Technological Opportunities, Academic Research, and Innovation Activities in the German Automobile Supply Industry

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February 1998

Abstract

In this paper the importance and the effects of technological opportunities, stemming from academic research, on the innovation activities of firms in the German automobile supply industry are investigated. We observe that the contribution of academic research to firms' innovation activities is less important than the relevance of industrial sources but yet, the most likely partners for formal R&D co-operations are universities. Using measures of suppliers' innovation input and output, we can outline differences in the effects of academic research on suppliers' innovation behavior. Although the proximity to academic research stimulates suppliers' activities in own R&D, the university knowledge substitutes suppliers' investment in R&D and other innovation activities. University co-operations seem to have a positive impact on the improvement of existing rather than on the development of new products or processes. But we can show that the influence of academic research on suppliers' inhouse innovation activities depend on their absorptive capacities.

Key words: Innovation Activities, Technological Opportunities, Academic Research, Absorptive Capacities, Automobile Supply Industry

JEL classification: O31, I20, H40

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Financial support by the research fund of the University of Augsburg (F-423) is gratefully acknowledged. We thank Jürgen Dietz for helpful support.

I. Introduction

In Germany, the development of automobiles belongs to those economic activities - next to the electrical and electronic industry as well as the chemical industry - with the highest R&D levels (Federal Ministry of Education, Science, Research, and Technology 1996). In 1995, more than one fifth of the total R&D expenditures in the private sector was used for the research and development of new automobiles or parts (lines of economics 244), such as motors, tires, electronic components, plastics, etc. A share of 5.9 per cent of R&D expenditures on sales in firms engaged in R&D is much higher in the automobile industry than in the German manufacturing industry as a whole with 3.4 per cent. The same is vaild for the share of R&D employment to total employment (6.0 per cent to 3.8 per cent).[1]

In recent years, the importance of suppliers for the innovation process of automakers has steadily increased (VDA 1996, Wildemann 1993). German automakers (e.g. Audi, BMW, Daimler Benz, VW) have changed their business strategies for developing new automobiles. Most of the R&D, innovation and production activities formerly done in-house are now outsourced to supplier firms. Nowadays, automakers purchase more parts from outside than they produce themselves (Meissner et al. 1994). As a consequence of outsourcing, supplier firms have more responsibility for the development and production of automobile parts (e.g. in the context of designing, R&D, prototyping and testing). On the other hand, the increasing pressure on the production costs in the automobile industry reduces the margin of supplier firms to invest in basic and applied research activities in order to develop new and technologically novel parts. This requires an efficient utilization of the inhouse R&D capacities as well as an improvement of complementary technological knowledge from outside (David 1994). Thus, firms in the automobile supply industry have to increase the use of external sources of new technological knowledge to expand their *technological capacities*. One possibility of replenishing scarce R&D resources is to adapt knowledge generated in *academic institutions* as a part of the total stock of technological opportunities firms can utilize from outside for their own purposes.

As stressed by Rosenberg and Nelson (1994), major innovation impulses, e.g. in modern micro-electronics, are based on academic research, generic technological knowledge and its direct adaptation and utilization in applied industrial research. Also, for the automobile supply industry, the importance of scientific knowledge has grown continuously over time because the development and production of automobile parts depends strongly on the findings and results from academic research. Automakers increasingly rely on external developers closely connected to academic institutions. The reasons for this can been seen in the interdependence of technological progress and scientific research, and the steadily intensified interrelation of fundamental and industrial research (Freeman 1982, Narin and Olivastro 1992).

[1] According to the classification of the level of average R&D intensities done in the *Frascati Manual* (OECD 1994), the automobile industry can therefore add to the *higher valued* technological sectors.

The dependence on scientific verification of technological developments has led to a rising demand for highly qualified personnel (scientists, engineers, technicians, etc.) in the automobile supply industry[2] and for research results from the academic sphere (Peters 1997). This is caused by the increasing importance of multidisciplinarity of R&D activities (Stephan 1996), the growing complexity of innovation processes (Becker 1996), and the increasingly shorter intervals for developing new automobile parts (Clark and Fujimoto 1993).

For the US manufacturing industry, the relevance of academic research in the innovation process, measured by variables regarding innovation input and output, has been investigated thoroughly (Acs et al. 1992, Jaffe 1989, Mansfield 1991). For German industry, however, the importance and effects of acadamic research on industrial innovation activities on both levels are theoretically and empirically less investigated.[3] An exception is the econometric study of Becker and Peters (1997). They have analysed the relevance and impacts of academic research on the innovation investments and innovation output of firms in the German manufacturing sector, using data from the Mannheim Innovation Panel (MIP) for the period of 1990-1992. They found highly significant and stimulating effects of German universities as external sources of technological information on firms' innovation input, even when controlling for industry effects. But influences of scientific-based technological opportunities on the innovation output of firms in the German manufacturing industry were ambiguous. No empirical evidence was found for significant stimulating impact of scientific and university knowledge on the development of new products, but all the more on the development of improved products. In their conclusion, Becker and Peters (1997) assume that the impact of academic research differs in the technology fields used and in the peculiarities of industries as pointed out by Cohen (1995).

The aim of this paper is to analyse the importance and impacts of technological knowledge generated in academic research on the innovation activities in the German automobile supply industry as a *specific* sector with a high level of R&D activities and to compare these results with the findings of Becker and Peters (1997) for the German manufacturing industry on the whole. In the automobile supply industry we observe different technologies in different lines of business for automobile parts, components or systems but all lines of business show almost the same demand structures. Thus, for a given industry we can investigate whether the variation of innovation and R&D activities can be explained by differences in the technological opportunities caused by the adaptation of knowledge generated by academic

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[2] In the time period 1990-1995 the share of highly qualified personnel with academic education has been increased in the automobile industry (West Germany) from 6.2 per cent to 7.9 per cent (Federal Ministry of Education, Science, Research, and Technology 1996).

[3] The existing studies in Germany focus their investigations on *special* aspects of the science-technology-innovation interface, e.g. the importance of academic research in science-based fields of technology (Grupp 1994, 1996), the role of universities in the technology transfer process especially for small and medium-sized firms (Beise et al. 1995, Harhoff and Licht 1996) or the relevance of the regional science and research infrastructure on the formation and location of firms (Harhoff 1995, Nerlinger 1996).

research. In this context, we also examine the influence of differences in suppliers' absorptive capacities because sufficient expertise is required in order to understand and implement external information for their own purposes (Veugelers 1997).

In the following section, basic theoretical considerations are made about the interrelation of technological opportunities, academic research, and inhouse innovation (R&D) activities. In the third section, the role of academic research for the German automobile (supply) industry is discussed, by using descriptive statistics. Thereafter, the data sets at hand are described, and the definitions of the innovation measures are given. In the fifth section, we present the results of several regression equations related to the effects of academic research as an external knowledge source on the innovation input and output of firms in the German automobile supply industry. In the sixth section, we checked some of our estimations for differences in suppliers' capacities to absorb technological information by contractual co-operations with universities. The last section closes with concluding remarks.

II. Theoretical Considerations about Technological Opportunities, Academic Research, and Innovation Activities

It is generally accepted that the level of the innovation activities of firms and/or the technical progress in industries depends on their opportunities to acquire and internalize usable technological (technical) knowledge (Geroski 1990, Harabi 1995, Klevorick et al. 1995). As recent econometric studies show, variances in R&D expenditures and innovation activities can be explained better by differences in the *level of technological opportunities* each firm or industry is faced with rather than by other factors, such as size, market structure, appropriability, etc. (for a survey, see Cohen 1995).

The theoretical concept of technological opportunities differs from this point of view. Within 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 and Levin 1989, p. 1083). In the framework of the evolutionary theory of technical progress, technological opportunities are seen as potentials of new technologies with (sometimes unknown) relationships to other technology fields or as technical advance along a technological trajectory (Coombs 1988, Dosi 1988).

But it's not the aim of this paper to make a contribution to obtain a '...consensus on how to make the concept of technological opportunity precise and empirically operational' (Cohen and Levin 1989, p. 1083). Rather we assume - in line with Cohen 1995, Dosi 1988 and Levin et al. 1987 - that technological opportunities relate to the contribution of *external* (knowledge) sources to firms' innovation activities, and that there are diverse kinds of sources of technological opportunities with varying usefulness not only from industry to industry but also from one firm to the other (Harabi 1995). One way for firms to expand their technological opportunities is to apply external knowledge originating from suppliers, customers and/or competitors. Another possibility is the adaptation of knowledge from sources beside the industrial sector, here in particular from the academic sphere. Scherer (1992, p. 1424) points out that "... the mysterious concept of ‘technological opportunity’ was originally constructed to reflect the richness of the scientific knowledge base tapped by firms". Information from scientific institutions are important sources for firms to expand their technological capacities because of the close interrelation of fundamental academic research and industrial research.

We assume that the degree to which firms use technological information stemming from scientific institutions (universities, technical institutions) is closely correlated with their technological *capacities* to develop new or improved products (Arvanitis and Hollenstein 1994, Harabi 1995). In this line, the adaptation of external knowledge from universities increase firms’ (inhouse) innovation capacities with positive effects on the innovation process. But the importance and usefulness of academic research for firms’ innovation activities differ in the fields of university research. Klevorick et al. (1995, p. 201) distinguish industries that are more strongly influenced by advances in basic research (e.g. drug industry) from those that are much less influenced (e.g. aircraft), and industries with rich technological opportunities (e.g. electronic components) from those which are not (e.g. metal products).

However, before we empirically analyse the effects of the kind and level of technological opportunities, influenced by the adaptation of external knowledge from academic research, on the innovation input and output of firms in the German automobile supply industry empirically, we will present a simple theoretical framework described in more detail by Becker and Peters (1997). Following this framework, we assume that the technological opportunities Ω_i result from the sum of the total appropriability stock of externally accumulated knowledge firm i is faced with:

$$\Omega_i = \Omega(R_i^C, R_i^I, R_i^S), \tag{1}$$

where R_i^C and R_i^I represent the technological opportunities brought forth by competitors and other industries (e.g. suppliers, customers). R_i^S reflects the contribution of scientific knowledge to the technological capacities of firm i. Because the technological opportunities (1) are represented by external information, the marginal effects of increasing the external resources R, with R = R_i^C, R_i^I, R_i^S, on the level of technological opportunities is strictly positive ($\partial\Omega_i / \partial R > 0$) with constant, diminishing, or increasing returns ($\partial^2\Omega_i / (\partial R)^2 \gtreqless 0$), depending on the initial level of firms’ technological capacities.

We assume that the innovation output w_{i} is influenced by the level of technological opportunities Ω_i and firms’ own R&D investments R_{i}:[4]

$$w_i = w(R_i, \Omega_i), \tag{2}$$

[4] 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 definition, technological opportunities are interpreted as an argument contained directly in the production function of innovation w_{i}.

with following conditions:

$$\partial w_i / \partial R_i > 0, \; \partial w_i / \partial \Omega_i > 0, \; \partial^2 w_i / \partial R_i \partial \Omega_i > 0 \qquad (2')$$

$$\partial^2 w_i / (\partial R_i)^2 \gtreqless 0, \; \partial^2 w_i / (\partial \Omega_i)^2 \gtreqless 0.$$

Higher investments in inhouse R&D enlarge firms' innovation output (e.g. improve the quality of own products or reduce the costs of production) with diminishing, constant, or decreasing rates of return, depending on the level of investments. The same conditions remain for the impact of the level of technological opportunities on firms' innovation output w_i. Thus, given the level of own R&D, an expansion of the technological opportunities increases firms' innovation capacities (potentials) and influences the innovation *output*.

Whereas the impacts of using external knowledge (from universities and other scientific institutions) on firms' innovation output seem to be clear, the effects on the innovation *input* (e.g. R&D expenditures) are ambiguous. The decisive question is, how and to which extent an expansion of Ω_i by utilizing external generated knowledge influences the innovation activities of firm *i* on the input side. We concentrate our considerations on technological opportunies resulting from knowledge from the academic sphere: $\Omega = \Omega(R_i^S)$. According to former considerations (Becker and Peters 1997), we distinguish *three* effects of Ω on firms' own (innovation) R&D input: (1) the productivity effect, (2) the absorptive capacity effect, and (3) the substitution effect.

(1) The input effect of the level of technological opportunities on the *marginal return* relates to the argument that the incentive of firm *i* to invest in R&D is positively correlated with the level of technological opportunities. This concept "... corresponds to the function that maps the flow of R&D into increases in the stock of knowledge" but with diminishing returns of inhouse R&D at the margin (Klevorick et al. 1995, p. 188). In this context, higher levels of technological opportunities enhance the marginal effect of inhouse R&D on product quality or cost reduction (as shown in (2')) as well as on firms' profit which stimulate their R&D investments. The productivity of inhouse R&D which maximizes profits is an increasing function of the level of technological opportunities. It is much easier for firms to realize a given (product or process) innovation with inhouse R&D, if the pool of technological opportunities is replenished (Rosenberg 1974).

(2) The effect of the level of technological opportunities on the *absorptive capacity* relates to the technological opportunities usable for firms' inhouse R&D $\tilde{\Omega}_i = \lambda_i \Omega_i$ which depends on firms' ability to adapt external generated knowledge for their own purposes. The parameter λ_i describes the extent to which firm *i* can absorb external generated knowledge and the easiness to which it has access to such resources, with $0 \leq \lambda_i \leq 1$ (Cohen and Levinthal 1989). At $\lambda_i = 1$ the degree of utilization is complete. $\lambda_i = 0$ shows there are no possibilities of utilizing external knowledge.

As Mowery and Rosenberg (1989) stress, firms have to invest in complementary inhouse R&D to understand and implement the results of externally performed R&D and to obtain full access to the research findings of other firms and institutions ($\tilde{\Omega}_i \approx \Omega_i$ or $\lambda_i \approx 1$). Veugelers (1997) finds empirical support for the importance of absorptive capacities to the adaptation of external knowledge in the Flemish manufacturing industry. She identifies significant positive effects of external sourcing on the level of R&D spending, if firms have absorptive capacity established as a full-time staffed R&D department. In this context, university knowledge should require higher absorptive capacities than information from other sources because it is related more to basic than to applied science. As Cohen and Levinthal (1989, p. 589) remark "... basic science is less targeted to the needs and concerns of the firm" which implicates that firms must invest more in their absorptive capacities to assimilate and exploit scientific knowledge.

3) The *substitution* effect refers to the fact that the adaptation and implementation of external resources can reduce firms' innovation expenditures, if external knowledge (Ω_i) can be used as a substitute for own (generic) R&D. This is the case when firms have to invest in idiosyncratic *and* generic R&D to realize an innovation output. To clearify this, we modify the relationship (2) to

$$w_i = w(R_i^{id}, R_i^{ge}, \Omega_i), \tag{3}$$

with the same conditions shown before. Whereas *idiosyncratic* R&D activities (R_i^{id}) primarily create firm-specific knowledge, *generic* R&D activities (R_i^{ge}) produce information which have more the character of a public good (Nelson 1992). New generic information (knowledge) can spill over to other actors without purchasing the right to do so.[5] We argue in line with Harhoff (1996) that investments in idiosyncratic and generic R&D are strategic complements: decreasing (increasing) the level of generic R&D lowers (stimulates) the investment in idiosyncratic R&D ($\partial^2 w_i / \partial R_i^{id} \partial R_i^{ge} > 0$, $\partial^2 w_i / \partial R_i^{id} \partial \Omega_i > 0$).

The adaptation of external (academic) knowledge will be a profit enhancing strategy, if the costs of searching and using externally generated knowledge are lower than the generation of generic knowledge inhouse. As Harhoff (1996) shows, if firms substitute their generic part of own R&D up to the level of generic R&D done formerly inhouse, they will strictly reduce their *whole* R&D cost. Given the efficiency of generic R&D information, the cost of generic R&D will decrease, whereas the amount of idiosyncratic R&D investment can not be higher than formerly with inhouse engagement in generic R&D. Only if firms decide to utilize more generic knowledge from external sources than

[5] R&D spillovers are externalities of R&D activities beyond their primary definition, where not the innovator alone has the benefit, but which can be applied also by other actors for their own innovative activities (Dosi 1988, Eliasson 1996, Griliches 1992). They basically change the characteristics of product factor inputs required for innovations. R&D spillovers between competitors can reduce firms' incentive to invest in R&D because of the inherent appropriability problem (Spence 1984).

they have formerly generated inhouse, the level of idiosyncratic R&D will rise. But it is impossible to make a clear statement about the level of firms' R&D investment on the whole. If the elasticity of idiosyncratic R&D with regard to generic R&D is small (high) the entire R&D costs can be lower (larger) with the utilization of scientific knowledge than formerly with generic R&D done inhouse. Thus, the extent of innovation activities and the level of innovation expenditures can be lower in the case of a high level of technological opportunities than in the case of a low level.

The whole impact of technological opportunities, e.g. stemming from academic research, on the innovation input depends on the strength of the different effects of using external sources of technological knowledge. But it also depends on the interaction of the three effects mentioned. For example, if firms have high (low) absorptive capacities to utilize external knowledge, the influence of technological opportunities on the productivity of their inhouse R&D may also be high (low). It can be assumed that firms with high (low) absorptive capacities have more (less) potentials to use external generated knowledge for own purposes and therefore can implement external knowledge more (less) efficiently inhouse.[6] For increasing efficiency in the utilization of generic R&D, it is also more likely for firms with high absorptive capacities that the substitution effect of technological opportunities is of low importance regarding to the level of R&D spending. Because of the increased efficiency, firms with high absorptive capacities use more external *generic* R&D than formerly done inhouse which enhances the marginal effect of *idiosyncratic* R&D. At least, they will invest more in their innovation activities than other firms.

Summarizing, whereas the adaptation and implementation of technological opportunities stemming from academic research may discourage (substitute) or encourage (complement) firms' innovation/R&D investment, it is more likely that high (low) levels of technological opportunities increase (decrease) the level of firms' innovation output. Within this theoretical framework the importance and effects of academic research on the innovation input and output of firms in the German automobile supply industry will be *empirically* investigated in the following sections.

III. Academic Research and Innovation Activities in the German Automobile Supply Industry

Due to the lack of official data for describing the innovation activities of automobile suppliers and their links to academic sources of external knowledge, we used data derived from two sample surveys conducted in the German automobile industry in the summer of 1995 and in the spring of 1996 (Peters 1997). These samples contain automobile suppliers acting on more than 18 lines of economics (SYPRO four digit) and 30 lines of business.

[6] Gambardella (1992) found empirical support for this assumption in the US drug industry. Firms with higher levels of inhouse R&D implement information of scientific research more effectively than other firms.

The first questionnaire contained data on the innovation activities of automobile suppliers, their technological opportunities, appropriability conditions, and on the kind of linkages to their customers (automakers or other automobile suppliers). Out of an initial sample of 1,306 automobile suppliers, 460 firms returned the questionnaire. After excluding firms in the fields of engineering, consulting and tuning, 401 innovative as well as non-innovative suppliers of automobile parts, components or subsystems remained. An innovative supplier was defined as a firm which has introduced new or improved products or processes in 1993 or 1994. In both of these years 78.0 per cent of the automobile suppliers had successfully introduced new products in their markets, whereas 74.5 per cent had successfully implemented new processes in their firms. In our analysis we included only the 348 innovative suppliers. The probability of realizing new or improved products or processes depends heavily on the size of the firm. Smaller firms with less than 250 employees realized much less innovations than larger firms (Peters 1998). On average, 38 per cent were small firms (less than 250 employees), 23 per cent were medium-sized firms (250-499 employees), and 39 per cent large firms (500 and more employees).

Next, in 1996, all automobile suppliers which had contributed to the initial survey were also asked to indicate the importance of academic research for their innovation activities and the kind of co-operations with universities. 138 innovative automobile suppliers returned the questionnaire, whereas four suppliers in the field of engineering and consulting were excluded.

The Innovation Activity of Automobile Suppliers

Before we turn to the empirical results related to the importance of the academic research to enhance firms' technological opportunities, we give a brief description of the innovation activities of German automobile suppliers in 1994. A more complete description of the sample can be found in Peters (1997). The data clearly illustrate the high level of innovation activities in the German automobile industry. On average, the *R&D-employment intensity* - which relates to the percentage of employees performing R&D tasks within or outside R&D departments (no full time equivalents) - was 5.3 per cent with a maximum value of 30.0 per cent (Figure 1). About 75 per cent of the innovative automobile suppliers in the data set had a formal R&D lab in 1994. One fifth of them invested in basic research, whereas three quarters of the suppliers were active in applied R&D regulary. However, 90 per cent remarked that *inhouse* R&D is neccessary for introducing new products or processes successfully. Solely for foundries, R&D is much more unimportant for realizing innovations than on average.

As Kleinknecht and Reijnen (1991) state, for a successful introduction of new products or processes firms not only need to perform R&D but to engage in related activities as well. The *innovation intensity* captures further characteristics of firms' innovation input, such as design and conception, construction, engineering, and fabrication of prototypes, trial production, pilot plans, etc.[7] The innovation expenditures per unit of sales (without costs of patenting, licensing, and staff training) were 5.5 per cent in average. As seen in Figure 1, R&D and innovation intensities vary among the lines of economics. Firms producing chemical materials receive the highest intensities, whereas foundries, drop forges and steel shaping firms receive the lowest intensities. In addition, innovative suppliers spend about 354,000 German Mark per unit of employee or 10,600 German Mark per unit of R&D employee in their innovation activities.

INSERT FIGURE 1 HERE

The survey also provides information on the innovation output, e.g. on the importance of innovation. For 42.8 per cent of the innovative suppliers the introduction of new automobile products was more important than the implementation of new processes. But they try to improve existing products or processes rather than to develop basic innovations. Only for 11.5 per cent of the suppliers the realization of fundamentally new innovations was more important than the technical improvement of existing automobile products or processes.

Sources and Acquisition of External Knowledge

After this brief description of the innovation behavior of firms in the German automobile supply industry, we want to look at the relevance of *academic (scientific) research* as an external source of knowledge to increase firms' *technological opportunities*. Different measures were used to show the influence of technological opportunities and academic research on the innovation activities. Following Levin and Reiss (1988), we assume that the degree to which firms are interested in scientific institutions (universities, technical institutions) as relevant sources of technological information is closely correlated with the level of their technological capacities (see also Arvanitis and Hollenstein 1994, Felder et al. 1996, Harabi 1995). Therefore, the innovative firms were asked to rate on a seven-point scale the importance of several *external sources of technological information* for their innovation activities in the years 1993-1994. As shown in Table 1, inter-industrial sources (customers and suppliers) were rated as the most important information sources for the innovation activities, followed by competitors as an intra-industrial information sources. Academic institutions (universities or professional associations) were ranked as less important sources for external technological knowledge.

INSERT TABLE 1 HERE

These results are consistent with the findings of Becker and Peters (1997) for the German manufacturing industry on the whole, using data from the first wave of the Mannheim Innovation Panel conducted in 1993. Also Harabi (1995, p. 70) shows for the Swiss industry

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[7] In the OSLO-Manual, expenditures for patenting and licensing as well as staff training are also part of the innovation expenses (OECD 1994). However, we only taken into account activities which refer to the course of the innovation process directly (Clark and Fujimoto 1991).

that the contribution of industrial sources to technical progress - especially for firms within the *same* line of business - appears to be most important, whereas non-industrial sources (university research, other government research institutions, state companies and agencies, professional associations, etc.) were rated as relatively unimportant.

Another possibility for automobile suppliers to expand their technological opportunities is the establishment of *R&D co-operations* (Sterlacchini 1994), in particular with academic institutions. R&D co-operations between innovative suppliers and academic institutions can be set up more or less systematically. The spectrum of formal and informal linkages ranges from irregular collaboration, such as sporadic consulting services (e.g. expertise, evaluation reports, etc.), and regular exchange of information and experience (workshops, symposia, etc.), to systematic contractual agreements within mutually financed R&D projects.

In the survey, the automobile suppliers were asked whether they had formed *contractual* R&D co-operations with other institutions or firms. Generally, 62.8 per cent of the innovative firms had signed up R&D contracts with other firms or universities to jointly develop new products or processes (Table 2). Whereas the contribution of technological information from universities to the innovation process is generally considered as less important, the most innovative automobile suppliers in 1993 and 1994 had formed formal R&D co-operations with universities rather than with industrial partners. Not suprisingly, suppliers with academic R&D-co-operations rated the importance of universities as external sources of technological information significantly higher than other firms (mean of 4.15 to 2.67). But no inter-industrial differences could be found by firms' responses to the question of R&D co-operation with universities.

INSERT TABLE 2 HERE

Table 2 also shows the rankings related to the importance of different co-operation partners for firms in the German manufacturing sector on the whole. The intensity of co-operation is much higher in the automobile supply industry than in the average of the whole manufacturing sector. In the manufacturing sector only 37 per cent had developed new products or processes jointly with other firms or public organizations. Even if the firms from the Mannheim Innovation Panel were asked for formal *and* informal R&D co-operations, the level of joint development is much higher in the automobile supply industry than in the whole manufacturing sector.

At least in the second survey, conducted in 1996, the innovative automobile suppliers were asked to evaluate the importance of different *fields of academic research* for their innovation activities within the last five to ten years. We used fields of academic research, specified by Harabi (1995) for the Swiss manufacturing sector, in which research seems to be foccused on facilitating technological advance of various kinds (see also Klevorick et al. 1995). Table 3 lists the relevance of different fields regarding basic science, applied science, and engineering science for supplier firms in the German automobile industry. New findings in theoretical basic research, applied mathematics and operation research were ranked as less important than research results in material science, mechanical engineering, and informatics and computer science. As Klevorick et al. (1995, p. 190) stress, “work in fields like metallurgy, material science, computer science, electrical engineering, and pathology, all of which are strongly represented in academia as well as in industry, directly facilitates technological advance and enhances the problem-solving capacity of those who endeavor to make such progress.“

INSERT TABLE 3 HERE

But the high standard deviations suggest that the relevance of academic research heavily depends on the technology produced. Thus, we examined the relevance of fields of academic research for effects in lines of business. Academic research in electronic science or electrical engineering was relevant only for suppliers of electronic components, whereas the results of applied chemistry were important solely for suppliers of chemical materials and plastic parts. In contrast, automobile suppliers in seven out of the nine investigated lines of economics rated new findings of the academic research in mechanical engineering and materials science as important.

The empirical results of the *descriptive* analysis of the importance of academic research as an external knowledge resource to enhance the technological opportunities of firms in the German automobile supply industry can summarized as follows: (1) The contribution of academic research on suppliers' innovation activities is generally cited as less important than that of inter-industrial or intra-industrial organizations. (2) Despite this lower importance, universities are the most likely partners of formal R&D arrangements for jointly developing new products or processes. (3) New findings in material science, informatics and computer science, and in mechanical engineering are the most important academic research fields for the German automobile suppliers.

IV. Measurement Issues and Data Description

In a next step, we want to estimate the effects of academic reserach and other factors on the innovation input and output of firms in the German automobile supply industry. The basic specification for explaining suppliers' innovation activities x_i is as follows:

$$x_i = a + b\,ATO_i + cITO_i + dTO + eTC_i + fMC_i + gAP_i + hA_i + \varepsilon_i\,, \qquad (4)$$

where *ATO* and *ITO* represent proxies of suppliers' technological opportunities stemming from academic research and industrial information sources, *TO* reflects the level of technological opportunities on the lines of economics. *TC* defines a parameter of suppliers' technological capability, *MC* represents conditions of suppliers' as well as the buyers' market structures, *AP* stands for the degree of appropriability, and *A* represents conditions regarding the size and the degree of interindustrial diversification of firms. Table 4 shows the different exogenous variables used in the estimations for the year 1994.

We use three different indicators for measuring the level of technological opportunities related to the relevance of academic research or other sources of new knoweldge: (1) the rating of the importance of universities and other firms or institutions as sources of technological information for firms' innovation activities, (2) dummies for suppliers with formal R&D-co-operations with universities and customers, and (3) the relevance of different fields of academic research.

ad (1): Following Arvanitis and Hollenstein (1994), and Felder et al. (1996), we reflect the *technological opportunities* of suppliers by the contribution of three different sources of information to their innovation activities, employed by the scores of factor analysis (see Appendix Table A1): scientific institutions like universities and professional associations (TEC_SCIE), customers and suppliers (TEC_CUSU), and competitors/reverse engineering (TEC_COMP).[8] We take suppliers' ratings of the importance of university information (TEC_UNI) separately in the regression to stress the relevance of acadamic research on their innovation activities.

ad (2): We use a dummy variable COOP_UNI which takes a value of 1, if suppliers have formed contractual R&D co-operations with universities. Further, the dummy variable COOP_CUST is included to check the influence of co-operative R&D arrangements among suppliers and their customers. As Veugelers (1997) and Colombo and Garrone (1996) stress, a problem of simultaneity can arise if suppliers' probability of co-operating depends on their inhouse R&D activities and vice versa. But we consider that suppliers' *regularity* to invest in R&D rather than the *level* of inhouse R&D determine suppliers' willingness to engage in co-operation, in particular with universities or customers. Therefore, we assume no causality relationship between suppliers' co-operative agreements with universities or customers and their intensities of R&D (innovation) activities.

ad (3): To investigate the effects of different *fields of academic research* on the innovation activities of firms in the German automobile supply industry we used the results of a factor analysis of the data from the second sample to obtain four factors describing special fields of academic research (Appendix, Table A2): theoretical and applied mathematics, physics, computer science (SCI_MATH), materials, metallurgy, mechanical engineering (SCI_MATL), electronics and electro-technics (SCI_ELEC), and theoretical and applied chemistry (SCI_CHEM). In this context, we delete industries with less than three observations. We then computed the mean values of the four factors for all lines of economics (see Figure 1) and linked them with the data from the first sample.

Industrial effects of the level of technological opportunities were also measured by the factor-specific contribution of technological know-how from industrial research (R&D_CAP). Using data from Meyer-Krahmer and Wessels (1989), a dummy variable reflects the lines of

[8] Reverse engineering is seen as one important possibility for firms to learn about the technological know-how of competitors.

economics with above average stocks of R&D-capital (chemicals, automobiles and electronic parts). Herewith, we correct for fixed industry effects. 47 per cent of the suppliers belonging to these lines of economics have above average stocks of R&D capital.

To capture suppliers' *internal technological capacities* (TEC_CUST), we used the responses to questions concerning the share of sales of automobile parts developed to the customers' specifications (detail-controlled parts). According to Cusumano (1989), automobile suppliers with low technological capacities make fewer R&D efforts with parts controlled in all details by their customers than firms with high technological capacities which mainly produce own developed and black-box parts. But the various specifications of automobile parts also show aspects of demand structures and the adaptation of external information (von Hippel 1988; Peters 1998). So, automobile parts produced from own supplier drawings may be less customer-specific than detail-controlled or black-box products. Consequently, automobile parts developed to customers' drawings, can be offered to a smaller number of customers, which promotes the market power of potential buyers. On average, 39.4 per cent of suppliers' automobile sales had been done with detail-controlled parts. In our estimations we also introduced variables reflecting further characteristics of suppliers and specific market conditions. As a proxy variable for *business unit size* the sales of automobile parts (in logs) is chosen (SIZE). This catches the effect of firm sizes specific to the automobile sector. As the literature does not offer a standard economic interpretation of size effects (Arvanitis and Hollenstein 1994), business unit size can be used as a proxy for various economic effects, and therefore can have ambiguous effects on the innovation activities of suppliers. In the samples used, business unit size is strongly correlated with the whole size of firms measured by the log of the number of employees. In order to control *inter-sectoral synergy effects* by the development of new products and processes, a dummy variable (DIVERS) was included, reflecting the 18 per cent of suppliers having made less than 40 per cent of their sales with automobile parts in 1994. We assume that suppliers acting in more than only in the automobile supply industry have more opportunities to adapt external knowledge generated in other sectors.

INSERT TABLE 4 HERE

Data on *market concentrations* were drawn from our survey and from the German Monopoly Commission (1994). To avoid the problem of simultaniety with innovation determining market concentration, we use lagged concentration data referring to 1991. The concentration in the domestic *supplier* markets is measured by the Herfindahl index, computed for the lines of business units (SCR). Where such a classification was not feasible, the SCR of the respective two-digit industry is used. For describing the supplier concentration in domestic *and* foreign markets, we use a dummy variable (COMP_H), which characterizes oligopolistically structured markets with 1 to 10 competitors. About 74.4 per cent of the sample firms had up to ten competitors.

Following Peters (1998), who found significant effects of *buyer concentration* on the innovation input and output of automobile suppliers, we use a sales weighted CR3-concentration ratio of domestic buyer markets (BCR). The weights of these buyer concentration index relate to the shares of suppliers' sales made directly with automakers, commercial vehicles or with first- and second-tier suppliers in 1994. The interaction of domestic buyer and supplier market structure is measured for each firm by the product of the supplier and buyer market concetration ratio SCR*BCR. In addition, a dummy was introduced to define all 21.6 per cent of suppliers with more than 10 buyers (customers) within the automobile industry at home and abroad (CUST_H).

Because the design of supplier contracts is most important for capturing innovation returns in the automobile industry (Peters 1998) three variables related to firms' *appropriability conditions* are included in the estimations. The relevance of contractual appropriation conditions is measured by a dummy variable (APPR_CO), characterizing the 17.3 per cent of suppliers who use long-term contracts (model-life contracts with a time of delivery of 3 to 5 years) to a higher extent than short-term contracts (contracts of one year or less). The extent to which suppliers were confronted with declining revenues in 1993 and 1994, due to a price pressure of the buyers, is also used as an indicator for firms' appropriability conditions (APPR_PR) with a mean of 5.55. Finally, we use the ratings of a question in our survey concerning the efficiency of patents to appropriate new technological findings as an exogenous variable (APPR_PA). In the sample, about 17 per cent of the suppliers reported that they can protect their R&D findings with patents very well.

Depending on the kind of innovation indicators, different *estimation methods* are used to analyse the effects of academic research on the innovation activities of firms in the German automobile supply industry. To estimate the different effects on the innovation *input* (see Table 5), such as the innovation intensity (INNO_INT), the R&D employment intensity (R&D_INT), the innovation employment intensity (INEMPL_INT), and the innovation R&D employment intensity (INR&D_INT), the standard Tobit model is employed because some innovative firms have no R&D employment or have not invested in their innovation process. But this method does not allow the identification of parameters affecting suppliers' decision to participate in R&D and the extent of intensity like the two-step version of the Heckman model used by Becker and Peters (1997).[9] An ordered probit model with sample selection is employed for estimating the extent of R&D to realize an innovation (from 0 = actually none to 6 = to a high extent). As some innovative firms have not performed any R&D, the probability for suppliers having to engage in R&D in order to be successful in realizing an innovation

[9] We have tried to use the two-step version of the Heckman model to estimate INNO_INT and R&D_INT. But only less than than 2.5 per cent of the innovative suppliers reported no innovation expenditures or R&D employment. This small number has rejected the application of the Probit estimations in the first step.

(R&D_NEC), and the extent of R&D for realizing an innovation (R&D_EXT) has been estimated.[10]

INSERT TABLE 5 HERE

We preferred a double censored Tobit model for analysing the effects of academic research on the innovation *output*. The impacts were checked according to the development of really new (INNO_NEW) and improved (INNO_IMP) products or processes. These indicators were computed by factor analysis on suppliers' ratings regarding the importance of the development of different types of innovations (Appendix, Table A3). When the problem of (multiplicative) heteroscedasticity was present, we corrected the standard deviations of the estimated parameters.

V. Regression Results

We investigated the impacts of academic research knowledge on the innovation activities of firms in the German automobile supply industry under different aspects. In *Model 1* we tested the effects of the engagement of suppliers in R&D co-operations with universities to enlargen their technological opportunities (COOP_UNI). In the basic specification (4), technological opportunities stemming from academic research were modified to

$$b\,ATO_i = b_1 COOP\_UNI_i + b_2 SCI\_MATH_j + b_3 SCI\_MATL_j + b_4 SCI\_ELEC_j, \qquad (5)$$

whereas *j* indicates the line of business of firm *i*. As the factor *Chemistry* is highly negative, correlated with the factor *Electronics*, we excluded the first factor (or otherwise).

In *Model 2* we checked the influence of universities as an external information source (TEC_UNI). Because of the problem of multicollinearity we have had to exclude COOP_UNI from Model 2. The specification (5) was modified as

$$b\,ATO_i = b_1 TEC\_UNI_i + b_2 SCI\_MATH_j + b_3 SCI\_MATL_j + b_4 SCI\_ELEC_j. \qquad (6)$$

In both models we took into consideration the variables representing technological opportunities stemming from industrial sources:

$$c\,ITO_i = c_1 TEC\_COMP_i + c_2 TEC\_CUSU + c_3 COOP\_CUST. \qquad (7)$$

Since the estimations testing the impact of universities as an external source for technological information on the level of *factor scores* (TEC_SCIE) in general yield the same sign of coefficients (but with lower statistical significance) as with TEC_UNI, the findings related to these aspects are not mentioned.

[10] The ordered probit model with sample selection can be described as follows (Greene 1990): In the first, we estimate $z^* = \gamma' w + u$, with $u \sim [0,1]$, whereas z^* is unobserved. But we observe $z=1$ if $z^*>0$ and $z=0$ if $z \leq 0$. In the second, y satisfies the ordered probit specifications, $y^* = \beta' x + \varepsilon$ only if $z=1$, with $(\varepsilon, u) \sim N2[0,0,1,1,\rho]$.

Estimation of the Impact of Technological Opportunities on Suppliers' Innovation Input

As seen in Table 6, technological opportunities stemming from academic research seem to substitute suppliers' investments in their R&D and innovation activities. The effects of COOP_UNI and TEC_UNI on the R&D employment intensity of firms in the German automobile supply industry (R&D_INT) are negative but without statistical significance. The estimations for the innovation employment intensity (INEMPL_INT) and the innovation R&D employment intensity (INR&D_INT) are also negative but statistically significant. Thus, firms with close relationships to universities spend lower innovation expenditures per unit of (R&D) employment than other firms. The data only reveal a small positive but insignificant impact of R&D co-operations with universities on suppliers' innovation expenditures per unit of sales (INNO_INT).

In general, the level of technological opportunities measured by the importance of different information sources has significant (high) effects, in particular for the R&D employment intensity (R&D_INT), as the values of the Wald Test and of the F-Test show. In this context, technological information stemming from competitors (TEC_COMP) or inter-industrial sources (TEC_CUSU) seem to be more important than information from universities (TEC_UNI). The adaptation of industrial know-how stimulates the R&D intensities, whereas academic information reduces the R&D intensities of automobile suppliers. In the other estimation models, the coefficient of TEC_CUSU has the expected positive sign but without any statistical significance.[11]

At a first glance, the findings for the input effects of academic research are surprising. Arvanitis and Hollenstein (1995) for the Swiss industry, and Becker and Peters (1997) for the German manufacturing industry, observe that academic research is positively related to firms' innovation input. Perhaps, in the German automobile supply industry firms seem to substitute their own (generic) innovation expenditures by using externally generated knowledge from academic research. Nevertheless, we found stimulating effects of COOP_UNI and TEC_UNI to the extent to which *inhouse* R&D is necessary for suppliers to realize an innovation. As shown in Table 7, R&D_EXT depends positively on the importance of academic information and on the willingness of suppliers to co-operate in R&D with universities. Suppliers with high inhouse R&D activities focus on academic research in order to be successful in their innovation activities. As expected, the necessity of R&D for being innovative (R&D_NEC) does not depend on the usage of the results of academic research. Rather, suppliers' decision to co-operate with universities had been influenced by (the necessity of) inhouse R&D activities (Veugelers 1997). But we have to remark that the estimated correlation between the error terms in the two step model is small and far from significant. Only minor threshold effects with respect to the necessity and extent of inhouse R&D activities can be observed.

[11] With one exception by the estimation of the necessity of R&D to realize an innovation (R&D_NEC).

The values of the Wald Test show joint significant effects of the *fields of academic research* on the innovation expenditures per unit of sales, on the R&D employment intensity as well as on the probability and extent of R&D necessary for suppliers to realize an innovation. But only the findings for the research fields electronics and electro-technics (factor scores) have an individual influence on suppliers' R&D employment intensity and on their innovation expenditures per unit of sales. The negative signs of the coefficients suggest that the adaptation of findings in the academic research of electronic/electro-technics reduces the suppliers' investment in own innovation activities. This can explain why academic information substitutes suppliers' spendings in own (generic) R&D.

INSERT TABLE 6 AND 7 HERE

Further, in all models, we have examined *industrial effects* of technological opportunities (R&D_CAP). Automobile suppliers acting on markets with high R&D capital stocks invest more money in their innovation activities per unit of employees and per unit of R&D employees than other firms. They also undertake relatively more R&D to realize an innovation than firms in industries with lower R&D capital stocks. But surprisingly, R&D_CAP shows a negative sign in the regression of the necessity to invest in R&D. One explaination is that firms in these industries are, on the one hand, less engaged in R&D but, on the other hand, - if they participate - invest more in R&D than in other industries.

We have also studied the relevance of industrial sources of knowledge, in particular of information generated by customers. It is interesting that suppliers' willingness to co-operate formally with their customers (COOP_CUST) affects their innovation input positively. By contractual R&D co-operations suppliers have the possibility to internalize their customers' knowledge, which increase the productivity of their own innovative efforts. Thus, the customers' information seems to be more relevant for suppliers within formal R&D agreements than vice versa. In general, this can explain the low influence of TEC_CUSU and the significant influence of COOP_CUST. However, in all cases we have to keep in mind that the relevance of customers in the innovation process of suppliers depends on the fact that customers can have information about demand and appropriability conditions rather than about aspects to enlargen the technological opportunities (Peters 1998, von Hippel 1988).

The influence of customers can also be seen in the kind of automobile parts produced by suppliers. Thus, the signs of the estimated parameters of TEC_CUST - except in the estimations for INEMPL_INT and R&D_NEC - reveal that an increasing share of black-box or own developed products (increasing technological capacities) had forced suppliers to be active in the R&D and innovation process. Strong positive effects of TEC_CUST are only observable in the estimation of the innovation expenditure per unit of R&D employment (INR&D_INT). As Peters (1998) shows, automobile suppliers with high shares of parts, developed to customers specifications, have a higher probability of realizing a process innovation than with lower shares. Further, as shown in Table 6, they invest less in their

(R&D) human capital per unit of employees which explains their lower R&D employment intensity. But if they have to improve their production process (e.g. by constructing rather than developing new machines or tools), they often have to bear large fixed innovation expenditures. Thus, they have to spend more money per unit of R&D employees comparing to other firms focussing on product innovations.

Before we turn to the effects of technological opportunities on suppliers' innovation output, we will briefly mention the impact of the other exogenous variables. As shown in Table 6, the concentration on buyer (BCR) and supplier markets (SCR) affect the innovation expenditure per unit of automobile sales and the R&D employment intensity. The interaction term of both domestic market structures indicates that both intensities will decline in buyer concentration, if supplier markets are lowly concentrated, and vice versa. Remarkably, the regression results strengthen the empirical findings of Peters (1998), even if new indicators of technological opportunities are taken into consideration. But significant effects of buyer and supplier market power (and of the interaction of SCR*BCR) could not be found in the other regressions. Therefore, we excluded the concentration variables out of these regressions.

Closely connected to the demand power of buyers are the appropriability conditions. The duration of supply contracts (APPR_CO) as a strategy for appropriating an innovation return stimulates firms in the automobile industry to invest in R&D human capital but lacks statistical significance in all other estimations. Furtheron, the efficiency of patents as a mechanism to protect new R&D findings has significant impacts on the R&D employment intensity. The estimations also underline that declining revenues in 1993 and 1994 due to price pressure of customers (APPR_PR), reduce suppliers' incentives to invest in their own R&D and innovation process remarkably. Low prices for automobile parts reduce suppliers' capability of financing their innovation activities internally.

Within the automobile supplier industry larger firms spend less money on their R&D and innovation activities than smaller ones. However, the probability of engaging in R&D increases with growing business units. This is conformable to results of other empirical studies (Felder et al. 1996, Kleinknecht and Bain 1993). While suppliers' inter-industry diversification has a significant negative influence on the innovation expenditures per unit of (R&D) employees (and on the novelty of innovations), the coefficient of DIVERS has no significant signs in all other estimations. As the innovation expenditures refer to automobile products only, whereas the number of (R&D) employees refers to the whole firm, it is not surprising that firms with low shares of sales in the automobile industry have lower innovation expenditures per unit of (R&D) employment.

Estimation of the Impact of Technological Opportunities on Suppliers' Innovation Output

Academic research has stimulating effects on the importance of new and improved products or processes. However, these effects on the innovation output of firms in the German automobile supply industry are only of low statistical significance and are ambiguous (see

Table 8). On the one hand, new technological information stemming from university research (TEC_UNI) increase the importance to develop *new* (INNO_NEW) or *improved* (INNO_IMP) automobile products or production processes, whereas the positive influence is much stronger on the development of really new than of improved technologies. This observation confirms the results of other studies that academic research is more related to basic research than to applied research (Becker 1996, Faulkner and Senker 1994, Mansfield 1991). The knowledge of useful scientific outcomes should be more important for the development of completely new technologies.

On the other hand, suppliers co-operate with universities (COOP_UNI) to realize improved products/production processes rather than to develop really new technologies. The signs of the coefficient of COOP_UNI are positive in the regressions of the innovation output but lack statistical significance in the estimations for the importance of the development of new products or processes (INNO_NEW). Becker and Peters (1997) show the same effects for firms which have jointly developed products with universities in the German manufacturing industry. Using sales shares of new and improved products as indicators of the innovation output, they found that academic R&D co-operations increase the probability of higher sales shares of improved products but not on those of completely new products.

In general, technological opportunities regarding to external information from customers/other suppliers (TEC_CUSU) and competitors (TEC_COMP) have no joint significant effect on INNO_NEW. But these information sources do have significant positive impacts on INNO_IMP. Formal R&D co-operations with customers (COOP_CUST) seem to increase the probability for automobile suppliers to realize completely new innovations, whereas no stimulating effect of customers for suppliers' innovation process can be observed by the kind of automobile parts produced (TEC_CUST). Also the dummy representing industries with high stocks of R&D capitals (R&D_CAP) shows no significant coefficients.

Our estimations underline the importance of new findings in academic research (SCI_ELEC, SCI_MATH, SCI_MAT), affecting the development of completely new innovations rather than the activities in technically improved existing technologies. But an individual significantly high and negative effect can only be found for SCI_MATL. Suppliers in the German automobile industry which use new academic findings of research fields, such as materials science, mechanical engineering, and metallurgy, pay more attention to the development of improved than of basically new innovations. On these markets, the main technological findings stem from large *input suppliers* which develop new materials of automobile parts or new tools (Greif 1992). These input suppliers, e.g. chemical companies, have the expertise to realize new basic innovations, whereas automobile suppliers as the users of these new technologies only try to improve these findings to their own specific needs. Thus, new findings of academic research in materials, machinery engineering and metallurgy are necessary to understand the basic innovations of input suppliers which yield in the improvement of automobile parts.

INSERT TABLE 8 HERE

Finally, we shortly turn to the discussion of the parameters reflecting conditions of market structure, appropriability conditions and firm size. The size of the stock of customers (CUST_H) has significant effects only in the estimation of INNO_IMP. The sign of the coefficient shows that a large stock of customers destimulates suppliers' willingness to invest in the development of improved technologies. But the data does not reveal a significant positive influence on the importance of realizing completely new technologies (INNO_NEW). If we attribute financial constraints to declining revenues, the intensity of the customers' price pressure (APPR_PR) also shifts suppliers' innovation activities from the development of completely new innovations to the improvement of existing products or production processes. The signs of the coefficient of APPR_PR reveal that financial constraints reduce the activities of firms in the automobile industry to invest in novel technologies but increase their engagement in the technical improvements. As observed for innovation input, the size of the business units (SIZE) has a highly significant and positive impact on the innovation output of firms in the German automobile industry. In general, independent of the novelty of innovations, the development of really new or improved products is more important for larger firms than for smaller ones.

VI. Absorptive Capacities and Academic Research

As Veugelers (1997) has pointed out, the phenomenon of linkages between internal and external R&D strategies is quite complex. In section II, we have argued that an effective adaptation of external technological opportunities (knowledge) requires the investment of inhouse R&D in absorptive capacities. As Cohen and Levinthal (1989) have pointed out, these investments have to be made by firms *prior* to the absorption of external knowledge. But a high level of absorptive capacities also encourage firms to invest in own R&D because it enhances the stimulating effects of technological opportunities on the productivity of own (idiosyncratic) R&D.

To assess the effects of interactions between *internal* absorptive capacities and *external* technological opportunities stemming from academic research on the innovation input and output of firms in the German automobile supplier industry, we re-run the regressions with special *interaction terms*. We modify specification (5) to

$$\begin{aligned} b\,ATO_i &= b_1COOP\_UNI_i + b_2COOP\_UNI_i{*}AC_i + b_3SCI\_MATH_j \\ &\quad + b_4SCI\_MATL_j + b_5SCI\_ELEC_j, \qquad (8) \end{aligned}$$

where AC_i is represented by a dummy variable R&D_LAB (R&D_BAS) taking the value of 1, if suppliers have their own staffed R&D department (are engaged regulary in basic research), and taking the value of 0 otherwise. Both variables are interpretated as indicators for firms' absorptive capacities. R&D_BAS seems to be an adaequate proxy, if we estimate the effects of academic research on the importance of the development of new innovations rather than the improvement of products or processes.[12]

Our investigations differ from the empirical study of Veugelers (1997) in two points. First, we use different measures of the innovation and R&D activities of firms, not only the (log of the) amount of inhouse R&D investments. Second, whereas Veugelers can distinguish between the level of internally financed R&D activities and firms' expenditures of R&D contracted from outside, we can only relate the R&D employment intensity (R&D_INT) and the extent of inhouse R&D for being successful in introducing new products or processes (R&D_EXT) to internally financed R&D.[13] As innovation expenditures can also capture expenses on R&D firms contracted out, we do not estimate the influences of the absorptive capacities on firms' innovation intensities. Instead, we estimate the effects of AC on suppliers' innovation output (INNO_NEW, INNO_IMP).

Table 9 shows the regression results. If we take absorptive capacity into account, in general the impact of co-operative R&D with universities on suppliers' innovation activities will be stronger and more significant than if we ignored absorptive capacity. We identify stimulating effects of absorptive capacities in the estimation of the extent of inhouse R&D necessary for realizing an innovation (R&D_EXT). The coefficient of the interaction term has a positive sign and is statistically significant, whereras the coefficient of COOP_UNI is positive but lacks statistical significance. In addition, in the estimation of the R&D employment intensity (R&D_INT), co-operative R&D with universities *substitutes* inhouse R&D employment, whereas we observe a *complementary* relationship, if contractual co-operative arrangements are connected with inhouse absorptive capacities.

The empirical results of Veugelers (1997) can also be confirmed in the estimations of suppliers' innovation output. Co-operative arrangements with universities seem to have no significant effect on the innovation output, if we neglect suppliers' absorptive capacities measured in terms of the regularity of *inhouse basic research* or in the presence of *staffed R&D departments*. The coefficients are positive and significant only if we consider suppliers' absorptive capacities.

In conclusion, our regression results vary in the signs and significance of academic research, if we explicitly take into account proxy variables for firms' absorptive capacities. But we have to remark that using alternative measure of suppliers' absorptive capacities yield in different results. Whereas the interaction term COOP_UNI*R&D_BAS indicates significant stimulating effects on the importance of realizing novel innovations, estimations of INNO_NEW with COOP_UNI*R&D_LAB reject the empirical significance of the absorptive

[12] We present only the results of the estimations regarding the suppliers' contractual co-operation with universities. Estimations with TEC_UNI*AC as interaction term yield the same basic regression results.

[13] A problem here was that the estimation of the participation model did not converge with the interaction terms. Therefore, R&D_EXT was estimated as if there were no selection.

capacities. The coefficient is positive but without statistical significance. The dummy R&D_BAS, indicating the regularity of suppliers' inhouse basic research, seems to be an advanced measure for absorptive capacities in the case of realizing new rather than improved products. In opposite, whereas R&D co-operations with universities have significant complementary effects on R&D_EXT, if suppliers are regularly active in basic research, the significance will diminish, if we measure suppliers' absorptive capacities by a dummy representing staffed R&D departments (COOP_UNI*R&D_LAB). This observation suggests that besides the *level* also the *kind* of suppliers' investments affects their ability of utilizing external knowledge. Which nature of technological opportunities firms can implement internally depends on the kind of inhouse R&D activities.

INSERT TABLE 9 HERE

VII. Conclusion

One way for firms to expand their technological opportunity is the use of knowledge stemming from academic research. Many authors have pointed out that this seems to be crucial for innovation success because technological opportunities exhaust with further progress in a given technological area. The aim of this paper was to investigate the importance of knowledge generated in universities for the innovation process in the German automobile supply industry. Our results can be summarized as follows:

- We found different effects of academic research on innovation input. On the one hand, technological opportunities stemming from university knowledge seem to substitute rather than to complement the automobile suppliers' investment in their innovation activities. The impact of academic research on the innovation expenditure per unit of (R&D) employment is negative and significant, whereas the negative influence on the innovation expenditures per unit of sales and on the R&D employment intensity lacks statistical significance.
- Proximity to academic research positively affects the extent to which R&D is necessary for realizing an innovation but does not stimulate firms' willingness to engage in own (inhouse) R&D. Also, positive effects on variables regarding the innovation output could be observed but these effects are weaker than those on variables regarding R&D activities.
- The effects of academic research depend on the absorptive capacities of the suppliers. Co-operations with universities have insignificant influence on firms' own R&D investments and their innovation output, unless they have inhouse capacities necessary for capitalizing on the complementarities between internal innovation ressources and external technological opportunities.
- The relevance of findings in different fields of academic research affected the innovation input and output but with varying power of explanation and statistical significance. However, in general, the individual effects were only small and frequently insignificant. E.g., in the estimations of the intensities (Table 6) only new findings of research in

electronics/ electro-technics have a strong substitutive character regarding inhouse R&D and innovation expenditures.

- Higher technological opportunities jointly represented by the importance of industrial and non-industrial information sources stimulates suppliers' innovation activities only in terms of higher innovation expenditures per unit of sales and of higher investments in R&D employments. No highly significant effects can be found in the regressions of the R&D input and of the innovation output.

In comparison with the empirical findings of other studies, especially with the results of Becker and Peters (1997) for the German manufacturing industry, we were able to outline the differences in the effects of academic reserach: First, for the manufacturing industry, in general the effects of technological opportunities stemming from university knowledge are larger comparing to the impact in the automobile supply industry. Second, academic research stimulates the expenditures for innovation activities and R&D of firms within the whole manufacturing industry, whereas in the automobile supply industry these effects are negative. Third, automobile suppliers are in average more engaged in (formal) R&D co-operations with customers, suppliers or universities than firms in the whole manufacturing industry.

To obtain more insight into the various effects of academic research on the industrial innovation process, further investigations are necessary. On one hand, the impact of different specific features of R&D co-operations with universities on the industrial innovation process has to be examined. Thus, more information has to be collected on the question why firms co-operate with universities and how are these co-operations structured. On the other hand, the importance of absorptive capacities for applying external knowledge efficiently needs to be clarified further - theoretically as well as empirically. Our results indicate that we have to take into account the organization of the R&D and innovation process to establish absorptive capacities. Depending on the kind of external information required, firms obviously apply different strategies for utilizing technological opportunities, not only in the automobile supply industry.

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Figure 1
R&D employment intensity and innovation intensity of innovative German automobile suppliers, differentiated by lines of economics

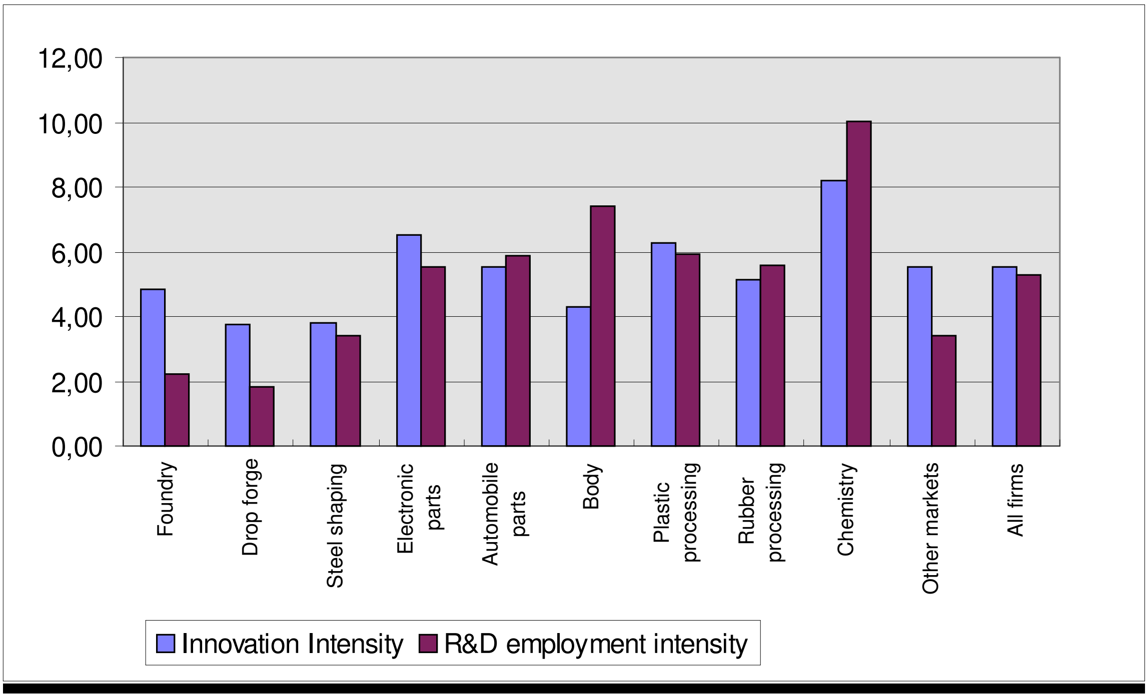

Table 1
Importance of external sources of technological information for suppliers' innovation activities (1 = no importance; 7 = high importance)

External sources of new knowledge		**Mean**	**Std. Dev.**	**Percentage of firms with valuation of** no importance (1)	**Percentage of firms with valuation of** high importance (5 to 7)
Inter-industrial sources	Customers [a]	5.07	1.50	1.7	69.4
	Suppliers	4.22	1.65	4.7	47.2
Intra-industrial sources	Competitors	3.29	1.55	12.5	23.8
Non-industrial sources	Universities	3.21	1.64	16.6	22.4
	Professional associations[b]	3.01	1.58	20.6	20.6

Remark: (a) automakers and/or systems-suppliers; (b) The responses vary significantly from industry to industry (level of significance: 0.01).

Table 2
Partners of firms with R&D-Co-operations [(a)]

Partners of R&D-co-operations	Percentage of innovative firms	
	Automobile supply industry[(b)]	Manufacturing sector[(c)]
Universities	36.8	18.0
Customers	35.4	14.6
Suppliers	30.1	12.9

Remark: (a) multiple answers possible; (b) the data relate to the years 1993-1994; only formal R&D co-operations; (c) the data relate to the year 1992; formal and informal R&D co-operations

Sources: Mannheim Innovation Panel of 1993; collected data in the German automobile supply industry in 1995.

Table 3
Relevance of fields of academic research for suppliers' innovation activities within the last 5 to 10 years (1 = no relevance; 7 = very high relevance)

Fields of academic research	Mean	Std. Dev.	Percentage of firms with valuation of	
			no relevance (1)	high relevance (5 to 7)
Basic Science				
Theoretical physics	2.48	1.81	49.2	18.5
Theoretical chemistry	2.00	1.59	62.1	11.3
Theoretical mathematics	1.89	1.52	63.9	11.5
Applied Science and Engineering				
Materials science	4.61	1.68	6.7	59.7
Mechanical engineering	4.51	1.81	8.3	49.6
Informatics and computer science	4.02	1.79	12.3	44.3
Metallurgy[(a)]	3.93	2.05	19.0	42.1
Electronic science[(a)]	3.65	2.08	23.3	43.3
Applied chemistry[(a)]	3.14	1.99	35.0	28.3
Electrical engineering[(b)]	3.11	1.89	29.4	25.2
Applied mathematics & operation research	2.28	1.56	41.0	10.3

Remark: (a) The responses vary significantly from industry to industry (level of significance: 0.01); (b) the responses vary significantly from industry to industry (level of significance: 0.05).

Table 4
List of Exogenous Variables and Description

Variable	Variable Description	Value
	Suppliers' technological opportunities	
TEC_SCIE TEC_CUSU TEC_COMP	Importance of information sources to innovation activities (scores of factor analysis): scientific institutions (universities and professional associations); customers and suppliers competitors and reverse engineering	metric
TEC_UNI	Importance of universities as information source to innovation activities (1 = no importance to 7 = high importance)	interval
COOP_CUST	1 = R&D-co-operation with customers; 0 = otherwise	metric
COOP_UNI	1 = R&D-co-operation with universities; 0 = otherwise	nominal
SCI_MATH SCI_MATL SCI_CHEM SCI_ELEC	Relevance of different fields of academic research (*Math*ematics, *Mat*eria*l*s and Engineering; *Chem*istry, *Elec*tronics and Electro-technics) for innovation activities within the last 5 to 10 years (scores of factor analysis)	nominal
	Technological opportunities of lines of economics	
R&D_CAP	Lines of economics having above average stocks of R&D-capital (1 = chemicals, automobile parts and automobile electronics, 0 = otherwise)	nominal
	Suppliers' internal technological capacities	
TEC_CUST	Shares of automobile products developed by suppliers at customers' specifications	metric
	Conditions on supplier markets	
SIZE	Firm size; Sales of automobile parts (in logs)	metric
DIVERS	Inter-industry diversification; Low shares of production of automobile parts regarding to the whole sales of suppliers (1 = shares smaller than 40 per cent, 0 = otherwise)	nominal
SCR	Domestic supplier concentration; Herfindahl index, computed for the lines of business units	metric
COMP_H	Supplier concentration in domestic and foreign markets; responses to a question concerning the number of competitors at home and abroad (1 = 1 - 10 competitors, 0 = otherwise)	nominal
	Conditions on buyer markets	
BCR	Domestic buyer concentration; sales weighted CR3-concentration index of domestic buyer markets (lines of business)	metric
CUST_H	Stock of customers; Responses to a question concerning the number of customers at home and abroad (1 = more than 10 customers, 0 = otherwise)	metric
SCR*BCR	Interaction of domestic supplier and buyer concentration	nominal
	Appropriability conditions	
APPR_CO	Contractual appropriation of innovation return; relative importance of long-term contracts (model-life contracts with a time of delivery of 3 and 5 years) regarding to short-term contracts of one year or less (1 = higher importance of long-term contracts; 0 = otherwise)	nominal
APPR_PR	Appropriation of innovation return by input prices; responses on a seven-point Likert scale to a question concerning lower rates of returns because of high price pressures by buyers. (1 = not at all accurate to 7 = very accurate)	interval
APPR_PA	Appropriation of innovation return by patent protection; responses on a seven-point Likert scale to a question concerning the efficiency of patents to protect R&D findings (1 = not at all accurate to 7 = very accurate)	interval

Table 5
List of Innovation Indicators and Description

Variable	Short Description of the Variable	Value
	Innovation Input	
R&D_INT	R&D employment in per cent of total employment	metric
INNO_INT	Innovation expenditure per unit of sales with automobile parts	metric
INEMPL_INT	Innovation expenditure per unit of total employment (in logs)	metric
INR&D_INT	Innovation expenditure per unit of R&D employment (in logs)	metric
	The rating of the extent of inhouse R&D to realize an innovation (0 = none; 6 = to a high extent) was splitted into two variables:	
R&D_NEC	Necessity of inhouse R&D: 1 = inhouse R&D is necessary to realize an innovation; 0 = none	nominal
R&D_EXT	Extent of inhouse R&D: 1 = to a small extent; 6 = to a high extent	interval
	Innovation Output	
INNO_NEW	Importance of the development of really new products or production processes (scores of factor analysis)	metric
INNO_IMP	Importance of the development of improved products or production processes (scores of factor analysis)	metric

Table 6

Results of the Estimations on R&D Employment and Innovation Intensity

Variables	**Coefficients (*Standard Deviation*)**			
	R&D_INT		**INNO_INT**	
	(1)	**(2)**	**(1)**	**(2)**
CONSTANT	0.1406*** (0.0274)	0.1459*** (0.0277)	0.1810*** (0.0246)	0.1815*** (0.0246)
SIZE	-0.0039** (0.0020)	-0.0041** (0.0196)	-0.0077*** (0.0017)	-0.0074*** (0.0016)
SCR	-0.0408* (0.0229)	-0.0431* (0.0230)	-0.0475** (0.0200)	-0.0479** (0.0200)
BCR	-0.0349 (0.0356)	-0.0346 (0.0356)	-0.1080*** (0.0357)	-0.1075*** (0.0363)
SCR*BCR	0.0731** (0.0350)	0.0767** (0.0352)	0.0815*** (0.0282)	0.0817*** (0.0282)
CUST_H	0.0075 (0.0061)	0.0072 (0.0061)	0.00618 (0.0051)	0.0061 (0.0051)
SCI_MATH	0.0035 (0.0101)	0.0020 (0.0102)	0.0088 (0.0088)	0.0080 (0.0089)
SCI_MATL	-0.0117 (0.0079)	-0.0129 (0.0079)	-0.0038 (0.0059)	-0.0037 (0.0059)
SCI_ELEC	-0.0297*** (0.0101)	-0.0288*** (0.0100)	-0.0228*** (0.0077)	-0.0220*** (0.0078)
TEC_CUSU	0.0067** (0.0030)	0.0071** (0.0029)	-0.0021 (0.0024)	-0.0022 (0.0023)
TEC_COMP	0.0117*** (0.0030)	0.0118*** (0.0030)	0.0001 0.0026	0.0002 (0.0026)
TEC_UNI		-0.0018 (0.0017)		-0.0002 (0.0015)
COOP_UNI	-0.0040 (0.0059)		0.0043 (0.0046)	
COOP_CUST	0.0127** (0.0061)	0.0123** (0.0061)	0.0164*** (0.0046)	0.0167*** (0.0045)
TEC_CUST	-0.0004*** (0.0001)	-0.0004*** (0.0001)	-0.0003*** (0.0001)	-0.0003*** (0.0001)
R&D_CAP	0.0069 (0.0081)	0.0065 (0.0081)	0.0095 (0.0061)	0.0093 (0.0063)
APPR_C	0.0277*** (0.0077)	0.0283*** (0.0077)		
APPR_PR	-0.0054*** (0.0018)	-0.0053*** (0.0018)	0.0030*** (0.0013)	-0.0030** (0.0013)
APPR_PA	-0.0030* (0.0017)	-0.0030* (0.0017)		
σ	0.0427*** (0.0019)	0.0426*** (0.0019)	0.1863*** (0.0744)	0.1904*** (0.0769)
χ^2 fields of research (3 d.o.f)	14.73***	14.94***	11.81***	10.67***
χ^2 information sources [a)]	20.21***	20.94***	2.18	0.98
Number of observation (d.o.f.)	245 (227)	245 (227)	234 (218)	234 (218)
Log likelihood	425.131	425.466	485.074	485.485
Model χ^2	333.26***	332.59***	26.40**	25.58*

Remark: Level of significance: * significant at the 0.1 level. ** significant at the 0.05 level. *** significant at the 0.01 level. Tobit- estimation results are corrected for multiplocative heteroscedasticity. The log of the variance of the error terms could be depicted as a linear function of business unit size and the concentration indices of domestic markets. a.) Model (1): 2 d.o.f.; Model (2): 3 d.o.f.

Table 6
Results of the Estimations on R&D Employment and Innovation Intensity (continued)

Variables	Coefficients (*Standard Deviation*)			
	INEMPL_INT		INR&D_INT	
	(1)	**(2)**	**(1)**	**(2)**
CONSTANT	8.649*** (0.4998)	8.9687*** (0.5207)	11.070*** (0.4562)	11.485*** (0.4767)
SIZE	-0.0139 (0.0678)	-0.0289 (0.0672)	0.0702 (0.06228)	0.0051 (0.0604)
DIVERS	-0.5937 (0.3095)	-0.5856* (0.3091)	-0.9720*** (0.2575)	-0.9739*** (0.2641)
COMP_H	-0.1149 (0.2351)	-0.0911 (0.2350)		
SCI_MATH	-0.3292 (0.3678)	-0.3814 (0.3701)	-0.3161 (0.2755)	-0.3855 (0.2821)
SCI_MATL	-0.1775 (0.2386)	-0.2194 (0.2370)	0.1550 (0.2340)	0.0955 (0.2215)
SCI_ELEC	-0.5288* (0.2918)	-0.4764 (0.2919)	-0.3935 (0.2430)	-0.3288 (0.2401)
TEC_CUSU	-0.0732 0.1017	-0.0414 (0.1019)	-0.0772 (0.1090)	-0.0463 (0.1077)
TEC_COMP	0.1190 (0.1019)	0.1118 (0.1012)	0.0368 (0.0972)	0.0350 (0.0959)
TEC_UNI		-0.1073* (0.0583)		-0.1170** (0.0544)
COOP_UNI	-0.3495* (0.2041)		-0.3343* (0.1819)	
COOP_CUST	0.4567** (0.2068)	0.4424** (0.2048)	0.2708 (0.1718)	0.2524 (0.1726)
TEC_CUST	-0.0030 (0.0028)	-0.0033 (0.0028)	0.0084** (0.0028)	0.0081*** (0.0027)
R&D_CAP	0.7753*** (0.2800)	0.7335*** (0.2790)	0.5570** (0.2645)	0.5112* (0.2632)
APPR_C	0.2797 (0.2457)	0.3101 (0.2479)		
χ^2 fields of research (3 d.o.f)	1.68	1.68	1.27	1.12
χ^2 information sources [a)]	0.96	1.58	0.42	1.79
Number of observation (d.o.f.)	119 (105)	119 (105)	125 (113)	125 (113)
Log likelihood				
Model $\overline{R}^2$	0.112	0.117	0.176	0.186
Model F-Test	2.15**	2.20**	3.41***	3.58***

Remark: Level of significance: * significant at the 0.1 level. ** significant at the 0.05 level. *** significant at the 0.01 level. OLS-estimation results are corrected for heteroscedasticity. a.) Model (1): 2 d.o.f.; Model (2): 3 d.o.f.

Table 7
Results of the Estimations on R&D Activity

Variables	Coefficients (*Standard Deviation*)			
	R&D_NEC		R&D_EXT	
	(1)	(2)	(1)	(2)
CONSTANT	-0.5333 (0.9285)	-0.8049 (0.9362)	-0.2697 (0.4991)	-0.3144 (0.4851)
SIZE	0.3103** (0.1336)	0.2857** (0.13441)	0.2204*** (0.0615)	0.2062*** (0.0576)
DIVERS	0.1406 (0.4408)	0.2110 (0.4423)	0.2746 (0.2811)	
COMP_H	0.6898* (0.3490)	0.7322** (0.3479)	0.2522 (0.1928)	0.1831 (0.1998)
CUST_H	0.0213 (0.3253)	0.0497 (0.3293)	-0.2561 (0.1654)	-0.2037 (0.1654)
SCI_MATH	-1.6342** (0.8142)	-1.5752* (0.8247)	-0.0378 (0.2878)	0.0497 (0.2868)
SCI_MATL	-0.8907** (0.3734)	-0.8722** (0.3710)	-0.3352 (0.2878)	-0.2371 (0.1988)
SCI_CHEM	-0.9001 (0.6076)	-0.8766 (-1.406)	0.5931*** (0.2331)	0.6090*** (0.2289)
TEC_CUSU	0.2729* (0.1539)	0.2503 (0.1586)	0.0926 (0.0929)	0.0595 (0.0926)
TEC_COMP	0.1045 (0.1772)	0.1049 (0.1795)	-0.0045 (0.0820)	-0.0272 (0.0814)
TEC_UNI		0.1321 (0.1020)		0.1102** (0.0485)
COOP_UNI	0.2008 (0.3634)		0.4581*** (0.1711)	
COOP_CUST	0.8659* (0.4529)	0.7966* (0.4575)	0.2851* (0.1626)	0.2899* (0.1628)
TEC_CUST	-0.0060 (0.0047)	-0.0052 (0.0048)	-0.0067** (0.0026)	-0.0076*** (0.0026)
R&D_CAP	-0.7942* 0.4145)	-0.7161* (0.4194)	0.3710* (0.1982)	0.3314* (0.1944)
APPR_PA	0.1025 (0.0950)	0.1044 (0.0962)	0.0368 (0.0450)	0.0544 (0.0454)
ρ			0.02 (124.98)	0.02 (79.95)
χ^2 fields of research (3 d.o.f.)	10.04**	9.20**	8.60**	8.44**
χ^2 information sources [a)]	3.45	4.84	3.07	5.7
Number of obs. (d.o.f.)	256 (241)	256 (241)	234 (219)	237 (219)
Log likelihood	-42.532	-41.793	-358.011	-351.555
McFadden R^2	0.433	0.443	0.106	0.095
Model F-Test	64.971	66.447	50.555	73.855

Remark: Level of significance: * significant at the 0.1 level. ** significant at the 0.05 level. *** significant at the 0.01 level.
a) Model (1): 2 d.o.f.; Model (2): 3 d.o.f.

Table 8
Results of the Estimations on the Innovation Output

Variables	Coefficients (*Standard Deviation*)			
	INNO_NEW		INNO_IMP	
	(1)	(2)	(1)	(2)
CONSTANT	-0.2991 (0.3735)	-0.4881 (0.3831)	-1.7204*** (0.3125)	-1.8388*** (0.3238)
SIZE	0.0874** (0.0419)	0.0918** (0.0408)	0.1704*** (0.0378)	0.1788*** (0.0373)
DIVERS	-0.3113* (0.1643)	-0.2946* (0.1626)		
CUST_H			-0.2280* (0.1194)	-0.2229** (0.1196)
SCI_MATH	0.2482 (0.2051)	0.2825 (0.2051)	0.3203* (0.1811)	0.3329* (0.1995)
SCI_MATL	-0.7125*** (0.1402)	-0.6893*** (0.1386)	0.1826 (0.1367)	0.2145 (0.1364)
SCI_ELEC	0.0618 (0.1706)	0.0299 (0.1705)	-0.0467 (0.0594)	-0.0721 (0.1665)
TEC_CUSU	0.0278 (0.0585)	0.0175 (0.0583)	0.1124** (0.0598)	0.1016* (0.0570)
TEC_COMP	-0.0113 (0.0599)	0.0169 (0.0597)	0.1000* (0.0594)	0.0997* (0.0596)
TEC_UNI		0.0612* (0.0336)		0.0443 (0.0333)
COOP_UNI	0.0962 (0.1197)		0.1935* (0.1175)	
COOP_CUST	0.2835** (0.1217)	0.2903** (0.1207)	0.0746 (0.1210)	0.0892 (0.1208)
TEC_CUST	0.0018 (0.0017)	0.0019 (0.0017)	0.0004 (0.0017)	0.0005 (0.0017)
R&D_CAP	0.0800 (0.1608)	0.0973 (0.1602)	0.0667 (0.1552)	0.0800 (0.1557)
APPR_PR	-0.1092*** (0.0342)	-0.1122*** (0.0341)	0.1103*** (0.0333)	0.1063*** (0.0334)
APPR_PA	0.0629* (0.0338)	0.0631* (0.0336)		
σ	0.8932*** (0.0393)	0.8884*** (0.0391)	0.8936*** (0.0393)	0.8869*** (0.0384)
χ^2 fields of research (3 d.o.f)	27.83***	27.26***	5.04	4.09
χ^2 information sources [a)]	0.26	3.52	5.39*	6.10
Number of observation	263	263	267	267
Degrees of freedom	249	249	254	254
Log likelihood	-343.492	-342.168	-346.806	-347.273
Model χ^2	324.18***	326.83***	314.30***	313.37***

Remark: Level of significance: * significant at the 0.1 level. ** significant at the 0.05 level. *** significant at the 0.01 level. Tobit estimations (double censored). a) Model (1): 2 d.o.f.; Model (2): 3 d.o.f.

Table 9
Results of the Estimations with Absorptive Capacities

Variables	Coefficients (*Standard Deviation*)			
	R&D_INT	**R&D_EXT**	**INNO_NEW**	**INNO_IMP**
CONSTANT	0.1373*** (0.0336)	-0.1736 (0.4811)	-0.2515 (0.4187)	-1.1617*** (0.4263)
SIZE	-0.0039* (0.0022)	0.2169*** (0.0595)	0.0785* (0.0445)	0.0808** (0.0407)
DIVERS	0.01211 (0.0095)	0.3319 (0.2499)	-0.3543* (0.2068)	-0.1853 (0.1831)
SCR	-0.0434** (0.0215)			
COMP_H	-0.0027 (0.0072)	0.2526 (0.1863)	-0.0333 (0.1322)	-0.0439 (0.1546)
BCR	-0.0276 (0.0470)			
SCR*BCR	0.0777*** (0.0288)			
CUST_H	0.0023 (0.0067)	-0.2679* (0.1564)		
SCI_MATH	0.0006 (0.0144)	-0.0258 (0.2816)	0.2716 (0.2202)	0.3347* (0.2010)
SCI_MATL	-0.0090 (0.0123)	-0.3365* (0.1883)	-0.7085*** (0.1564)	0.2489 (0.1539)
SCI_ELEC/SCI_CHEM	-0.0272** (0.0123)	0.5604** (0.2263)	0.0547 (0.2036)	-0.0869 (0.1801)
TEC_CUSU	0.0053* (0.0031)	0.0794 (0.0829)	0.0145 (0.0578)	0.0839 (0.0571)
TEC_COMP	0.0121*** (0.0037)	0.0207 (0.0779)	-0.0081 (0.0612)	0.0901 (0.0636)
COOP_UNI	-0.0133* (0.0081)	0.2059 (0.1919)	0.0172 (0.1506)	-0.4352 (0.2841)
COOP_UNI*R&D_BAS	0.0240** (0.0113)	0.8496*** (0.2794)	0.3662* (0.2126)	
COOP_UNI*R&D_LAB				0.7060** (0.3011)
COOP_CUST	0.0118* (0.0072)	0.3150** (0.1575)	0.2810** (0.1266)	0.0293 (0.1341)
TEC_CUST	-0.0004*** (0.0001)	-0.0077*** (0.0025)	0.0016 (0.0019)	0.0008 (0.0020)
R&D_CAP	0.0044 (0.0095)	0.3323* (0.1899)	0.1019 (0.1876)	0.1327 (0.1930)
APPR_C	0.0250*** (0.0081)			
APPR_PA	-0.0025 (0.0016)	0.0352 (0.0445)	0.0592* (0.0350)	-0.0212 (0.0329)
APPR_PR	-0.0051*** (0.0019)		-0.1013*** (0.0377)	0.1126*** (0.0329)
σ			1.0853*** (0.3040)	1.2066*** (0.2831)
χ^2 fields of research (3 d.o.f)	10.91**		22.39***	4.99
Number of obs. (d.o.f.)	236 (215)	234 (218)	256 (240)	256 (240)
Log likelihood	416.934	-352.690	-330.111	-328.070
McFadden R²		0,081		
Model F-Test	5.27***			
Model χ^2	349,66***		440.87***	351.77***

Remark: Level of significance: * significant at the 0.1 level. ** significant at the 0.05 level. *** significant at the 0.01 level.

Appendix

Table A1
Factor Matrix of External Sources of Technological Information

External Sources	TEC_COMP	TEC_SCIE	TEC_CUSU
Reverse engineering	***0.845***	0.033	0.094
Competitors	***0.770***	0.232	0.131
Professional associations	0.074	***0.847***	0.108
Universities	0.153	***0.791***	0.043
Suppliers	-0.026	0.098	**0.873**
Customers[a)]	0.320	0.051	**0.624**
Eigenvalue	2.071	1.048	0.923
Explained variance	0.345	0.175	0.154

Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.6087; Bartlett Test of Sphericity: 210.680.
Remark: (a) automakers and/or systems-suppliers.

Table A2
Factor Matrix of Fields of Academic Research for Suppliers' Innovation Activities

Fields of academic research	SCI_MATH	SCI_MATL	SCI_CHEM	SCI_ELEC
Theoretical mathematic	***0.878***	-0.087	0.201	0.137
Applied mathematic & operation research	***0.864***	0.196	0.067	-0.033
Theoretical physic	***0.618***	-0.019	0.527	0.246
Informatic and computer science	***0.599***	0.438	-0.144	0.214
Metallurgy	-0.051	***0.775***	0.044	0.135
Materials science	0.181	***0.751***	0.352	0.040
Mechanical engineering	0.137	***0.683***	-0.016	0.282
Theoretical chemistry	0.265	0.002	***0.875***	-0.028
Applied chemistry	-0.055	0.216	***0.840***	-0.064
Electrical engineering	0.125	0.148	-0.009	***0.925***
Electronic science	0.105	0.278	-0.026	***0.899***
Eigenvalue	3.703	2.040	1.488	1.030
Explained variance	0.337	0.185	0.135	0.094

Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.6998; Bartlett Test of Sphericity: 561.235.

Table A3
Factor Matrix of the Novelty of Innovations

Kind of Innovation	**INNO_NEW**	**INNO_IMP**
New products	***0.862***	-0.017
New production processes	***0.789***	0.398
Improved products	0.208	***0.809***
Improved production processes	0.027	***0.772***
Eigenvalue	1.410	1.339
Per cent of explained variance	0.352	0.335

Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.7546; Bartlett Test of Sphericity: 414.204.

Remark: Importance of the development of new or improved products or production processes (rating on a seven-point Likert scale from 1 = no importance to 7 = high importance.