Innovation Effects of Science-Related Technological Opportunities

Theoretical Considerations and Empirical Findings For Firms in the German Manufacturing Industry

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Abstract

This paper investigates the innovation effects of science-related technological opportunities. Against the background of theoretical considerations about the interrelation of innovation and the adaptation of external (knowledge) resources, the impacts of technological opportunities stemming from scientific institutions on firms' innovation input and output are empirically analyzed for the German manufacturing industry. The investigations focus on the question whether science-related technological opportunities are used as complements or substitutes in the innovation process.

The estimations indicate complementary relationships between firms' innovation input and technological opportunities stemming from scientific institutions. The adaptation of science-related knowledge resources has stimulating effects on the intensity of inhouse R&D. The results for the innovation output effects are ambiguous. On the one hand, empirical evidence for complementary impacts on the realisation of improved products could be found. On the other hand, science-related technological opportunities have no enhancing effects on the probability of realizing new products. Obviously, knowledge from universities and research institutes stimulates the development of new products more indirectly by increasing inhouse capacities and enhancing R&D efficiency.

Key words: Innovation Activities, Technological Opportunities, Scientific Institutions, Manufacturing Industry

JEL classification: O31, I20, L20, L60

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1. Introduction

As a consequence of the dynamics of technological advance and the globalisation of R&D and technology markets, firms continuously have to expand their innovation potentials and to optimize their inhouse R&D capacities by applying technological opportunities from outside (Dosi 1988; Griliches 1995; Mairesse/Saasenou 1991; Meyer-Krahmer 1999). Especially *science-related technological opportunities* are crucial for the innovation process and the performance of R&D.

The importance of external (knowledge) resources stemming from universities and research institutes has increased continuously over time because the development of new and improved products (technologies) depends increasingly on the findings of scientific research (Martin/Nightingale 2000; Narin/Hamilton/Olivastro 1997; Rosenberg/Nelson 1994). This is closely related to the growing importance of multi- and interdisciplinary R&D and the strengthened interrelation of basic research and industrial application. Important innovation impulses in key technologies, such as telecommunication technology and biotechnology, are drawn from scientific research (Gibbons et al. 1994; Mansfield 1995; Nelson/Wolff 1997). But also technologies in mass production sectors, such as in the chemical and machinery sector, have reached development levels requiring a specific degree of optimizing internal resources through technological opportunities stemming from scientific institutions (Faulkner/Senker 1994; Grupp 1996; Klevorick et al. 1995).

For the American manufacturing industry, the role of scientific research in the innovation process has been empirically investigated in several studies.[1] Jaffe (1989) delivers pathbreaking empirical proof of stimulating effects of university research[2] on the innovation activities of firms. Knowledge from scientific research significantly influences the number of patents applied by firms in the same state. This impact becomes even more evident when the number of firms' innovations are used as a dependent variable rather than the frequency of patent applications (Acs/Audretsch/Feldman 1992). The findings can be interpreted as showing that new advances in university research act not only at the basic research stage but affect the entire innovation chain and stimulate a market-oriented application of new knowledge.

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[1] For an overview see: Cohen 1995; Stephan 1996.

[2] We use university research and academic research synonymously.

Klevorick et al. (1995) find that science-related technological opportunities in the US are particularly relevant for firms in R&D intensive industries, such as the computer industry, aircraft industry, and the pharmaceutical industry. Firms in these industries mainly utilize findings from applied sciences (mechanical engineering, electrical engineering, chemical engineering) while new findings from basic research in physics and mathematics are of lower relevance for industrial innovation.

For the German manufacturing industry, the importance of scientific research for the development of new and improved products has been subjected to less empirical investigation compared with other countries, especially the U.S. The existing studies focus on *distinct aspects* of the science-technology interface, e.g. the relevance of scientific knowledge in specific technology fields (Beise/Stahl 1999; Grupp 1992; Peters/Becker 1998; Wagner 1987), the role of universities in the technology transfer especially for small and medium-sized firms (Beise/Licht/Spielkamp 1995; Meyer-Krahmer/Schmoch 1998; Schmoch/Licht/Reinhard 2000; Wagner 1990), the dynamics of knowledge flow from science to technology as reflected in patent indicators (Grupp 1996, Schmoch 1993), or the importance of regional science and research infrastructure on the formation of new firms (Fritsch/Meyer-Krahmer/Pleschak 1998; Licht/Nerlinger 1998; Harhoff 1997).

Against this background, the aim of our paper is to analyze the effects of science-related technological opportunities on the innovation activities of firms in the German manufacturing industry from a *broader perspective*. In doing so, the issue in this paper is novel mainly in two points. First, the analysis is concentrated on the impacts both on the innovation input and output side. Second, the investigations are focussed on the basic question whether internal R&D and external kowledge resources stemming from scientific institutions are used as complements or substitutes in the innovation process.

The paper is organized as follows. In section 2, we discuss the interrelation of innovation process and adaptation of external (knowledge) sources from a *theoretical* point of view. In section 3, the importance of science-related technological opportunities for the innovation input and output activities of firms in the German manufacturing sector are investigated from an *empirical* point of view. Section 4 summarizes the main findings and gives an outlook on further research.

2. Theoretical Considerations: Innovation Process and Adaptation of Science-related Technological Opportunities

Successful innovations are determined by different and related factors (Flaig/Stadler 1998; Kleinknecht 1996; Martin 1994). These factors can be divided into *firm-specific* determinants (R&D intensity, firm size, etc.) and *external* influences, such as technological opportunities, market structures, industrial technology level, etc.

Concerning firm-specific determinants, *inhouse R&D*[3] plays a major role in the development of new and improved products (technologies). Basic reasons for R&D can be seen in the expansion of know-how and the increasing probability of realizing product and process innovations. In addition, R&D is performed because of its positive impact on productivity, turnover and profits (Bozeman/Melkers 1993; Griliches 1995; Harhoff 1998). Thus, the level of firms' R&D depends on the possibilities of acquiring external (knowledge) resources for own purposes. Variances in R&D expenditures and innovation activities can be explained by differences in the *technological opportunities* each firm or industry are faced with (Geroski 1990; Harabi 1995; Klevorick et al. 1995).

The concept of technological opportunities differs from the theoretical point of view. Within the neo-classical theory technological opportunities can be described as ”... the set of production possibilities for translating research resources into new techniques of production that employ conventional input” (Cohen/Levin 1989, p. 1083). In the framework of the evolutionary theory of technical progress two types of technological opportunities can be distinguished (Coombs 1988; Dosi 1988). Extensive technological opportunities are seen as potentials of new technologies with (sometimes unknown) relationships to other technology fields whereas intensive technological opportunities shape technical advance along special technological trajectories.

We have no ambition in this paper to obtain ”... consensus on how to make the concept of technological opportunity precise and empirically operational” (Cohen/Levin 1989, p. 1083). Rather, we define technological opportunities as the total amount (pool) of the currently existing and exploitable external resources for firms.

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[3] *R&D* is a part of firms' activities to develop new and improved products. *Innovation activities* include also expenditures for product design, trial production, purchase of patents and license, and training of employees, etc. In this paper, the discussion is concentrated on R&D as the *main* part of firms' innovation activities.

Empirical studies underline the role of technological opportunities in the innovation process (Becker/Peters 2000; Geroski 1990; Levin et al. 1987; Mamuneas 1999; Sterlacchini 1994). The strength and sources of external resources are important factors explaining firm-specific and cross-industry differences in R&D intensity, productivity of R&D, and technological advance. The adaptation of external resources changes the characteristics and influences the performance of factor inputs required for innovations. For the recipients, the utilization of exogenously generated knowledge leads to an improved quality of the factor inputs. Depending on the absorptive capacities,[4] firms can expand their capabilities to develop product and process innovations which can increase the probability of being successful in R&D (Cohen/Levinthal 1989; Klevorick et al. 1995). But this means that firms become more dependent on the know-how of other companies and institutions (Arora/Gambardella 1990; Feldman 1993; Leyden/Link 1999).

Science-related technological opportunities are of major interest for firms with a high level of R&D (innovation) activities due to the close interrelation of basic research and industrial research. Scherer (1992, p. 1424) points out that ”... the mysterious concept of ‘technological opportunities’ was originally constructed to reflect the richness of the scientific knowledge base tapped by firms”. Technological opportunities are ”... mainly fostered by the advances of scientific knowledge and positively affect the productivity and thus the intensity of R&D” (Sterlacchini 1994, p. 124).

In the early 60’s, Nelson (1959) and Arrow (1962) emphasized the importance of *‘new scientific knowledge’* as a driving force behind innovation, technological and economic progress. Ever since, its magnitude in the development of new and improved products has continuously grown (Henderson/Jaffe/Trajtenberg 1998; Mansfield/Lee 1996; Stephan/Audretsch 2000). The increasing dynamics of technological progress as well as the growing complexity of innovation process account for this. ”What university research most often does today is to stimulate and enhance the power of R&D done in industry ...” (Rosenberg/Nelson 1994, p. 340). The bottom line is, as scientific knowledge increases, the cost of successfully undertaking any given science-based invention decreases. This leads - ceteris paribus - to a rise in the productivity of firms’ innovation activities. ”The consequence is that the research process is more efficient. There is less trial-and-error;

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[4] Absorptive capacities can be defined as the ability ”... to identify, assimilate, and exploit knowledge from the environment ...” (Cohen/Levinthal 1989, p. 569). Firms have to invest in complementary inhouse R&D in order to understand and implement the results of externally performed R&D (Arora/Gambardella 1994; Cantner/Pyka 1998; Veugelers 1997).

fewer approaches need to be evaluated and pursued to achieve a given technological end. From this perspective, the contribution of science is that it provides a powerful heuristic guiding the search process associated with technological change" (Cohen 1995, p. 217-218).

To investigate the interrelation of firms' innovation activities and the adaptation of science-realated technological opportunities theoretically in more detail, we make *three basic assumptions*:

a.) To realize innovations, firm *i* has to invest in idiosyncratic and generic R&D. Whereas *idiosyncratic* R&D activities R_i^{id} primarily generate firm-specific knowledge, *generic* R&D activities R_i^{ge} produces information having more the character of a public good (Nelson 1992). New generic information (knowledge) can spill over to other actors.[5]

b.) Science-related technological opportunities TO_i_SCIE can be a substitute for *generic* inhouse R&D (R_i^{ge}).

c.) Investments in idiosyncratic and generic R&D are closely related. Decreasing (increasing) the level of generic R&D lowers (enlargens) the productivity of idiosyncratic R&D.

Against this background, the innovation effects induced by science-related technological opportunities may occur in two specific ways (Becker 1996; Brooks 1994; Hoppe/Pfähler 2001). First, the adaptation of external resources from scientific institutions can lead to an extension of firms' technological capacities (capabilities)[6] to develop new and improved products. This becomes evident in an increase of technological know-how and improved skills *(innovation input side)*. Second, the implementation of science-related technological opportunities can raise the probability of realizing innovations *(innovation output side)*.

Looking at the *innovation input side* in more detail, productivity and substitution effects of TO_i_SCIE on internal R&D can be distinguished:

- ➢ The *productivity effects* relate to the argument that the incentive to invest in (idiosyncratic) R&D is positive correlated with the level of usable technological

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[5] R&D spillovers are externalities beyond their primary definition, where not only the innovator benefits, but also other actors (Encaoua et al. 2000; Peters 1998; Smolny 2000).

[6] In general, technological capacities (capabilities) can be 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; Cohen/Levinthal 1990; Teece/Pisano 1994).

opportunities. This comprehension "... corresponds to the function that maps the flow of R&D into increases in the stock of knowledge" (Klevorick et al. 1995, p. 188). At this, the stock of knowledge expands only with diminishing returns of inhouse R&D at the margin because technological opportunities exhaust with further progress in a given technological area. Therefore, firms (industries) have to invest more in R&D.

In this context, higher levels of technological opportunities - large flow of scientific knowledge - enhance the productivity of inhouse R&D with stimulating impacts on R&D investment. Thus, the level of R&D (investments) which maximizes profits depends on the interaction between firms' inhouse capacities and TO_i_SCIE.

- The *substitution effects* refer to the fact that the adaptation of science-related technological opportunities can reduce firms' R&D expenditures. As Sterlacchini (1994) notes, basic research on their own can be more expensive and less effective for firms than funding scientific research to realize an innovation. The decision to use technological opportunities stemming from scientific institutions as a substitute for own generic R&D depends on the costs of inhouse R&D $c(R_i^{ge})$ and on the costs of adaptation external resources $c(TO_i\_SCIE)$.

If $c(TO_i\_SCIE) \geq c(R_i^{ge^*})$, there will be *no* motivation for firm *i* to absorb scientific knowledge. In this case, $c^* = c(R_i^{id^*}, R_i^{ge^*}) = c(R_i^{id^*}) + c(R_i^{ge^*})$ as firms' total costs of R&D. The adaptation of TO_i_SCIE will be a *profit enhancing* strategy, if the costs of implementing external resources are lower than the production of generic knowledge inhouse: $c(TO_i\_SCIE) < c(R_i^{ge^*})$. If generic R&D information produced outside has the character of a public good, firms can use this information without purchasing the right to do so (Nelson 1992). In the case of R&D spillovers, firms have no incentives to invest in own generic R&D: $c(R_i^{ge^{**}}) = 0$. Then, $c_i^{**} = c(R_i^{id^{**}}) + c(TO_i\_SCIE^{**})$.

If firms substitute their generic part of inhouse R&D *up to the level* of generic R&D done formerly inhouse $(TO_i\_SCIE \leq R_i^{ge^*})$, they will - as Harhoff (1996) shows - reduce their R&D investment. Given the efficiency of generic R&D, the costs of generic R&D will decrease up to $c(R_i^{ge^*})=0$, whereas the amount of idiosyncratic R&D investments $c(R_i^{id^*})$ can not be higher than formerly with inhouse engagement in generic R&D.

Only if firms decide to utilize *more* generic knowledge from scientific institutions than they had formerly generated inhouse ($TO_i\_SCIE > R_i^{ge^*}$), the level of idiosyncratic R&D will rise: $R_i^{id^*} < R_i^{id^{**}}$; $c(R_i^{id^*}) < c(R_i^{id^{**}})$. But in such a case it is impossible to make a clear statement about the total level of firms' R&D investment. If the elasticity of idiosyncratic R&D with regard to $TO_i\_SCIE(\eta_{R_i^{id}TO_i\_SCIE})$ is small (high), the entire R&D costs can be lower (higher) with the adaption of scientific resources than formerly with generic R&D activities done inhouse. Thus, the level of R&D expenditures will be lower in the case of high levels of technological opportunities than in the case of low levels.

The *whole impact* of science-related technological opportunities on firms' innovation input depends on the strength of productivity and substitution effects. Further, it depends on the interaction of both effects. For example, for increasing efficiency in the utilization of generic R&D it is more likely that firms will substitute their inhouse production of generic knowledge by scientific institutions. Due to their increased efficiency, firms are able to use more external generic R&D than was formerly done inhouse, thus enhancing the productivity effect of idiosyncratic R&D. At the very least, they will invest more in inhouse activities. In this case, complementary effects of using external knowledge resources from scientific institutions dominate.

The impacts of science-related technological opportunities on *firms' innovation output* w_i - indicated by new products or by the extent of cost reductions - seem to be theoretically more precise to interpretate.[7] The relationship can be expressed by

$$w_i = w(R_i^{id}, R_i^{ge}, TO_i\_SCIE) \tag{1}$$

with the following conditions:

$$\begin{aligned} &\partial w_i / \partial R_i^{id} > 0,\ \partial w_i / \partial R_i^{ge} > 0,\ \partial w_i / \partial TO_i\_SCIE > 0, \qquad (1')\\ &\partial^2 w_i / \partial R_i^{id^2} \overset{\geq}{<} 0,\ \partial^2 w_i / \partial R_i^{ge^2} \overset{\geq}{<} 0,\ \partial w_i / \partial TO_i^2\_SCIE > 0,\\ &\partial^2 w_i / \partial R_i^{id} \partial R_i^{ge} > 0,\ \partial^2 w_i / \partial R_i^{id} \partial TO_i\_SCIE > 0, \end{aligned}$$

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[7] We asuume that w_i is a function of the level of inhouse R&D engagement (investment) R_i and TO_i_SCIE. This view differs from the definition of Griliches (1979, p. 98) who characterizes technological opportunities as "... one or more parameters in a production function relating research resources to increments in the stock of knowledge, with the stock of knowledge entering in turn as an argument, along with conventional inputs, in the production for output". In our analysis, science-related technological opportunities are interpreted as an argument contained directly in the production function of w_i.

$$\partial^2 w_i / \partial R_i^{ge} \partial TO_i\_SCIE \geq 0 .$$[8]

Higher investments in idiosyncratic or generic R&D enlarge firms' innovation output with diminishing, constant, or increasing rates of return, depending on the initial level of firms' inhouse R&D. The same conditions apply for the impact of technological opportunities on w_i. Thus, given the level of inhouse R&D, an expansion of usable TO_i has stimulating effects on firms' innovation output. For example, using new materials or information technologies enables advances in product quality directly.

To analyze the profit maximization problem regarding to the R&D investments and to their total output q_i, the framework of Levin and Reiss (1988) can be used. We assume that firms invest in R&D to develop innovations and have standard Cournot-Nash conjectures. In this case:

$$\underset{R_i^{id}, R_i^{ge}, q_i}{Max} \Pi_i = P(q_i, w_i, Q, W)q_i - f(L_i, K_i)q_i - c(R_i^{id}, R_i^{ge}), \tag{2}$$

where P describes the inverse demand function of firm i, given an aggregate utility function $U(G)$, with $G = w_1 q_{1+} w_2 q_{2+ \dots} w_n q_n$ as a quality weighted sum of firms' total output q_i. Q and W indicate the output and product qualities of competitors, $f(.)$ and $c(.)$ represent the (unit) cost of production and R&D, with L_i, and K_i as the input factors labour and capital. The profit maximization values of q_i and of the R&D investments that characterize any potential equilibrium are denoted by $q_i^* = q_i^*(A,\Omega_i)$, $R_i^{id*} = R_i^{id*}(A,\Omega_i)$, and $R_i^{ge*} = R_i^{ge*}(A,\Omega_i)$, whereas A describes conditions to the price elasticity of demand, size of the markets, number of competitors, etc.

3. Empirical Findings for Firms in the German Manufacturing Industry

In the following, the innovation effects of science-related technological opportunities are *empirically* investigated for firms in the German manufacturing industry. More than 90 per cent of private R&D investments in Germany are performed by firms from the manufacturing sector (Bundesministerium für Bildung und Forschung 2001).

We start with a description of the data set and variables used in the empirical analysis. Then, information about model specification and estimation methods to explain firms'

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[8] If firms' own generic R&D and science-related technological opportunities are *(perfect) substitutes*, no

innovation activities is given. After that, the estimation results on the importance of science-related technological opportunities for the innovation input and output activities of firms in the German manufacturing sector are presented.

3.1. Data Set and Variables

In the empirical analysis, data from the first wave of the Mannheim Innovation Panel conducted in Germany in 1993 *(MIP-93)* are used.[9] In this survey about 2,900 firms participated and filled in a questionnaire about their innovation activities for the period of 1990-1992.[10] Hereby, an *innovative* firm is defined as a company which had introduced new or improved products *to the market* in the years 1990-1992 or had intended to do so in the period of 1993-1995. In all, 1,494 innovative firms are included in the empirical analysis.[11]

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

- Insert Table 1 here -

The *innovation input* variables measure the intensity of firms' inhouse activities of realizing new and improved products. We distinguish between *R&D expenditure intensity* (R&D_EXP_INT), measured by the R&D expenditures to sales ratio, and *R&D employment intensity* (R&D_EMP_INT), measured by the ratio of R&D employment to total employment as a proxy for firms' investment in human capital. The log of the two

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productivity effects can exist between R_i^{ge} and TO_i_SCIE $((\partial^2 w_i / \partial R_i^{ge} \partial TO_i\_SCIE = 0)$.

[9] We thank the Center of European Economic Research (ZEW) for the permission to use *MIP-93* data.

[10] For more details: Janz et al. 2001; Harhoff/Licht 1994.

[11] We have tested the model specifications for *all* firms in the ZEW data set. In the regression no basic differences related to the influences of the independent variables on the innovation input and output could be found. Further, we have split the data set in a sub-sample with *West* German firms only. No fundamental distinctions between the regressions results for the West German firms and all firms were observable. In empirical studies working with the *MIP 1993*, generally a variable EAST is implemented in the regressions to control for location effects in East Germany (e.g., Felder et al. 1996; König/Licht 1995). East German firms have received many tax incentives and subsidies from the government in order to support their development. In regression with EAST as independent variable, not reported here, we found mostly similiar patterns as reported in section 3.3.

intensities are computed because of problems with non-normal distributions.[12] The *innovation output* of firms is measured by the *realization* of new products (IN_RE_PRD) and improved products (IN_RE_PRC).

Table 2 shows the *independent variables* used to explain the innovation activities of firms in the German manufacturing industry: the importance of external knowledge sources *(technological opportunities)*, the extent to which firms can protect their knowledge from other firms *(appropriability conditions)* and *market-related* specific variables, such as firm size, demand factors, market concentration, etc.

- Insert Table 2 here -

To measure the importance of *science-related technological opportunities* and other kinds of external knowledge resources, the scores generated by a factor analysis of ten external scources of technological information (see Appendix A1) are employed. In the *MIP-93* survey firms were asked to rate on a five-point scale the importance of external knowledge resources for their innovation activities in the years 1990-1992. Scientific institutions were ranked at a medium level. Customers were rated as the most important sources. Competitors and suppliers were also highly ranked. According to this, we distinguish technological opportunities stemming from scientitific institutions (TO_SCIE), competitors/customers (TO_CUCO), and suppliers (TO_SUPP). In line with Levin/Reiss (1988) we assume that the degree to which firms rate scientific institutions as important knowledge resources is positive related to their inhouse capabilities of developing product and process innovations. Along this line, the higher the level of technological opportunities, the larger firms' incentive to invest in innovation (R&D) activities are.

The degree to which external knowlegde resources can be adapted depends on *appropriability conditions*. "For example, one firm's feasible advances in technology may be blocked by the property rights of another" (Klevorick et al. 1995, p. 186). Appropriability conditions define the ability of innovators to retain the returns of R&D (Cohen/Levinthal 1989; König/Licht 1995; Levin et al. 1987). The better firms can protect their knowledge from other companies, the higher their incentives for inhouse R&D. By

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[12] Given a lack of data, we can not distinguish between idiosyncratic and generic R&D in which firms can invest inhouse. Therefore, we are not able to estimate the different effects of technological opportunities regarding to the engagement of firms in both kinds of internal R&D separately.

this, scores of factor analysis on firm-specific and law-specific mechanism of protecting internal knowledge (AP_FIRM, AP_LAW) are used (see Appendix A2).[13]

The variables *firm size* (SIZE_), *product diversification* (DIV_PROD), *international sales* (INT_SALE) and *sales expectations* (SALE_EXP) are implemented in the estimations to reflect the importance of order and demand factors, which may explain differences in firms' innovation input and output activities.

The role of firm size in the innovation process is difficult to judge. Following Schumpeter (1942), positive correlation between *absolute* size of a firm and R&D expenditures can be expected. Large firms can benefit from economies of scale in R&D, financing, and production, economies of scope and market power. Otherwise, empirical evidence could be found that the *shares* of R&D is lower for large firms than for small ones (Acs 1999; Acs/Audretsch 1990; Kleinknecht 1996). The innovation effects of demand factors are less ambiguous. It can be assumed that a high degree of diversification (Kamien/Schwartz 1982; Nelson 1959), high export shares of sales (Felder et al. 1996; Wakelin 1998) and high sales expectations (Kleinknecht/Verspagen 1990; Schmookler 1966) will influence the innovation activities of firms' positively *('demand pull hypothesis').*

To measure the influence of *industry-specific conditions*, we implement a variable reflecting the *degree of market concentration* (MARK_CON). 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/Hollenstein, 1996; Crépon/Duget/Kabla, 1996).

Further, *industrial technology levels* are used as independent variables. The innovative behavior of firms is closely linked to the development of an industry along with technology and demand (Cantner/Pyka 2001; DeBresson 1996; Erdmann 1993). At a given time, the technological regime represents the specific environment for firms at the sectoral level.

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[13] Appropriability conditions and R&D spillovers are closely related (Cohen 1995; Griliches 1992). Appropriability problems caused by R&D spillovers may motivate firms 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. We assume that the variables of technological opportunities can be used to measure especially the evidence of R&D spillovers in the innovation process (Cantner/Hanusch/Klepper 2000; Jaffe 1986; Sterlacchini 1994).

These circumstances lead to specific patterns of innovation activities in industries (Audretsch 1997; Malerba/Orsenigo 1993; Pavitt 1984). In particular, firms in industries with high dynamics of technological change are forced to be steadily active in R&D to survive and secure their market competitiveness. Against this background, the sectors of the German manufacturing industry are divided - in line with common OECD classification (OECD 1994, p. 94) - in three technology groups (LOW_IND, MED_IND, HIGH_IND). The variable HIGH_IND is defined as basic group.

3.2. Specification of the Empirical Model and Estimation Methods

The *basic model specification* for explaining the innovation activities x_i of firms in the German manufacturing industry is as follows:

$$x_i = \alpha_1 + \alpha_2 TO\_SCIE_i + \alpha_3 TO\_CUCO_i + \alpha_4 TO\_SUPP_i + \alpha_5 AP_i + \alpha_6 MR_i + \varepsilon_i, \qquad (3)$$

where x_i reflects firms' innovation input and output. TO_SCIE, TO_CUCO and TO_SUPP represent proxies of technological opportunities stemming from scientific institutions, customers/competitors, and suppliers. *AP* stands for firms' appropriability conditions, and *MR* represents market-related determinants, such as firms size, sales expectations, etc.; ε_i is an unobserved, additive error term.

We investigate the effects of science-related technological opportunities on firms' innovation activities under three constellations. In *Model 1*, we measure the impacts of TO_SCIE together with TO_CUCO and TO_SUPP. In *Model 2,* we check the contribution of scientific institutions as external knowledge resources in combination with the variable TO_CUCO. In *Model 3*, the effects of TO_SCIE are investigated together with TO_SUPP.

Depending on the kind of variables, different *estimation methods* are used. By this, two problems arise. On the one hand, the available data for the innovation input variables R&D_EXP_INT and R&D_EMP_INT are censored both at point 0.15 (before logs are taken) to avoid the identification of firms. On the other hand, some innovative firms have not performed any R&D. The problems can solved by using a Tobit model. But we use the *two-step version of the Heckman model* (Heckman 1979) because independent variables in the model specifications can simultaneously determine the probability and intensity of R&D (Cohen/Levin/Mowery 1987). The Heckman model allows us to identify the parameters affecting firms' decision to *participate* in R&D and the *level* of R&D

expenditures. In the case of dichotomous dependent variables (IN_RE_PRD, IN_RE_PRC) we employ the Probit method.

3.3. Innovation Effects of Science-Related Technological Opportunities

The econometrical analysis concentrates on the question if and to which extent technological opportunities stemming from scientific institutions (and other exogenous variables) have significant effects on the innovation input and output activities of firms in the German manufacturing industry. By this, it will be investigated whether science-related resources act as complements or substitutes to firms' inhouse activities.[14] Against the background of the theoretical considerations it can be expected that the adaptation of external knowledge resources from universities and research institutes will encourage (discourage) the innovation input activities of firms if science-related technological opportunities are used as complements (substitutes) for inhouse R&D.

3.3.1. Input Effects

The estimation results for the effects of technological opprtunities stemming from scientific institutions on firms' innovation input activities are summarized in Table 3.

- Insert Table 3 here -

Using the two-step version of the Heckman model, highly significant effects of TO_SCIE on the probability to *participate* in R&D could be found for R&D_EXP_INT and R&D_EMP_INT. A high assessment of scientific knowledge resources increases the probability that firms are engaged in the development of new and improved products (technologies). Further, the estimations indicate stimulating effects of science-related technological opportunities on the *level* of inhouse R&D. The coefficients are always positive, for R&D_EXP_INT highly significant.

In general, the estimations point out that external knowledge resources stemming from scientific institutions are used as *complements* in the German manufacturing industry. The complementarity effect of using science-related technological opportunities dominates. The adaptation of knowledge from universities and research institutes encourages firms' engagement in R&D. These findings are similiar to studies from other countries

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[14] Due to data restrictions we are unable to investigate separately productivity and substitution effects of using external knowledge resources from scientific institutions as discussed theoretically in section 2.

(Bloedon/Stokes 1994; Henderson/Jaffe/Trajtenberg 1998; Mansfield/Lee 1996; Leyden/ Link 1991).

On the other hand, it has to be mentioned that the impact of public R&D on the level of private R&D may differ across industries (David/Hall/Toole 2000; Harabi 1995; Klevorick et al. 1995). In some technology fields the results of scientific research are used as substitutes. For example, Peters/Becker (1998) find substitutive effects of academic research on the inhouse activities of firms in the German automobile supply industry. Specific kind of innovation activities, such as testing and prototype building, are outsourced by German automobile suppliers to university and scientific laboratories, which yields remarkable savings in innovation costs (Peters/Becker 1999). In this case, the extent of cost savings is larger than the stimulating (complementary) impact of academic research on inhouse R&D.

In the model specifications, no significant effects of TO_SUPP as the stock of external knowledge generated by suppliers on firms' R&D engagement could be found. But, the positive sign of the coefficients for R&D_EXP_INT indicates a complementary use of technological opportunities stemming from suppliers. External knowledge resources related to customers and competitors (TO_CUCO) unfold their positive impacts especially on the level of firms' R&D expenditures (at the 0.05 level). The coefficients for TO_CUCO are weakly significant for the probability of R&D investments in human capital (R&D_EMP_INT).

The results for the other independent variables correspond mostly to the theoretically expected signs. *Appropriability conditions* have enhancing effects on firms' R&D engagement. A high degree of appropriability conditions motivates firms in the German manufacturing industry to invest in the development of new and improved products. Mechanisms of protecting knowledge from other companies by law (AP_LAW) affect the participation in R&D and the level of R&D employment positively (at the 0.05 level). Firm-specific strategies (AP_FIRM) increase the probability to participate in R&D significantly (at the 0.01 level).

In addition, negative and highly significant effects of the used *firm size* classifications (SIZE_) on the probability of being engaged in R&D could be found. The probability of investing in R&D is much more lower for small and middle-sized firms than for big firms. The effects of the incurred firm size variables (SIZE_SMA, SIZE_MED) on the level of R&D expenditures are positive, in the most cases significant. These results are conform with studies in other countries (Cohen/Klepper 1996; Evangelista et al. 1997; Kleinknecht 1996). In general, large firms have a higher probability of being engaged in R&D than small firms but - if they participate in R&D - they spend less money compared to their sales in R&D than smaller firms.

Further, high *sales expectations* (SALE_EXP) stimulate the intensity of inhouse R&D (significant at the 0.01 level). A high degree of *product diversification* (DIV_PROD) and *export shares of sales* (INT_SALE) affect the decision of firms in the German manufacturing industry to invest in R&D positively (at the 0.01 level). The effects on the intensity of firms' R&D engagement are also positive but with less significance. These findings support the demand-pull hypothesis (Felder et al. 1996; Kleinknecht/Verspagen 1990; Wakelin 1998).

The effects of industry-specific variables coincides with the theoretically expected signs. The engagement in R&D is positively influenced by the degree of *market concentration* (MARK_CON). Further, the estimations indicate highly significant effects of *industrial technology levels* (LOW_IND, MED_IND). The lower (higher) the technology level of industries, the less (more) intensive the engagement and investment in R&D are.

3.3.2. Output Effects

The same set of explanatory variables as on the innovation input side is used to estimate the output effects of science-related technological opportunities. The estimation (Probit) results regarding to the probability of realizing *new* products (IN_RE_PRD) and *improved* products (IN_RE_PRC) are put together in Table 4.

- Insert Table 4 here -

For technological opportunities stemming from scientific institutions (TO_SCIE), the estimations indicate negative effects on the probability of realizing *new* products (with lack of significance). This result corresponds with the findings of Arvanitis/Hollenstein (1996). They also found negative (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 this finding can be seen in the fact that knowledge from universities and research institutes affect the development of new products more *indirectly* by increasing firms' R&D efficiency and enhancing inhouse technological capacities.

”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, p. 340). A second reason can be seen in the time-lag between the generation of new scientific knowledge and the product introduction to the market (Mansfield 1991; Meyer-Krahmer 1997).

On the other hand, the estimations point out positive and significant effects of TO_SCIE on IN_RE_PRC. High assessment to science-related technological opportunities increases the probability of realizing *improved* products. These findings strengthen the argument that scientific knowledge resources are used as *complements* in the innovation process to save production costs and to improve the quality of existing products.

Looking at the other kind of technological opportunities, the investigations uncover the following remarkable connections: TO_CUCO has positive and highly significant impacts (at the 0.01 level) on IN_RE_PRD. The higher firms rank the importance of technological opportunities stemming from customers and competitors, the higher the probability of realizing *new* products is. The results for TO_SUPP representing external knoweldge resources from suppliers are similiar, but without statistical significance. Further, the effects of TO_CUCO and TO_SUPP on the probability to realize *improved* products (IN_RE_PRC) are negative with lack of significance. Obviously, firms in the German manufacturing industry fall by on the industrial knowledge pool to enhance their inhouse capacities to develop new products by tracking down market needs. One important factor for success in competition is to evaluate future changes in demand and to address customers’ needs (Christensen/Bower 1996).

The findings regarding to the additional independent variables correspond mostly to the theoretically expected signs. The impacts of *appropriability conditions* (AP_) on the innovation output are - with one exception - positive and highly significant. The better firms in the German manufacturing industry can protect their internal knowledge, the higher the probability of realizing product and process innovations is.

The effects of the used *firm size* classifications (SIZE_SMA, SIZE_MED) are negative and mostly highly signifcant. For small and middle-sized firms in the German manufacturing industry the probability of investing in inhouse R&D is much lower than for big firms. These findings strengthen the presumption that larger firms work more sufficiently (efficiently) on the realization of product and process innovations than smaller firms although they invest less money compared to their sales in R&D as shown in section 3.3.1.

However, a high degree of *product diversification* (DIV_PROD) and high *export shares of sales* (INT_SALE) increases the probabilty of realizing new products significantly (at the 0.01 level). Contrary, the effects on INT_SALE on the realization of improved products are negative (without significance). Obviously, firms in the German manufacturing industry have to focus on the development of new products to be competitive on international markets. Additionally, high *sales expectations* (SALE_EXP) have stimulating impacts on IN_RE_PRD and IN_RE_PRC (without significance).

The influence of *market concentration* (MARK_CON) is ambiguous. The probability of realizing new products decreases with market concentration significantly (at the 0.05 level). Otherwise, positive (insignifcant) effects of MARK_CON on the realization of improved products could be found. The reasons for these peculiarities have to be revealed in further research.

Finally, the estimations underline - with one exception - empirical evidence of the *technology level* of industry groups (LOW_IND, MED_IND). In general, the higher the industrial technology level, the greater the probability of realizing product and process innovations is.

4. Concluding Remarks

Innovative firms continuously have to expand and optimize their inhouse R&D potentials by adaptation external resources. The importance of science-related technological opportunities has increased continuously over time because the development of new and improved products depends increasingly on the findings of universities and research institutes.

The aim of the paper was to analyze the innovation effects of technologicalical opportunities stemming from scientific institutions. Against the background of theoretical considerations about the interrelation of innovation and adaptation of external (knowledge) resources, the impacts of science-related technological opportunities – in line with other exogenous variables – on the innovation input and output activities of firms in the German manufacturing industry were empirically investigated. By this, it was analyzed, whether science-related technological opportunities are used as complements or substitutes.

The estimation results for the innovation effects of science-related technological opportunities can be summarized as follows:[15] In the German manufacturing industry, *complementary* relationships between the innovation *input* activities and technological opportunities stemming from scientific institutions exist. The adaptation of science-related knowledge resources has stimulating effects on firms' R&D activities. Inhouse capacities can be expanded with positive impacts on the probability and the level of R&D activities to develop new and improved products.

The empirical findings for the innovation *output* effects are ambigious. On the one hand, empirical evidence for enhancing impacts of technological opportunities stemming from scientific institutions on the realization of *improved* products could be found. This strengthens the assumption that scientific knowledge resources are used as *complements* to improve the quality of existing products and to save production costs. On the other hand, science-related technological opportunities have no enhancing impacts on the probability of realizing *new* products. Obviously, knowledge from universities and research institutes stimulates the development of new products more *indirectly* by increasing inhouse capacities and enhancing R&D efficiency. One reason can be seen in the time-lag between the generation of new scientific knowledge and the product introduction to the market.

Further theoretical and empirical work has to be done to analyze the interdependence between science-related technological opportunities and firms' innovation activities under more intra- and intersectoral aspects. Investigations will also be conducted to specify the relevance of different kind (quality) of scientific knowledge resources and their effects on firms' R&D/innovation activities. By this, the influence of firms' absorptive capacities to use science-related technological opportunities efficiently has to be analyzed in more detail. Finally, the innovation effects of scientific knowledge resources have to be investigated under longitudinal aspects.

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[15] In general, the results for the other independent variables correspond mostly to the theoretically expected signs.

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Table 1: Dependent Variables

Variable	Description	Empirical Measurement	Value (Range)	Mean	Std. Dev.
Innovation Input					
R&D_EXP_INT	R&D expenditures intensity	Logs of R&D expenditures to sales ratio (1992)	Metric	-5.74	2.72
R&D_EMP_INT	R&D employment intensity	Logs of R&D employment to total employment ratio (1992)	Metric	-5.35	3.00
Innovation Output					
IN_RE_PRD	Realization of innovations	Realization of product innovation in 1990-1992	Nominal	0.91	0.28
IN_RE_PRC		Realization of process innovation in 1990-1992	Nominal	0.78	0.41

Table 2: Independent Variables

Variable	Description	Empirical Measurement	Value (Range)	Mean	Std. Dev.
Technological Opportunities					
TO_SCIE	Importance of external knowledge resources	Scientific institutions as knowledge sources (factor scores)	Metric	0.00	1.00
TO_CUCO		Customers and competitors as knowledge sources (factor scores)	Metric	0.00	1.00
TO_SUPP		Suppliers as knowledge sources (factor scores)	Metric	0.00	1.00
Appropriability Conditions					
AP_FIRM	Extent to which inhouse knowledge can be protected from others	Firm-specific mechanism (factor scores)	Metric	0.00	1.00
AP_LAW		Law-specific mechamism (factor scores)	Metric	0.00	1.00
Market-related Variables					
SIZE_SMA	Firm size *(firms with 250 and more employees as basic group)*	1 = up to 49 employess, 0 = otherwise	Nominal	0.31	0.46
SIZE_MED		1 = 50 up to 249 employees, 0 = otherwise	Nominal	0.32	0.47

SALE_EXP	Sales expectations	Expected change of sales in 1993-1995 1 = low up to 5 = very high	Interval (1-5)	3.24	1.09
DIV_PROD	Degree of diversification	Inverse of the sum of squared sales shares for the four major product groups (1992)	Metric	1.53	0.63
INT_SALE	Share of international sales	Foreign sales/whole sales (1992)	Metric	0.20	0.23
MARK_CON	Degree of market concentration	Herfindahl index for industrial sectors (1992)	Metric	0.03	0.05
	Industrial technology levels *(high level sectors as basic group)*				
LOW_IND		Classification of sectors of the German manufacturing industry according to OECD (1994)	Nominal	0.37	0.48
MED_IND			Nominal	0.30	0.46

Table 3: Innovation Input Effects of Science-related Technological Opportunities

Variables	**R&D_EXP_INT**						**R&D_EMP_INT**					
	Particip.	**Level**	**Particip.**	**Level**	**Particip.**	**Level**	**Particip.**	**Level**	**Particip.**	**Level**	**Particip.**	**Level**
	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)
INTERCEPT	0.729***	-4.645***	0.725***	-4.653***	0.713***	-4.661***	0.770***	-4.443***	0.767***	-4.479***	0.752***	-4.465***
	(3.792)	(-9.849)	(3.775)	(-10.151)	(3.717)	(-10.253)	(3.982)	(-13.537)	(3.966)	(-13.591)	(3.899)	(-13.339)
AP_FIRM	0.152***	0.081	0.155***	0.084	0.160***	0.092	0.152***	0.194***	0.155***	0.205***	0.161***	0.202***
	(3.876)	(0.961)	(3.985)	(1.010)	(4.091)	(1.105)	(3.840)	(2.911)	(3.960)	(3.051)	(4.100)	(2.950)
AP_LAW	0.103**	0.038	0.105**	0.041	0.113***	0.049	0.092**	0.107*	0.094**	0.117**	0.104**	0.115**
	(2.422)	(0.583)	(2.473)	(0.638)	(2.683)	(0.756)	(2.157)	(1.918)	(2.209)	(2.089)	(2.458)	(2.003)
SIZE_SMA	-0.857***	0.756*	-0.853***	0.762*	-0.854***	0.747*	-0.894***	0.345	-0.890***	0.347	-0.891***	0.330
	(-8.225)	(1.703)	(-8.218)	(1.781)	(-8.210)	(1.777)	(-8.526)	(1.171)	(-8.518)	(1.180)	(-8.510)	(1.107)
SIZE_MED	-0.326***	0.290*	-0.324***	0.293**	-0.313***	0.302**	-0.347***	0.280**	-0.344***	0.284**	-0.330***	0.283**
	(-3.198)	(1.890)	(-3.179)	(1.964)	(-3.082)	(2.076)	(-3.381)	(2.114)	(-3.361)	(2.144)	(-3.239)	(2.152)
SALE_EXP	0.034	0.162***	0.035	0.164***	0.033	0.163***	0.035	0.165***	0.036	0.171***	0.035	0.166***
	(0.929)	(4.226)	(0.960)	(4.303)	(0.920)	(4.257)	(0.973)	(3.831)	(1.004)	(3.960)	(0.961)	(3.835)
DIV_PROD	0.191***	0.045	0.191***	0.045	0.192***	0.050	0.192***	0.138*	0.193***	0.141*	0.193***	0.142*
	(2.615)	(0.589)	(2.625)	(0.602)	(2.642)	(0.668)	(2.615)	(1.905)	(2.624)	(1.930)	(2.633)	(1.937)
INT_SALE	0.972***	0.651*	0.964***	0.644*	1.000***	0.671*	0.927***	0.813***	0.918***	0.801***	0.962***	0.840***
	(4.811)	(1.652)	(4.793)	(1.692)	(4.969)	(1.742)	(4.584)	(2.851)	(4.562)	(2.814)	(4.774)	(2.862)
MARK_CON	1.608*	1.813	1.576*	1.806	1.667*	1.971	1.578*	1.984	1.544*	1.977	1.642*	2.073
	(1.775)	(1.343)	(1.745)	(1.366)	(1.843)	(1.470)	(1.740)	(1.516)	(1.708)	(1.510)	(1.815)	(1.567)
LOW_IND	-0.680***	-0.953***	-0.680***	-0.954***	-0.684***	-0.972***	-0.673***	-1.189***	-0.673***	-1.200***	-0.678***	-1.204***
	(-6.676)	(-2.836)	(-6.674)	(-2.931)	(-6.728)	(-3.030)	(-6.610)	(-5.342)	(-6.610)	(-5.374)	(-6.662)	(-5.318)
MED_IND	-0.227**	-0.366***	-0.228**	-0.365***	-0.219**	-0.347***	-0.222**	-0.513***	-0.224**	-0.514***	-0.213**	-0.507***
	(-2.169)	(-2.993)	(-2.180)	(-3.029)	(-2.099)	(-2.946)	(-2.121)	(-4.308)	(-2.134)	(-4.290)	(-2.041)	(-4.275)
TO_SCIE	0.135***	0.192***	0.134***	0.192***	0.129***	0.182***	0.142***	0.093	0.142***	0.095	0.135***	0.091
	(3.039)	(2.743)	(3.030)	(2.793)	(2.925)	(2.727)	(3.205)	(1.530)	(3.193)	(1.546)	3.062	(1.495)
TO_CUCO	0.062	0.119**	0.061	0.119**			0.073*	0.055	0.073*	0.056		
	(1.588)	(2.477)	(1.584)	(2.507)			(1.884)	(1.068)	(1.880)	(1.085)		
TO_SUPP	0.018	0.024			0.017	0.025	0.019	0.068			0.018	0.068
	(0.455)	(0.582)			(0.442)	(0.608)	(0.480)	(1.435)			(0.463)	(1.429)
Number of observations	1468	1059	1468	1059	1468	1059	1489	1086	1489	1086	1489	1086
Log likelihood	-698.770	-1676.453	-698.874	-1677.140	-700.027	-1681.402	-695.272	-1882.116	-695.387	-1883.495	-697.043	-1882.792
McFaddens R^2	0.20		0.20		0.20		0.20		0.20		0.20	
Model F-statistics		20.1***		21.6***		20.8***		11.5***		12.2***		12.3***

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

Table 4: Innovation Output Effects of Science-related Technological Opportunities

Variables	**IN_RE_PRD**			**IN_RE_PRC**		
	1	**2**	**3**	**1**	**2**	**3**
	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)
INTERCEPT	1.267***	1.254***	1.223***	0.970***	0.978***	0.975***
	(4.015)	(3.969)	(3.915)	(4.966)	(5.017)	(4.996)
AP_FIRM	0.159***	0.170***	0.181***	0.172***	0.165***	0.168***
	(2.965)	(3.205)	(3.416)	(4.263)	(4.154)	(4.218)
AP_LAW	0.193***	0.196***	0.219***	-0.012	-0.016	-0.017
	(2.844)	(2.907)	(3.270)	(-0.275)	(-0.372)	(-0.378)
SIZE_SMA	-0.586***	-0.573***	-0.573***	-0.666***	-0.677***	-0.665***
	(-3.584)	(-3.513)	(-3.533)	(-6.071)	(-6.198)	(-6.062)
SIZE_MED	-0.220	-0.212	-0.181	-0.527***	-0.543***	-0.531***
	(-1.299)	(-1.253)	(-1.082)	(-5.110)	(-5.196)	(-5.157)
SALE_EXP	0.071	0.071	0.067	0.061	0.059	0.061
	(1.347)	(1.366)	(1.287)	(1.640)	(1.586)	(1.636)
DIV_PROD	0.377***	0.383***	0.377***	0.091	0.090	0.091
	(2.708)	(2.744)	(2.736)	(1.305)	(1.290)	(1.301)
INT_SALE	0.997***	0.970***	1.068***	-0.179	-0.166	-0.190
	(2.777)	(2.712)	(2.995)	(-0.939)	(-0.874)	(-1.000)
MARK_CON	-2.697**	-2.784**	-2.479**	0.837	0.919	0.816
	(-2.172)	(-2.252)	(-2.016)	(0.824)	(0.906)	(0.804)
LOW_IND	-0.170	-0.171	-0.183	0.123	0.122	0.124
	(-1.075)	(-1.087)	(-1.172)	(1.163)	(1.152)	(1.174)
MED_IND	-0.205	-0.207	-0.184	-0.029	-0.026	-0.033
	(-1.264)	(-1.279)	(-1.147)	(-0.292)	(-0.262)	(-0.333)
TO_SCIE	-0.062	-0.065	-0.075	0.100**	0.101**	0.103**
	(-0.926)	(-0.978)	(-1.142)	(2.178)	(2.196)	(2.255)
TO_CUCO	0.148***	0.147***		-0.026	-0.026	
	(2.724)	(2.716)		(-0.642)	(-0.628)	
TO_SUPP	0.064		0.062	-0.043		-0.042
	(1.151)		(1.130)	(-1.057)		(-1.048)
Number of observations	1494	1494	1494	1494	1494	1494
Log likelihood	-283.270	-283.929	-286.936	-656.056	-656.616	-656.262
McFadden R^2	0.17	0.17	0.16	0.07	0.07	0.07

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

Appendix A1: External Knowledge Sources - Factor scores

	Factor TO_SCIE	**Factor TO_SUPP**	**Factor TO_CUCO**
TEC_TI	0.854	0.041	0.042
TEC_UNIV	0.816	0.034	0.022
TEC_AGEN	0.754	0.115	0.059
TEC_RI	0.731	0.059	0.112
TEC_PADI	0.582	0.092	0.218
TEC_JOUR	0.157	0.814	-0.011
TEC_FAIR	-0.006	0.812	0.171
TEC_SUP	0.056	0.484	0.099
TEC_CUST	0.108	0.127	0.817
TEC_COMP	0.139	0.129	0.802

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.80; Bartlett-Test of sphericity: 4348.81

Appendix A2: Firms' appropriability conditions - Factor scores

	Factor AP_LAW	**Factor AP_FIRM**
AP_PA_PR	0.820	0.032
AP_PA_PZ	0.814	0.147
AP_CO_PZ	0.788	0.165
AP_CO_PR	0.751	0.046
AP_DE_PZ	0.093	0.741
AP_LE_PZ	0.224	0.711
AP_LO_PZ	-0.047	0.702
AP_LO_PR	-0.046	0.618
AP_DE_PR	0.048	0.614
AP_SE_PZ	0.397	0.587
AP_LE_PR	0.299	0.546
AP_SE_PR	0.367	0.502

Kaiser-Meyer-Olkin measure of sampling adequacy: 0.67; Bartlett-Test of sphericity: 8829.78