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Evaluation of the Role of Universities in the Innovation Process

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Abstract

The aim of the paper is to evaluate the role of universities in the innovation process. Against the background of theoretical considerations about the interrelation of innovation and the adaptation of external resources, the effects of university-based (knowledge) resources – together with other exogenous variables - on the innovation input and output of firms in the German manufacturing industry are empirically investigated and evaluated.

The estimation results on the innovation input side can be summarized as follows: High assessments to university-based resources and joint R&D with universities increase the probability that firms are engaged in the development of new products and technologies. Further, the estimations point out stimulating effects of science-related resources on the level of in-house R&D. In general, resources stemming from universities are used as complements in the German manufacturing industry. In-house capacities can be expanded with positive impacts on the probability and the level of R&D activities

The estimation results for the innovation output side are ambiguous: On the one hand, empirical evidence of enhancing impacts of resources stemming from universities on the realization of process innovations has been found. This strengthens the assumption that science-related resources are used to optimize production processes and to save production costs. On the other hand, external resources from the academic sphere have no stimulating effects on the probability of realizing product innovations. University-based resources stimulate the development of new products more indirectly by increasing in-house capacities and enhancing R&D efficiency. But finally, the empirical analysis point out positive impacts of joint R&D with universities on the realization of product innovations. Obviously, collaboration in R&D with universities offer possibilities of efficient knowledge transfer, resource exchange and organizational learning.

Key words: Innovation Activities, Universities, Scientific Institutions, Manufacturing Industry

JEL classification: O31, I20, L20, L60

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1. Introduction

The role of universities in the innovation process has increased continuously over time because the development of new products or technologies depends increasingly on the findings of university (scientific) research[1] (Martin/Nightingale 2000; Narin/ Hamilton/Olivastro 1997; Rosenberg/Nelson 1994; Tijssen 2002). 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 university research (Gibbons et al. 1994; Mansfield 1995; Nelson/Wolff 1997). But also technologies in mass production sectors, such as chemicals and machinery, have reached development levels requiring a specific degree of optimizing internal capacities through external resources stemming from universities (Faulkner/Senker 1994; Grupp 1996; Klevorick et al. 1995).

For the United States of America, the role of universities in the innovation process has been empirically investigated in several studies.[2] Jaffe (1989) delivers path breaking empirical proof of stimulating effects of university research 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 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.

Klevorick et al. (1995) find that the results of university research 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. Mansfield (1991) finds that after all, 11 per cent of all product innovations, and 9 per cent of all process innovations developed in research intensive industries (drugs, metals, information processing, etc.) in the US in 1975 to 1985 could not have been realized without the respective results from university research.

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[1] University research and academic research are used synonymously.

For Germany, the importance of universities for the development of new products and technologies has been subjected to less empirical investigations 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 university research in specific technology fields (Beise/Stahl 1999; Grupp 1992; Peters/Becker 1998; Wagner 1987), the role of universities in the technology transfer in particular 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 the paper is to evaluate the role of universities in the innovation process for firms in the German manufacturing industry from a *broader perspective*. In doing so, the issue is novel mainly in two points: First, analysis concentrates on the impacts both on the innovation input and output side. Second, investigations focus on the question of whether internal R&D and external resources stemming from university research 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 the adaptation of external resources from more *theoretical* aspects. Section 3 describes data set, variables used and estimation methods. In section 4, the results of the *empirical* analysis on the impacts of resources associated with universities on the innovation input and output activities of firms in the German manufacturing sector are presented and discussed. Section 5 contains a summary of the main findings.

2. Theoretical Considerations about Innovation Process and Universities as External Resources

The innovation activities of firms depend on the interaction of internal (in-house) R&D and the extent to which external resources can be adapted and implemented for own purposes (Flaig/Stadler 1998; Kleinknecht 1996; Martin 1994). In this way, firms have to decide on

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

the most efficient way to augment their technological capabilities[3] either through in-house efforts or external sourcing.

The *use of external resources* changes the characteristics of factor inputs required for innovations. For the recipients, the utilization of resources from outside leads to an improved quality of the factor inputs. Depending on the absorptive capacities,[4] firms can expand their capabilities for developing product and process innovations which can increase the probability of being successful in R&D (Cohen/Levinthal 1989; Klevorick et al. 1995; Smith/Barfield 1996). But this means that firms become more dependent on the know-how of other companies and institutions (Arora/Gambardella 1990; Feldman 1993; Geuna et al. 2003; Leyden/Link 1999).

External resources stemming from *universities* are a fraction of the pool of technological opportunities each firm or industry is faced with.[5] Such resources are of major interest for innovative firms 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 product and process innovations 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. The bottom line is, as scientific knowledge increases, the cost of successfully undertaking any given science-based

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3 In general, *technological capabilities* can be defined as the ability to allocate the resources available within a firm in such a way that competitive products will be developed and produced (Cantwell 1994; Cohen/Levinthal 1990; Teece/Pisano 1994).

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 in-house R&D in order to understand and implement the results of externally performed R&D (Arora/Gambardella 1994; Cantner/Pyka 1998; Veugelers 1997).

5 *Technological opportunities* define the total amount of the currently existing and exploitable external resources for firms (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. 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).

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; 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 external resources form universities theoretically in more detail, we make *two basic assumptions*:

a.) To develop innovations, firm *i* has to invest in idiosyncratic and generic R&D. Whereas *idiosyncratic* R&D R_i^{id} focuses on the generation of firm-specific knowledge, *generic* R&D R_i^{ge} produces information having more the character of a public good (Nelson 1992). New generic information can spill over to other parties.[6]

b.) External resources from universities ER_i_UNI can be a substitute for *generic* in-house R&D (R_i^{ge}).

Against this background, the innovation effects induced by technological opportunities stemming from universities may occur in two specific ways (Becker 1996; Brooks 1994; Hoppe/Pfähler 2001; Pavitt 1991). First, the adaptation of such resources can lead to an extension of firms' capabilities for developing new products and technologies. This becomes evident in an increase of technological know-how and improved skills *(innovation input side)*. Second, the implementation of science-related resources can raise the probability of realizing innovations *(innovation output side)*.

Looking at the *innovation input side*, it has to been mentioned that basic research on their own can be more expensive and less effective for firms than funding university research to realize an innovation. In this way, the decision to use external resources from universities as complements or substitutes for own generic R&D depends on the costs of in-house R&D $c(R_i^{ge})$ and on the costs to implement external resources $c(ER_i\_UNI)$:

- If $c(ER_i\_UNI) \geq c(R_i^{ge^*})$ there will be *no* motivation for firm *i* to implement university resources. 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.

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

- The adaptation of ERi_UNI will be a profit enhancing strategy, if the costs of external resources are lower than the production of generic knowledge in-house: c(ERi_UNI)<c($R_i^{ge^*}$).
- If generic R&D information produced outside has the character of 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, $c_i^{**} = c(R_i^{id^{**}}) + c(ER_i\_UNI^{**})$.

If firms *substitute* their generic part of in-house R&D *up to the level* of generic R&D done formerly in-house *($ER_i\_UNI \leq R_i^{ge^*}$)* 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 driven down to *$c(R_i^{ge^*})=0$*, whereas the amount of idiosyncratic R&D investments *$c(R_i^{id^*})$* cannot be higher than formerly with in-house activities in generic R&D.

Only if firms decide to utilize *more* generic knowledge stemming from universities than they had formerly generated in-house *($ER_i\_UNI > R_i^{ge^*}$)* 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 of *complementarity* use 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 *ER_i_UNI* is small (high) the entire R&D costs can be lower (higher) in the case of using scientific resources than formerly with generic R&D activities done in-house. 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 impacts of external resources stemming from universities on *firms' innovation output* w_i - indicated by the realization of new products or technologies - seem to be theoretically more precise to interpret. The relationship can be expressed by

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

with the following conditions:

$$\partial w_i / \partial R_i^{id} > 0,\ \partial w_i / \partial R_i^{ge} > 0,\ \partial w_i / ER_i\_UNI > 0, \tag{1'}$$
$$\partial^2 w_i / \partial R_i^{id^2} \gtrless 0,\ \partial^2 w_i / \partial R_i^{ge^2} \gtrless 0,\ \partial w^2{}_i / \partial ER_i^2\_UNI > 0,$$
$$\partial^2 w_i / \partial R_i^{id} \partial R_i^{ge} > 0,\ \partial^2 w_i / \partial R_i^{id} \partial ER_i\_UNI > 0,$$

$$\partial^2 w_i / \partial R_i^{ge} \partial ER_i\_UNI \geq 0 .^7$$

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' in-house R&D. The same conditions apply for the impacts of university-based resources on w_i. Thus, given the level of in-house R&D, an extension of usable ER_i_UNI has stimulating effects on firms' innovation output. For example, using new materials or information technologies enables advances in the innovation process directly.

3. Data Set, Variables and Estimation Methods

At the beginning, information about data set and variables used in the empirical analysis is given. Then, the specification of the empirical model and the estimation methods to evaluate the role of universities for firms in the German manufacturing industry are described.

3.1. Data Set and Variables

For the empirical analysis, data from the first wave of the Mannheim Innovation Panel *(MIP)* conducted in the German manufacturing industry are used.[8] More than 2800 firms participated in this survey completing a questionnaire about their innovation activities for the period of 1990-1992.[9]

In our investigations, analysis focuses on *innovative* firms defined as companies which have introduced new or improved products to the market in the years 1990-1992 or have intended to do so in the period of 1993-1995. In this way, 1584 firms are included in the empirical analysis.[10]

The data set defines the frame for the selection and specification of the variables in the econometric estimations. The dependent variables capture the innovation behaviour of

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[7] If firms' own generic R&D and university-related resources are *(perfect) substitutes*, no productivity effects can exist between R_i^{ge} and ER_i_UNI ($(\partial^2 w_i / \partial R_i^{ge} \partial ER_i\_UNI = 0$).

[8] We thank the Center of European Economic Research (ZEW) for the permission to use this data set.

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

[10] Model specifications for *all* firms also have been tested. In these regressions no basic differences related to the influences of the independent variables on firms' innovation input and output have been found. Further, the data set has been splitted 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.

firms in the German manufacturing industry. The *innovation input* variables measure – as described in Table 1 in detail - the intensity of firms' in-house activities for developing product and process innovations.

- INSERT TABLE 1 HERE -

We distinguish between *R&D expenditure intensity* (R&D_EXP_INT),[11] 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.[12] The log of the two intensities are computed because of problems with non-normal distributions. Firms' *innovation output* is measured by dummy variables indicating by the realization of product innovations (IN_RE_PROD) and process innovations (IN_RE_PROC) in the period 1990-1992.

The independent variables are listed in Table 2. To capture the innovation effects of *external resources from universities*, three variables are instrumented in the empirical analysis.

- INSERT TABLE 2 HERE -

First, the scores generated by a factor analysis of ten external knowledge sources are employed.[13] According to this, we distinguish *universities together with research institutions* (ER_UNI_T), competitors/customers (ER_CUCO), and suppliers (ER_SUPP) as knowledge sources. Second, in the estimations a variable reflecting *separately* the role of universities as knowledge sources (ER_UNI_S) is used. We assume that the degree to which firms rate universities as important external resources is positive related to their in-house capabilities for developing product and process innovations (Arvanitis/Hollenstein 1994; Gambardella 1992; Levin/Reiss 1988).

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[11] R&D expenditures are the main fraction of firms' innovation engagement. Innovation expenditures also include investment in product design, trial production, purchase of patents and licenses, etc. In regressions, not reported here, similar results for innovation expenditures to sales ratio (INNO_INT) have been found.

[12] Given a lack of data, it was not possible to distinguish between idiosyncratic and generic R&D in which firms can invest in-house.

[13] In the first wave of the Mannheim Innovation Panel firms were asked to rate on a five-point scale the importance of external knowledge sources for their innovation activities in the years 1990-1992.

Third, the empirical evidence of *R&D cooperation with universities* as a direct form of collaboration between academic research and firms will be checked.[14] The variable ER_UNI_COOP is used to identify firms involved in such cooperation. Members of inter-organizational arrangements in R&D are defined as firms taking part in joint R&D with universities. Bivariate analysis indicate close correlation between regularity of in-house R&D and involvement in R&D cooperation. Therefore, it can be assumed that firms collaborating with universities have been involved in R&D cooperation in the years before.

We use several control variables to explain the innovation activities of firms in the German manufacturing industry.[15] Variables related to *appropriability conditions* (APPR_)[16] are employed because the more firms can secure their knowledge against others and retain the returns of their R&D, the higher the incentives for R&D are (Cohen/Levinthal 1989; König/Licht 1995; Levin et al. 1987). We use scores of factor analysis on firm-specific (APPR_F) and law-specific (APPR_L) mechanism of protecting internal knowledge.

The variables firm size (SIZE_)[17], degree of product diversification (PROD_DIV) and intensity of international sales (INTERNAT) capture the influence of order and demand in the innovation process. The role of *firm size* is a priori difficult to assess. Following Schumpeter (1942), a 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 and production. Otherwise, empirical evidence has been found that the share of R&D in sales of large firms is lower than that of small firms (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 *product diversification* (Kamien/Schwartz 1982; Nelson 1959) and high *export*

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[14] To general aspects of joint R&D between universities (public research) and firms (industry) see: Beise/Stahl 1999; Fritsch/Schwirten 1999; Hall/Link/Scott 2000; Schartinger et al. 2002.

[15] In empirical studies working with the first wave of the Mannheim Innovation Panel, 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, mostly similar patterns as reported in section 4 have been found.

[16] Appropriability conditions and R&D spillovers are closely related (Cohen et al. 2002; Griliches 1992). Appropriability problems caused by R&D spillovers may motivate firms to underinvest in R&D because they cannot completely internalize the benefit from their private engagement for developing innovations. In general, the higher (lower) the appropriability conditions of firms are, the less (more) R&D spillovers will occur.

[17] The variable SIZE_BIG is defined as basic group.

shares of sales (Felder et al. 1996; Wakelin 1998) will influence the innovation activities of firms positively *('demand pull hypothesis')*.

The influence of *competitive conditions* is captured by a variable on the *degree of market concentration* (HERFIN). Empirical studies indicate positive effects of market (industrial) concentration on firms' R&D intensity (Geroski 1994; Martin 1994; Vossen 1999). Further, *industrial technology levels* are used as independent variables. The innovation behaviour of firms is closely linked to sectoral developments along with technology and demand (Audretsch 1997; Malerba/Orsenigo 1993; Souitaris 2002). In particular, firms in industries with high dynamics of technological change are forced to be constantly active in R&D to survive and secure their market competitiveness. Against this background, the sectors of the German manufacturing industry are divided – according to the common OECD classification (OECD 1994, p. 94) - in three technology groups (LOW_GROUP, MED_GROUP, HIGH_GROUP). The variable HIGH_GROUP 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:

$$x_i = \alpha_1 + \alpha_2 ER_i\_UNI\_ + \alpha_3 ER_i\_CUCO + \alpha_4 ER_i\_SUPP + \alpha_5 APPR_i\_ + \alpha_6 MR_i + \varepsilon_i, \quad (2)$$

where x_i captures firms' innovation input and output. $ER_i\_UNI\_$, ER_i_CUCO and ER_i_SUPP represent proxies of external (knowledge) resources stemming from universities (and research institutions), customers/competitors, and suppliers. $APPR_i\_$ stands for firms' appropriability conditions, and MR_i represents market-related determinants, such as firm size, export shares of sales, etc.; ε_i is an unobserved, additive error term.

Depending on the kind of variables, adequate *estimation methods* have to be used. In our case, two problems are important. On the one hand, the available data for the innovation input variables R&D_EXP_INT and R&D_EMP_INT are censored in the upper tail of the distributions both at point 0.15 (before logs are taken) to prevent identification of individual firms. On the other hand, some firms did not perform any R&D as well as had no R&D expenditures. Accepting a misspecification of the model, the problem can be solved by using a Tobit model with censoring in both tails of the distributions. Possible misspecification may be attributed to the fact that independent variables can simultaneously determine the probability as well as the expenditures of innovation activities (Cohen/Levin/Mowery 1987; Greene 1997). Therefore, we use *the two-step version of the Heckman method* (Heckman 1979). This method allows the identification of the parameters affecting firms' decision to *participate* in R&D and the *level* of R&D expenditures. In the case of the dichotomous dependent variables (IN_RE_PROD, IN_RE_PROC) we employ the Probit method (Greene 1997; Ronning 1991).

The estimation strategy is as follows: In *Model 1*, we test the effects of universities as external knowledge sources together with other research institutions on firms' innovation input and output (ER_UNI_T). In *Model 2,* we check the contribution of universities separately as information sources (ER_UNIV_S). In *Model 3*, we incure the dummy variable ER_UNI_COOP to measure the effects of joint R&D on the realization of product and process innovations.

The model specifications are estimated using the Maximum Likelihood method and the asymptotic covariance matrices by the negative inverse Hessian. When problems of heteroscedasticity arise, the standard deviations of the estimated parameters are corrected. In all estimations, industry effects are controlled. .

4. Results of the Empirical Analysis

In the following, the empirical findings on the importance of external (knowledge) resources associated with universities for firms in the German manufacturing industry[18] are presented and evaluated. Before we point out the econometric results, descriptive information about the empirical evidence of universities as innovation resource is given.

4.1. Evidence of Universities as External Knowledge Sources

On the first wave of the Mannheim Innovation Panel firms were asked to rate on a five-point scale the importance of several external knowledge sources for their innovation activities. As shown in Table 3, customers were rated as the most important sources for firms in the German manufacturing sector. Fairs and exhibitions, journals and conferences were also ranked as very important external resources. Universities/applied universities

[18] The econometric investigations are focused on the secondary sector because more than 90 per cent of the entire R&D investments in Germany are performed by firms in these industries (Bundesministerium für Bildung und Forschung 2001).

were ranked at a medium level, whereas the contributions of other scientific sources (e.g. industry-financed research and technical institutes) were rated on a lower level.

- INSERT TABLE 3 HERE -

Firms use information from customers, fairs and exhibitions as well as from journals and conferences to introduce new and improved products successfully 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). Thus, knowledge from universities and other scientific information seem to be less important for industrial innovations, which apparently use more market-related information than new scientific findings.

Firms were also asked whether they had formed R&D cooperation with other parties. 37.2 per cent had developed new products or technologies together with firms or other institutions. The various partners in the year 1992 are listed in Table 4.

- INSERT TABLE 4 HERE -

Although firms ranked the contribution of knowledge from universities as of moderate size, most of the innovative firms in the German manufacturing industry have been engaged in joint R&D with universities/applied universities (22 per cent). Private-financed research institutions as cooperation partners are much less important for firms than universities or other public-financed organizations.

4.2. Effects on the Innovation Input Side

The estimation results for the effects of university-based external (knowledge) resources on firms' innovation input are summarized in Table 5.

- INSERT TABLE 5 HERE -

Using the two-step version of the Heckman method, highly significant effects of ER_UNI_T, ER_UNI_S and ER_UNI_COOP (at the 0.01 level) on the probability of *participating* in R&D has been found for R&D_EXP_INT and R&D_EMP_INT. High assessments to scientific/university knowledge sources and joint R&D with universities increase the probability that firms are engaged in the development of innovations. Further, the estimations indicate stimulating effects of external resources stemming from universities on the *level* of in-house R&D. The coefficients are always positive and - with one exception (ER_UNI_COOP) - highly significant.

In general, the empirical investigations underline that external resources stemming from universities are used as *complements.* The adaptation of such resources encourages the R&D intensities of German firms. In-house capacities can be expanded with positive effects on firms' activities for developing new products and technologies.[19] In this context, Nelson/Wolff (1997) gives empirical support on the level of certain lines of US business that the outcome of science can be regarded as pure opportunity enhancing.

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. The extent of cost savings is larger than the stimulating (complementary) impact of academic research on in-house R&D. For example, Peters/Becker (1998) found substitutive effects of academic research on the in-house activities of firms in the German automobile supply industry. Specific kind of innovation activities, such as testing and prototype building, are outsourced by suppliers to university and scientific laboratories, which yields remarkable savings in innovation costs (see also Peters/Becker 1999).

In the model specifications, no significant effects of ER_SUPP as the stock of external knowledge generated by suppliers on firms' R&D intensity have been found. But, the positive signs of the coefficient indicate a complementary use of technological opportunities stemming from suppliers. External knowledge sources related to customers and competitors (ER_CUCO) unfold their positive impacts especially on the level of firms' R&D expenditures (at the 0.05 level). The coefficients for ER_CUCO are weakly significant for the probability of R&D investments in human capital (R&D_EMP_INT).

The results for the other control variables correspond mostly to the theoretically expected signs. A high *degree of appropriability* motivates firms in the German manufacturing industry to invest more in the development of new products and technologies. Mechanisms of protecting knowledge from other companies by law (APPR_L) affect the participation in R&D and the level of R&D employment positively (at the 0.05 level). Firm-specific strategies (APPR_F) increase the probability of participating in R&D significantly (at the 0.01 level).

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[19] These findings are similar to studies from other countries (Bloedon/Stokes 1994; Henderson/Jaffe/Trajtenberg 1998; Mansfield/Lee 1996; Leyden/ Link 1991).

In addition, negative and highly significant effects of the used *firm size* classification (SIZE_) on the probability of being engaged in R&D have been found. The likelihood of investing in R&D is much lower for small and middle-sized firms than for big firms. The effects of the incurred firm size variables on the level of R&D expenditures are positive, in the most cases significant. In general, large firms have a higher probability of being active in R&D than small firms but - if they participate in R&D - they spend less money relative to their sales in R&D than smaller firms.[20]

Further, a high degree of *product diversification* (PROD_DIV) and *export shares of sales* (INTERNAT) affect the decisions of firms in the German manufacturing industry to invest in R&D positively (at the 0.01 level). The effects on the level of firms' R&D are positive too, supporting the demand-pull hypothesis. The impacts of *competitive conditions* coincide with the theoretically expected sign. Firms' R&D is positively influenced by the degree of market concentration (HERFIN). Finally, the estimations indicate highly significant effects of *industrial technology levels* (_GROUP). The lower (higher) the level of industries, the less (more) intensive the R&D activities are.

4.3. Effects on the Innovation Output Side

To estimate the output effects of external resources stemming from universities the same set of explanatory variables as on the innovation input side is used. The estimation (Probit) results regarding to the probability of realizing product innovations (IN_RE_PROD) and process innovations (IN_RE_PROC) are put together in Table 6.

- INSERT TABLE 6 HERE -

Surprisingly, we found no stimulating effect of external knowledge sources from universities separately (ER_UNI_S) and together with other research institutions (ER_UNI_T) on the probability of developing *product* innovations. For both proxies, the coefficients are negative (with lack of significance). These results correspond with the findings of Arvanitis/Hollenstein (1996). They also found negative effects of technological opportunities stemming from scientific knowledge sources on the sales shares of new products in the case of Swiss manufacturing firms.

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[20] These results are conform with studies in other countries (Cohen/Klepper 1996; Evangelista et al. 1997; Kleinknecht 1996).

One reason that explains these findings can be seen in the fact that knowledge from universities, research institutions, etc. affects the development of product innovations more *indirectly* by increasing firms' R&D efficiency and enhancing in-house 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 (Cohen et al. 1998; Mansfield 1991; Meyer-Krahmer 1999).

Similar to the input-related estimations, the empirical analysis point out positive impacts of ER_UNI_COOP on IN_RE_PROD. R&D cooperation with universities increase the probability of realizing product innovations. Obviously, collaboration in R&D with universities offers possibilities of efficient knowledge transfer, resource exchange and organizational learning.

Further, the estimations indicate positive and significant effects of ER_UNI_T on IN_RE_PROC (at the 0.05 level). High assessments of universities and research institutions as knowledge sources increase the probability of realizing *process* innovations in the German manufacturing industry. It is remarkable that universities separately as information sources (ER_UNI_S) do not have statistical relevant impacts on the innovation output. On the other side, the estimations show clear evidence and statistical significance (at the 0.01 level) for the important role of R&D cooperation with universities (ER_UNI_COOP) to realize new technologies. The increasing dynamic of technical progress, the growing complexity of technology and the expanding stress of competition strengthen the necessity of collaboration with universities to reduce productions costs and to improve production technologies.

Looking at the other kind of external resources, the investigations reveal the following noteworthy points: ER_CUCO has positive and highly significant impacts (at the 0.05 level) on IN_RE_PROD. The higher firms rank the importance of customers and competitors, the higher the probability of realizing product innovations is. The results for ER_SUPP representing external knowledge sources from suppliers are similar, but with lack of statistical significance. Further, the effects of ER_CUCO and ER_SUPP on the probability of realizing process innovations (IN_RE_PROC) are negative. Obviously, firms in the German manufacturing industry fall by on the industrial knowledge pool to enhance their in-house capacities to develop new technologies by tracking down market needs.

The findings for the additional control variables correspond mostly to the theoretically expected signs. *Appropriability conditions* (APPR_) affect the innovation output positive with mostly high significance. The effects of the used *firm size* classifications (SIZE_) are negative and mostly highly significant. For small and middle-sized firms in the German manufacturing industry the probability of investing in in-house 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 relative to their sales in R&D as shown in section 4.2.

However, a high degree of *product diversification* (PROD_DIV) and high *export shares of sales* increase the probability of realizing new technologies significantly. In contrast, the effects of INTERNAT on the realization of new technologies are negative (without significance). Obviously, firms in the German manufacturing industry have to focus more on the development of product innovations to be competitive on international markets. Finally, the influence of *market concentration* (HERFIN) is ambiguous: The probability of realizing product innovations decreases with market concentration significantly (at the 0.05 level). Otherwise, positive (insignificant) effects of HERFIN on the realization of process innovations have been found. The reasons for these peculiarities have to be revealed in further research.

5. Concluding Remarks

Innovative firms continuously have to expand and optimize their in-house R&D capacities by using external resources. The importance of university-based resources has increased continuously over time because the development of new products and technologies depends increasingly on the findings of scientific research.

The aim of the paper was to evaluate the role of universities in the innovation process. Against the background of theoretical considerations about the interrelation of innovation and the adaptation of external resources, the effects of university-based (knowledge) resources – together with other exogenous variables - on the innovation input and output of firms in the German manufacturing industry are empirically were analyzed and evaluated.

The estimation results on the innovation input side can be summarized as follows: High assessments to university (scientific) knowledge sources and joint R&D with universities increase the *probability* that firms are engaged in the development of new products and technologies. Further, the estimations point out stimulating effects of science-related resources on the *level* of in-house R&D. In general, external resources stemming from universities are used as *complement*s in the German manufacturing industry. In-house capacities can be expanded with positive impacts on firms' commitment for developing new products and technologies.

The estimation results on the innovation output side are ambiguous: On the one hand, empirical evidence of enhancing impacts of resources stemming from universities on the realization of process innovations has been found. This strengthens the assumption that science-related resources are used to optimize production processes and to save production costs. On the other hand, external resources from the academic sphere have no stimulating effects on the probability of realizing product innovations (negative signs). University (scientific) resources stimulate the development of new products more indirectly by increasing in-house 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. Finally, the empirical analysis point out positive impacts of joint R&D with universities on the realization of product innovations. Obviously, collaboration in R&D with universities offer possibilities of efficient knowledge transfer, resource exchange and organizational learning.

What are the (political) implications of the empirical results? The mains points - reflecting the discussion about the increasing role of universities in the development of innovations and their contribution to solve the economic challenges in a fast-changing global world - can be formulated as follows:[21]

- The motivation of members of universities to cooperate with firms in the industrial and welfare sector has to been more stimulated through financial incentives ('promotion of public-private partnerships').
- The research productivity of universities must evaluate more systematically with financial consequences ('benchmarking industry-science relationships').

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[21] To these points in detail see: Adams/Griliches 2000; Dierkes/Merkens 2002; Etzkowitz/Leydesdorff 1997; Meyer-Krahmer/Kulicke 2002; Popp/Stahlberg 2002; Priest et al. 2002; Schmoch/Licht/Reinhard 2000.

- The (knowledge) transfer between universities and firms has to been organized more flexible across discipline boundaries and more focused on central issues to master the future challenges (‘efficient management and organization of joint R&D’).
- Strategies of successful R&D cooperation and innovation networks between universities and firms have to been more analyzed and evaluated (‘best practices in transfer of science and technology’).
- The motivation of members of universities to found a new firm to develop mew products and technologies has to been stimulated efficiently through financial, organizational and technical support (‘promotion of spin-offs from universities).

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Table 1: Dependent Variables

Variable	**Description**	**Empirical Measurement**	**Value (Range)**
R&D_EXP_INT	R&D expenditures intensity	Logs of R&D expenditures to sales ratio	Metric
R&D_EMP_INT	R&D employment intensity	Logs of R&D employment to total employment ratio	Metric
	Realization of innovations		
IN_RE_PROD		Realization of product innovation in 1990-1992	Nominal
IN_RE_PROC		Realization of process innovation in 1990-1992	Nominal

Table 2: Independent Variables

Variable	**Description**	**Empirical Measurement**	**Value (Range)**
	Importance of external (knowledge) resources		
ER_UNI_T		Universities together with other research institutions as external resource (factor scores)	Metric
ER_UNI_S		Universities as single external resource	Ordinal
ER_UNI_COOP		Joint R&D with universities	Nominal
ER_SUPP		Suppliers as external resource (factor scores)	Metric
ER_CUCO		Customer/competitors as external resource (factor scores)	Metric
	Appropriability conditions		
APPR_F		Firm-specific mechanism (factor scores)	Metric
APPR_L		Law-specific mechanism (factor scores)	Metric
	Firm size		
SIZE_SMA		1 = up to 49 employees, 0 = otherwise	Nominal
SIZE_MED		1 = 50 up to 249 employees, 0 = otherwise	Nominal
SIZE_BIG		1 = 250 and more employees 0 = otherwise	Nominal
PROD_DIV	Degree of product diversification	Inverse of the sum of squared sales shares for the four major product groups	Metric

INTERNAT	Share of international sales	Foreign sales/whole sales	Metric
HERFIN	Degree of market concentration	Herfindahl index for industrial sectors	Metric
	Industrial technology levels		
LOW_GROUP		Classification of sectors of the German manufacturing industry according to OECD (1994)	Nominal
MED_GROUP			Nominal
HIGH_GROUP			Nominal

Table 3: Importance of External (Knowledge) Resources

External (Knowledge) Resources*	Mean	Std. Dev.	Percentage of Firms with Valuation of low importance (1)	Percentage of Firms with Valuation of high importance (4 and 5)
Agencies of technology transfer	1.9	1.11	49.2	11.2
Competitors	3.5	1.19	8.1	56.8
Customers	4.3	0.94	1.9	83.7
Fairs and exhibitions	3.8	1.00	3.3	67.7
Industry-financed research institutions	2.0	1.15	45.3	13.5
Journals and conferences	3.7	0.98	3.0	63.7
Market research, advertising	2.2	1.12	37.2	13.1
Patent disclosures	2.6	1.35	30.4	30.4
Suppliers	3.2	1.22	11.8	47.6
Technical institutes	2.0	1.14	49.3	12.7
Universities/applied universities	2.6	1.33	32.3	29.1

* Multiple answers possible.

Source: First wave of the Mannheim Innovation Panel.

Table 4: R&D Cooperation and Partners

Kinds of Partner*	Percentage of Firms with Joint R&D
Competitors	7.1
Consultants	6.7
Customers	20.5
Private-financed research institutions	7.0
Other public-financed research institutions	12.5
Suppliers	17.2
Universities/applied universities	22.0

* Multiple answers possible.

Source: First wave of the Mannheim Innovation Panel.

Table 5: Innovation Input and External Resources stemming from Universities

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	0.839***	-0.411***	0.564***	-4.417***	0.624***	-4.191***	0.781***	-4.122***	0.595***	-4.123**	0.667***	-3.788***
	(5.378)	(-10.176	(3.177)	(-8.474)	(3.817)	(-8.989)	(5.075)	(-14.906)	(3.321)	(-11.517)	(4.047)	(-14.711)
APPR_F	0.156***	0.895	0.162***	0.103	0.144***	0.109	0.165***	0.223***	0.162***	0.197***	0.146***	0.156***
	(3.967	(1.058)	(4.185)	(1.187)	(3.660)	(1.386)	(4.212)	(3.248)	(4.160)	(2.864)	(3.672)	(2.692)
APPR_L	0.094**	0.361	0.106**	0.064	0.136***	0.890	0.084**	0.117**	0.954**	0.091*	0.126***	0.086*
	(2.229)	(0.590)	(2.574)	(1.011)	(3.296)	(1.241)	(2.013)	(2.101)	(2.317)	(1.657)	(3.047)	(1.650)
SIZE_SMA	-0.860***	0.827*	-0.864***	0.812*	-0.738***	0.829**	-0.939***	0.400	-0.899***	0.509*	-0.772***	0.789***
	(-8.330)	(1.890)	(-8.380)	(1.861)	(-6.932)	(2.225)	(-9.253)	(1.333)	(-8.669)	(1.688)	(-7.192)	(3.555)
SIZE_MED	-0.317***	0.330**	-0.322***	0.308**	-0.257**	0.328***	-0.317***	0.252**	-0.342***	0.357***	-0.277***	0.452***
	(-3.122)	(2.229)	(-3.183)	(2.053)	(-2.457)	(2.648)	(-3.201)	(1.934)	(-3.360)	(2.716)	(-2.626)	(3.993)
PROD_DIV	0.194***	0.040	0.196***	0.047	0.201***	0.320	0.223***	0.134*	0.197***	0.119	0.200**	0.079
	(2.667)	(0.528)	(2.700)	(0.611)	(2.619)	(0.455)	(3.084)	(1.796)	(2.692)	(1.645)	(2.583)	(1.210)
INTERNAT	0.942***	0.615	0.949***	0.625	0.878***	0.569*	0.822***	0.952***	0.906***	0.706**	0.816***	0.489**
	(4.700)	(1.617)	(4.734)	(1.631)	(4.260)	(1.667)	(4.247)	(3.489)	(4.514)	(2.467)	(3.942)	(2.076)
HERFIN	1.493*	.503	1.650*	1.671	1.434	1.685	1.414	2.110	1.635*	1.581	1.435	1.123
	(1.659)	(1.149)	(1.835)	(1.262)	(1.566)	(1.319)	(1.582)	(1.606)	(1.817)	(1.215)	(1.561)	(0.910)
LOW_GROUP	-0.673***	-0.960***	-0.668***	-0.960***	-0.621***	-0.951***	-0.671***	-1.358***	-0.661***	-1.112***	-0.618***	-0.960***
	(-6.635)	(-2.939)	(-6.583)	(-2.986)	(-5.975)	(-3.284)	(-6.724)	(-6.278)	(-6.514)	(-5.035)	(-5.933)	(-5.578)
MED_GROUP	-0.237**	-3.965***	-0.221**	-0.384***	-0.230**	-0.377***	-0.262**	-0.539***	-0.216**	-0.509***	-0.222**	-0.467***
	(-2.278)	(-3.180)	(-2.124)	(-3.122)	(-2.145)	(-3.133)	(-2.557)	(-4.329)	(-2.074)	(-4.277)	(-2.060)	(-4.189)
ER_CUCO	0.063	0.123**	0.560	0.116**	0.783**	0.118**	0.062	0.821	0.067*	0.047	0.092**	0.044
	(1.621)	(2.537)	(1.449)	(2.441)	(1.981)	(2.341)	(1.612)	(1.598)	(1.729)	(0.921)	(2.300)	(0.898)
ER_SUPP	0.166	0.431	0.118	0.392	0.186	0.449	0.190	0.643	0.013	0.073	0.017	0.075
	(0.424)	(1.062)	(0.301)	(0.971)	(0.468)	(1.091)	(0.492)	(1.334)	(0.326)	(1.548)	(0.428)	(1.630)
ER_UNI_T	0.139***	0.199***					0.128***	0.182***				
	(3.148)	(2.791)					(2.970)	(3.049)				
ER_UNI_S			0.104***	0.118**					0.110***	0.104**		
			(3.280)	(2.197)					(3.451)	(2.256)		
ER_UNI_COOP					0.920***	0.353					1.020***	0.399**
					(6.710)	(1.261)					(7.023)	(2.413)
Number of observations	1475	1063	1475	1063	1452	1047	1496	1052	1496	1090	1473	1074
Log likelihood	-703.323	-1694.083	-702.913	-1697.849	-670.616	-1675.803	-727.887	-1300.209	-699.348	-1903.958	-663.767	-1879.464
McFaddens R^2	0.20		0.20		0.22		0.20		0.20		0.23	
Model F-statistics		19.8***		19.7***		18.6***		36.7***		11.1***		11.2***

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

Table 6: Innovation Output and External Resources stemming from Universities

Variables	IN_RE_PROD			IN_RE_PROC		
	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)	Coeff. (t-values)
INTERCEPT	1.553***	1.654***	1.428***	1.161***	1.079***	1.104***
	(5.677)	(5.468)	(5.070)	(7.449)	(5.981)	(6.922)
APPR_F	0.246***	0.236***	0.230***	0.254***	0.260***	0.253***
	(4.803)	(4.674)	(4.512)	(6.523)	(6.759)	(6.563)
APPR_L	0.231***	0.212***	0.190***	0.012	0.281	0.034
	(3.607)	(3.409)	(3.103)	(0.283)	(0.674)	(0.821)
SIZE_SMA	-0.613***	-0.597***	-0.554***	-0.623***	-0.641***	-0.584***
	(-3.734)	(-3.635)	(-3.232)	(-5.755)	(-5.925)	(-5.296)
SIZE_MED	-0.217	-0.206	-0.1867	-0.497***	-0.522***	-0.463***
	(-1.276)	(-1.214)	(-1.058)	(-4.853)	(-5.011)	(-4.478)
PROD_DIV	0.389***	0.381***	0.416***	0.103	0.103	0.078
	(2.771)	(2.730)	(2.864)	(1.457)	(1.469)	(1.103)
INTERNAT	0.823**	0.820**	0.7412**	-0.210	-0.197	-0.228
	(2.412)	(2.380)	(2.116)	(-1.109)	(-1.043)	(-1.178)
HERFIN	-2.548**	-2.664**	-2.761**	0.499	0.602	0.537
	(-2.089)	(-2.197)	(-2.263)	(0.498)	(0.602)	(0.535)
LOW_GROUP	-0.180	-0.179	-0.143	0.130	0.122	0.140
	(-1.156)	(-1.149)	(-0.911)	(1.237)	(1.163)	(1.318)
MED_GROUP	-0.190	-0.198	-0.153	-0.048	-0.038	-0.384
	(-1.174)	(-1.226)	(-0.919)	(-0.474)	(-0.384)	(-0.379)
ER_CUCO	0.114**	0.120**	0.135**	-0.024	-0.030	-0.022
	(2.094)	(2.221)	(2.442)	(-0.603)	(-0.742)	(-0.549)
ER_SUPP	0.039	0.043	0.442	-0.532		-0.058
	(0.705)	(0779)	(0.791)	(-1.328)		(-1.440)
ER_UNI_T	-0.099			0.086**		
	(-1.255)			(1.950)		
ER_UNI_S		-0.376			0.334	
		(-0.818)			(1.035)	
ER_UNI_COOP			0.478**			0.302***
			(2.103)			(2.663)
Number of observations	1584	1584	1559	1527	1527	1500
Log likelihood	-287.555	-288.385	-279.613	-661.623	-662.907	-650.754
McFadden R^2	0.20	0.20	0.21	0.08	0.08	0.08

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