with other firms and institutions in R&D offer a crucial way for innovative firms to make external resources usable because they offer possibilities of intensive knowledge transfer, resource exchange and organizational learning. Complementary assets and capabilities can be combined and merged generating synergies and cross-fertilization effects.

Against this background, the aim of the paper was to analyze in a simultaneous equation framework the role of R&D cooperation in the innovation process under two specific aspects. First, the analysis was concentrated on the impact of R&D cooperations on firms' *innovation input and output*. Second, it was analyzed how the *number of cooperation partners* affects the development of new products.

The importance of R&D cooperation as an innovation factor - in line with other exogenous variables - was *empirically* investigated for firms in the German manufacturing industry. A set of firm-specific, environmental and market-related variables was used to estimate the role of R&D cooperation as a determinant of firms' innovative behaviour. The estimation results for the innovation effects of R&D cooperation can be summarized as follows:[19]

In the German manufacturing industry, R&D cooperations are used complementary in the innovation process, enhancing the innovation input and output of firms measured by the intensity of inhouse R&D respectively the realization of product innovations. On the input side, joint R&D with other firms and institutions stimulates the intensity of inhouse R&D. The number of partners cooperating efficiently with each other affects the intensity of firms' R&D activities

[19] In general, the results for the other exogenous variables used in the estimations correspond mostly to the theoretically expected signs.

positively. The mix of heterogeneous actors in R&D cooperation enfolds synergetics and enhance research productivity in a specific way. Also, the intensity of inhouse R&D stimulates the probability and the number of R&D cooperations with other firms and institutions. On the output side, collaborations in R&D enhance the probability of realizing new products. Further, the realization of product innovations rises with the number of actors in R&D cooperation. This underlines the networking effects of inter-organizational R&D arrangements.

In further work, the relationship between R&D cooperation and innovation activities of firms has to be analyzed under specific intra- and inter-sectoral aspects. In addition, the duration (continuity) of such cooperation and the kind (intensity) of knowledge transfer and resource exchange has to be taken more into consideration. Thereby, the decision-making processes and the mechanism of generating synergies and cross-fertilization effects within R&D cooperation can be uncovered. Further, the innovation effects of joint R&D have to be analyzed under longitudinal (dynamic) aspects with special attention to regional innovation systems. Finally, additional research has to be focussed on the importance of industry-specific conditions by the partner selection. By doing so, information about the efficiency of R&D cooperation depending on the type and number of partners can be gained and implications for the public policies can be drawn.

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Table 1: List of variables

Variable	Description	Empirical Measurement	Value (Range)	Mean	Std. Dev.
Innovation Input and Output					
R&D_INT	R&D intensity	Logs of R&D expenditures to sales ratio (1992)	Metric	-5.891	2.708
IN_RE_PRD	Realization of product innovations	1 = Realization of product innovations (1990 – 1992), 0 = otherwise	Nominal	0.755	0.430
R&D Cooperation					
COOP	Joint R&D activities with other firms or institutions	1 = R&D cooperation in 1992, 0 = otherwise	Nominal	0.351	0.478
COOP_CLA	Number of cooperation partners	0 = no partners, 1 = 1 up to 3 partners, 2 = 4 up to 6 partners, 3 = 7 or more partners	Ordinal (0-3)	0.419	0.762
Aims and Barriers of Innovation Activities					
AIM_COST	Aims of innovation activities	Reduction of innovation costs (factor scores)	Metric	0.016	0.999
AIM_DEMI		Expansion of demand in the home country (factor scores)	Metric	-0.026	0.989
AIM_DEMA		Expansion of demand abroad (factor scores)	Metric	0.040	0.998
AIM_ENVI		Improvement of environmental issues (factor scores))	Metric	0.027	0.990
AIM_PROD		Enlargement of production program (factor scores)	Metric	-0.018	1.008
BAR_COST	Barriers of innovation activities	Costs and riskness of innovation activities (factor scores)	Metric	-0.23	1.008
BAR_GOV		Governmental intervention (factor scores)	Metric	0.006	1.003
BAR_MARK		Market impulse and demand condition (factor scores)	Metric	-0.017	0.995
BAR_TEC		Internal technological resources (factor scores)	Metric	0.008	0.994
BAR_FIN		Financial restrictions (factor scores)	Metric	-0.002	0.998
Appropriability Conditions					
	Extent to which technological knowledge can be protected from others				
AP_FIRM		Firm-specific mechanism to protect innovations (factor scores)	Metric	-0.020	1.013
AP_LAW		Mechanisms to protect innovations by law (factor scores)	Metric	0.002	1.002
Market-related Factors					
SIZE_SALE	Firm size	Sales in log	Metric	2.825	2.093
DIVERS	Degree of diversification	Inverse of the sum of squared sales share for the four major product groups	Metric	0.015	0.006
INTERNAT	Intensity in international sales	Foreign sales/whole sales	Metric	0.182	0.226

Technological Opportunities					
TEC_SUPP	Importance of external knowledge to firms' innovation activities	Suppliers (factor scores)	Metric	0.007	1.006
TEC_CUCO		Customers and competitors (factor scores)	Metric	0.004	1.005
TEC_SCIE		Universities and scientific institutions (factor scores)	Metric	-0.028	0.998
Industry-specific Conditions					
COMP_INT	Development of competition intensity (1990 – 1992)	Herfindahl index for industrial sectors	Ordinal (1-5)	3.863	0.902
	Industrial technology levels	Classification of German manufacturing industries in technology levels according to OECD (1994)			
LOW			Nominal	0.459	0.499
MEDIUM			Nominal	0.339	0.473
HIGH			Nominal	0.202	0.402

Table 2: Simultaneous estimation results for R&D intensity (R&D_INT), R&D cooperation (COOP), and number of R&D cooperation partners (COOP_CLA)

	Model 1 a		Model 1 b		Model 2 a		Model 2 b	
	R&D_INT	**COOP**	**R&D_INT**	**COOP**	**R&D_INT**	**COOP_CLA**	**R&D_INT**	**COOP_CLA**
	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)
INTERCEPT	-4.733***	0.300***	-4.555***	-0.296**	-4.257***	0.292***	-4.886***	0.013
	(-11.463)	(2.918)	(-9.107)	(-2.048)	(-8.497)	(3.601)	(-11.779)	(0.109)
COOP	0.867***		0.786***					
	(3.126)		(3.632)					
COOP_CLA					0.921***		0.797***	
					(3.829)		(3.237)	
R&D_INT		0.239***		0.275***		0.358***		0.199***
		(14.832)		(13.036)		(28.999)		(10.961)
AIM_COST	-0.075		-0.049		-0.016		-0.079	
	(-1.227)		(-0.906)		(-0.299)		(-1.354)	
AIM_DEMA	0.349***		0.322***		0.280***		0.385***	
	(4.843)		(4.459)		(4.349)		(5.091)	
AIM_ENVI	-0.223***		-0.226***		-0.168***		-0.253***	
	(-3.589)		(-4.173)		(-2.832)		(-4.327)	
AIM_PROD	0.231***		0.268***		0.220***		0.264***	
	(3.735)		(4.723)		(4.071)		(4.246)	
AIM_DEMI	0.027		0.034		0.036		0.047	
	(0.480)		(0.644)		(0.715)		(0.809)	
BAR_COST		0.070***		0.085***		0.070***		0.069***
		(8.810)		(7.685)		(11.389)		(7.317)
BAR_GOV		0.076***		0.116***		0.068***		0.111***
		(9.214)		(9.750)		(10.063)		(11.535)
BAR_MARK		0.120***		0.111***		0.107***		0.129***
		(14.359)		(9.495)		(16.219)		(13.080)
BAR_TEC		-0.032***		0.031***		0.047***		-0.041***
		(-3.962)		(2.960)		(7.990)		(-4.230)
BAR_FIN		0.076***		0.102***		0.068***		0.092***
		(8.234)		(7.921)		(9.828)		(8.136)
AP_FIRM	0.128*	0.044***	0.045	0.045***	0.046	0.001	0.137**	0.063***
	(1.887)	(4.762)	(0.756)	(3.796)	(0.858)	(0.191)	(1.971)	(5.788)
AP_LAW	0.197***	-0.060***	0.260***	-0.085***	0.256***	-0.161***	0.223***	-0.026**
	(3.252)	(-6.389)	(4.539)	(-6.097)	(4.855)	(-20.933)	(3.512)	(-2.232)
SIZE_SALE	-0.115**	0.139***	-0.131**	0.271***	-0.168***	0.235***	-0.094*	0.164***
	(-2.511)	(30.194)	(-2.013)	(37.212)	(-2.668)	(61.707)	(-1.938)	(29.219)
INTERNAT	0.910***	-0.230***	0.989***	-0.081	0.766***	-0.097***	1.050***	-0.230***
	(3.032)	(-5.162)	(3.495)	(-1.353)	(2.844)	(-2.964)	(3.415)	(-4.276)
DIVERS	8.425	10.728***	14.373*	5.793***	10.814	3.317***	11.947	12.281***
	(0.928)	(8.773)	(1.798)	(3.541)	(1.481)	(3.841)	(1.280)	(8.234)
TEC_SUPP	-0.208***	0.037***			-0.244***	0.100***		
	(-3.528)	(4.226)			(-4.480)	(15.147)		
TEC_CUCO	0.190***	-0.138***			0.198***	-0.134***		
	(3.131)	(-17.128)			(3.968)	(-20.436)		
TEC_SCIE	0.074	0.183***			-0.047	0.236***		
	(0.696)	(18.548)			(-0.416)	(31.997)		
COMP_INT	0.131**	0.005	0.134**	-0.009	0.125**	-0.012*	0.135**	-0.000
	(2.095)	(0.584)	(2.309)	(-0.735)	(2.342)	(-1.789)	(2.113)	(-0.006)
LOW	-1.273***	0.080**	-1.456***	0.364***	-1.378***	0.412***	-1.342***	0.057
	(-7.434)	(2.372)	(-10.521)	(8.228)	(-10.633)	(16.325)	(-8.008)	(1.439)
MEDIUM	-0.826***	0.073***	-0.951***	0.249***	-0.869***	0.243***	-0.870***	0.077***
	(-5.327)	(2.907)	(-6.845)	(7.464)	(-6.668)	(12.690)	(-5.653)	(2.655)
Number of observations	1169	1169	1171	1171	1085	1085	1087	1087
Adj. R^2	0.579	0.248	0.626	0.318	0.092	0.129	0.307	0.335

Notes: * significant at the 0.1 level, ** significant at the 0.05 level, *** significant at the 0.01 level.

Table 3: Probit estimation results for the realization of new products (IN_RE_PRD)

	Model 1 a	Model 1 b	Model 2 a	Model 2 b
	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)	Coeff. (t-value)
INTERCEPT	1.501*** (3.172)	1.596*** (3.523)	1.548*** (3.158)	1.663*** (3.547)
COOP	0.544*** (2.601)	0.446** (2.249)		
COOP_CLA			0.231 (1.224)	0.145 (0.834)
R&D_INT	0.143*** (4.706)	0.153*** (5.317)	0.160*** (4.971)	0.171*** (5.616)
AP_FIRM	0.094 (1.502)	0.101* (1.776)	0.094 (1.479)	0.103* (1.785)
AP_LAW	0.110 (1.491)	0.073 (1.088)	0.105 (1.378)	0.068 (0.986)
SIZE_SALE	0.127*** (3.090)	0.119*** (3.034)	0.129*** (2.987)	0.120*** (2.936)
INTERNAT	0.593 (1.317)	0.657 (1.569)	0.603 (1.331)	0.698* (1.659)
DIVERS	35.999** (2.145)	35.464** (2.206)	41.409** (2.348)	40.856** (2.417)
TEC_SUPP	-0.069 (-0.937)		-0.076 (-1.012)	
TEC_CUCO	0.190*** (3.050)		0.201*** (3.127)	
TEC_SCIE	-0.143* (-1.894)		-0.139* (-1.756)	
COMP_INT	0.035 (0.483)	0.015 (0.209)	0.038 (0.499)	0.011 (0.151)
LOW	-0.159 (-0.750)	-0.122 (-0.613)	-0.117 (-0.542)	-0.077 (-0.382)
MEDIUM	-0.021 (-0.092)	0.004 (0.020)	-0.053 (-0.227)	-0.013 (-0.058)
Number of observations	1222	1239	1131	1148
Log likelihood	-214.265	-229.578	-204.597	-220.137
$R^2_{McFadden}$	0.261	0.240	0.264	0.242

Notes: * significant at the 0.1 level, ** significant at the 0.05 level, *** significant at the 0.01 level.

Appendix A1: Barriers of innovation activities - Factor scores

	Factor BAR_COST	Factor BAR_GOV	Factor BAR_MARK	Factor BAR_TEC	Factor BAR_FIN
BAR_5	0.799	0.077	0.064	0.094	0.157
BAR_6	0.795	0.085	0.083	0.080	0.044
BAR_1	0.707	0.073	0.157	0.099	0.051
BAR_2	0.672	0.102	0.144	0.138	0.122
BAR_7	0.586	0.095	0.096	0.139	0.050
BAR_13	0.084	0.888	0.096	0.072	0.066
BAR_12	0.086	0.884	0.086	0.091	-0.030
BAR_14	0.232	0.653	0.190	0.015	0.109
BAR_15	0.174	0.109	0.813	0.085	0.047
BAR_16	0.104	0.201	0.751	0.157	0.067
BAR_17	0.176	0.057	0.702	0.161	0.002
BAR_9	0.010	0.082	0.018	0.712	0.071
BAR_10	0.114	0.083	0.127	0.710	-0.045
BAR_11	0.078	0.094	0.120	0.677	0.115
BAR_8	0.210	-0.071	0.187	0.540	0.002
BAR_4	0.150	0.047	0.074	0.059	0.913
BAR_3	0.181	0.069	0.023	0.042	0.912

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.81; Bartlett-Test of sphericity: 13052.35

Appendix A2: Firms' appropriability conditions - Factor scores

	Factor AP_LAW	Factor AP_FIRM
AP_PA_PR	0.820	0.033
AP_PA_PZ	0.815	0.147
AP_CO_PZ	0.788	0.165
AP_CO_PR	0.752	0.047
AP_DE_PZ	0.093	0.741
AP_LE_PZ	0.225	0.711
AP_LO_PZ	-0.045	0.703
AP_LO_PR	-0.047	0.615
AP_LE_PR	0.047	0.614
AP_SE_PZ	0.397	0.588
AP_LE_PR	0.300	0.548
AP_SE_PR	0.367	0.503

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.68; Bartlett-Test of sphericity: 8837.76

Appendix A3: Aims of innovation activitites - Factor scores

	Factor AIM_COST	Factor AIM_DEMA	Factor AIM_ENVI	Factor AIM_DEMI	Factor AIM_PROD
AIM_14	0.775	0.025	-0.096	0.038	0.108
AIM_15	0.723	0.059	0.118	0.034	0.107
AIM_17	0.696	0.064	0.259	0.068	0.080
AIM_18	0.584	0.050	0.416	-0.005	0.023
AIM_16	0.556	-0.030	0.497	0.118	-0.084
AIM_13	0.433	-0.047	0.370	0.140	0.231
AIM_9	0.034	0.880	-0.002	-0.063	0.089
AIM_8	0.003	0.816	0.090	-0.060	0.078
AIM_10	0.047	0.792	0.019	0.135	0.053
AIM_7	0.075	0.599	0.004	0.481	0.159
AIM_20	0.165	0.055	0.801	-0.001	-0.050
AIM_12	-0.072	0.118	0.702	0.050	0.243
AIM_19	0.335	-0.016	0.671	0.099	-0.025
AIM_11	0.224	-0.024	0.447	0.070	0.272
AIM_5	0.078	0.112	0.044	0.831	0.119
AIM_6	0.082	-0.038	0.131	0.793	0.103
AIM_2	0.089	0.015	0.045	0.119	0.670
AIM_1_	0.068	0.240	-0.003	-0.089	0.661
AIM_3_	0.008	0.007	0.105	0.171	0.553
AIM_4	0.073	0.048	0.047	0.032	0.438

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.82; Bartlett-Test of sphericity: 9720.49

Appendix A4: External sources of technological knowledge - Factor scores

	Factor TEC_SCIE	Factor TEC_SUPP	Factor TEC_CUCO
TEC_TI	0.851	0.019	0.051
TEC_UNIV	0.824	-0.032	0.019
TEC_RI	0.777	0.121	0.123
TEC_ADV	0.528	0.174	0.281
TEC_SUP_INV	0.127	0.855	0.003
TEC_SUP_PRE	0.017	0.850	0.112
TEC_CUST	0.083	0.048	0.821
TEC_COMP	0.138	0.054	0.816

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.72; Bartlett-Test of sphericity: 3072.62