



ELSEVIER

Research Policy 30 (2001) 297–312

research  
policy

www.elsevier.nl/locate/econbase

# Who cooperates on R & D?

Michael Fritsch\*, Rolf Lukas

*Technical University Bergakademie Freiberg, Faculty of Economics and Business Administration, Lessingstraße 45,  
D-09596 Freiberg, Germany*

Accepted 3 December 1999

---

## Abstract

Based on a sample of 1800 German manufacturing enterprises, we analyze the propensity to maintain different forms of R&D cooperation with customers, suppliers, competitors and public research institutions. We find a relatively stable set of characteristics of those enterprises that are engaged in R&D cooperation. According to our results, enterprises that maintain such relationships tend to be relatively large and have a high share of R&D. They are likely to have a ‘Gatekeeper’ who is screening the environment relevant for the innovation activity and are characterized by a relatively high aspiration level of their R&D activities. Industry effects are mainly found with regard to the number of R&D cooperations and are much less pronounced for the propensity to engage at all in cooperative R&D. The interregional differences pertain to the propensity to cooperate as well as to the number of cooperative relationships. © 2001 Elsevier Science B.V. All rights reserved.

*JEL classification:* D21; L6; O32

*Keywords:* R&D cooperation; Innovation; Manufacturing industries

---

## 1. Introduction

A division of innovative labor between different organizations includes the exchange of information between the parties involved. However, many kinds of such information relevant for innovation processes cannot simply be traded on neoclassical ‘spot markets’ (cf. Geroski, 1995). A transfer of such information often needs the framework of a ‘cooperative’ relationship or is at least stimulated by such kind of a relationship. Therefore, R&D cooperation consti-

tutes a crucial ingredient of a division of innovative labor.

In contrast to its importance for innovation processes, our knowledge about the determinants and effects of R&D cooperation is still rather limited. In this paper we analyze the characteristics of manufacturing enterprises<sup>1</sup> that maintain different forms of R&D cooperation in contrast to those enterprises that do not cooperate on R&D. Such an investigation may lead us to a number of insights. First, it can provide hints on the factors that are responsible for

---

\* Corresponding author. Tel.: +49-3731-39-24-39; fax: +49-3731-39-36-90.

*E-mail address:* fritschm@vwl.tu-freiberg.de (M. Fritsch).

---

<sup>1</sup> The term ‘enterprise’ here refers to a productive unit at a specific location that may be part of a firm with several such units at different locations. This kind of observation unit is sometimes also referred to as ‘establishment’.

the decision to cooperate on R&D.<sup>2</sup> Second, in analyzing the differences between firms with and without R&D cooperation, we can test a number of hypotheses. Such hypotheses may concern, for example, the importance of a ‘Gatekeeper’ for cooperative relationships or the impact of R&D cooperation on internal R&D activities. Third, knowing the characteristics of firms that cooperate is necessary for analyzing regional or industry-specific effects. These characteristics are the variables to be controlled for when we want to answer questions like “Is the propensity for R&D cooperation in Industry A or Region A higher than in Industry B or Region B?”

Starting with a brief description of our data base (Section 2) we give an overview on hypotheses explaining the behavior of firms with regard to R&D cooperation (Section 3). We then examine the distribution of different forms of R&D cooperation in the sample (Section 4). In Section 5, we develop our empirical model and report results of the multivariate analyses. Finally, we draw some conclusions (Section 6). In general, our analyses reveal that R&D cooperation is a rather widespread phenomenon. However, we find considerable differences between enterprises and industries in the propensity to cooperate on R&D and with regard to the number of cooperative relationships with different types of partners. In contrast to previous studies, we are able to clearly identify a certain set of variables that distinguish firms that cooperate on R&D from firms that do not. This set of variables appears to be more or less the same for all the different kinds of R&D cooperation analyzed.

<sup>2</sup> A comparison of firms or enterprises that cooperate with those that do not cooperate provides only indirect and uncertain evidence about the determinants of the R&D cooperation, because these characteristics may not be a reason for the cooperation but a result of it. To identify those characteristics of firms that may have an impact on the decision to cooperate, such an analysis has to be conducted for a point in time that lies before the beginning of the cooperative relationship. However, all analyses we know that try to investigate the determinants of R&D cooperation based on a larger number of cases do not fulfil this demand but compare firms that cooperate with firms that do not. We suspect that the reason for this shortcoming is missing data.

## 2. Data

Our analysis is based on data gathered by postal questionnaires from manufacturing enterprises in three German regions. These regions were Baden (the south-west part of the state of Baden-Württemberg), Hanover–Brunswick–Göttingen in the state of Lower Saxony, and Saxony, one of the new German states and until 1990 under a communist regime.<sup>3</sup> The questionnaire was sent out to all enterprises with 10 or more employees.<sup>4</sup> The resulting data set contains information on certain characteristics of the enterprises such as the number of employees, the amount of turnover, the product program, the resources devoted to innovation and the number of cooperative relationships with other firms as well as with public research institutions. For the three Ger-

<sup>3</sup> A dominate aim of the project was to analyze differences in the workability of regional innovation systems. In order to secure sufficient variance in the data, the case study regions chosen were expected to show significant differences with regard to their innovation systems. Baden can be characterized as a rather prosperous region with a far above-average performance with regard to innovation. According to conventional wisdom, transfer institutions and cooperative relationships are well developed in this region (see Semlinger, 1993; Cooke, 1996; Heidenreich and Krauss, 1998). The region Hanover–Brunswick–Göttingen has a high share of employment in large-scale industries (e.g., automobiles, steel) and the proportion of employment in new innovative industries is comparatively low. Despite various policy attempts to improve innovation performance in this region, the innovation system is said to have considerable deficiencies (cf. Schasse, 1995). Saxony has a long tradition in manufacturing, particularly in the mechanical engineering industry. Due to the breakdown of the manufacturing sector after the fall of the Iron Curtain, it is dominated by small establishments. For an analysis of the performance of the three regions with regard to innovation see Fritsch et al. (1999). The database and the regional framework are more fully described in Fritsch and Lukas (1999).

<sup>4</sup> The response rate amounted to 17.8% in Baden, 20.6% in the Hanover region and 27.7% in Saxony. Because the focus of the questions was on innovation, one could expect a relatively low representation of non-innovative enterprises in the data. A non-response analysis revealed that there is no such bias with respect to the share of innovative enterprises, however, the innovative enterprises in the sample tend to have a slightly higher share of R&D personnel than the overall sample.

man regions our data set comprises more than 1800 enterprises.<sup>5</sup>

To gather information on cooperation necessitates defining what a cooperation is. Giving such a definition, however, is a delicate task. In our questionnaire, we tried to assess the existence of cooperative relationships with different types of partners separately. These types of cooperation partners were

- customers,
- manufacturing suppliers<sup>6</sup>,
- “other” firms, and
- publicly funded research institutions.

The “other” firms are non-vertically related businesses, particularly including competitors. Most of the relationships to “other” firms are horizontal in nature. In a first question, respondents were asked if in the last 3 years their enterprise had maintained relationships with customers, manufacturing suppliers or “other” firms which in character went beyond “normal” business interaction. In the subsequent questions, four categories of such cooperative relationships were given that constitute a closer definition. Respondents were asked to attach weights to these types of cooperative relationships on a three-grade scale ranging from “unimportant” (= no such kind of cooperation) to “very important.” For cooperative relationships with customers and manufacturing suppliers these categories were “casual contact for information purposes”, “organized exchange of information and experiences”, “involvement in planning and operation of projects” and “pilot use of an innovation.” For the assessment of cooperations with “other” firms the two last categories were substituted by “joint use of equipment or laboratories” and “joint R&D projects”. With regard to cooperation with publicly funded research institutions the cate-

gories for the type of relationship were “use of equipment or laboratories”, “research contracts”, “joint R&D projects” and “collaboration with regard to thesis” (cf. Table 1). We also inquired about the number of cooperative relationships with the different types of partner.

Because of the way the questions were formulated, we cannot completely preclude that respondents have reported cooperative relationships that had nothing to do with innovation activities. However, to judge the degree to which a certain relationship is completely separate from innovation activities or not may be quite hard or even impossible even for the managers of the respective firms. For this reason,

Table 1  
Share of enterprises with a certain kind of cooperative relationship (percentages)

Type of relationship	Share of enterprises with the respective type of relationship (%)
Customers	61.6
• casual contact for information purposes	52.6
• organized exchange of information and experiences	40.0
• involvement in planning and operation of projects	44.0
• pilot use of an innovation	32.2
Suppliers	49.5
• casual contact for information purposes	40.8
• organized exchange of information and experiences	31.2
• involvement in planning and operation of projects	36.1
• pilot use of an innovation	21.4
“Other” firms	32.5
• casual contact for information purposes	25.6
• organized exchange of information and experiences	19.3
• joint use of equipment or laboratories	12.8
• joint R&D projects	14.6
Publicly funded research institutions	33.8
• use of equipment or laboratories	16.5
• research contracts	14.9
• joint R&D projects	22.2
• thesis collaboration	18.8

<sup>5</sup> We are not aware of a certain bias of the sample when taking the data for all three regions together. By including regional dummy variables in the multivariate analyses we control for region specific effects.

<sup>6</sup> Information on R&D cooperation with service firms was gathered on the basis of a different kind of question in a different way and is not included here.

we decided not to generally limit the first question to those cooperative relationships that — in the eyes of the respondents — were associated with innovation but to ask with the second question about the importance of different types of relationship. In analyzing the characteristics of enterprises that were engaged in a certain form of cooperative relationship with a certain kind of partner (cf. Fritsch and Lukas, 1998), we find no serious differences between the various forms of cooperative relationship. Obviously, the characteristics of enterprises that cooperate are more or less similar, largely independent of how closely the relationship is associated with innovation activities.

### 3. Hypotheses and indicators

What kind of enterprises can be expected to maintain cooperative relationships? The literature on the motives for becoming involved in an R&D cooperation discusses a number of characteristics of firms, the market structure, the effect of positive and negative spillovers of R&D activities on other enterprises, the opportunity to realize cost-savings, to overcome internal bottlenecks and to reduce time to market, the firm's strategy as well as certain features of the relevant technology.<sup>7</sup> With regard to the relationship between the characteristics of a firm and its involvement in R&D cooperation, we expected firm size to be an important factor. Assuming that there exists a given probability for cooperation per unit of economic activity, we may predict that large enterprises, which, by definition, are characterized by a relatively large amount of economic activity, will be more likely to cooperate than smaller enterprises and will have a higher number of cooperative relationships. The indicator representing business-size in our estimates is (the natural logarithm of) the number of employees. We also expected that the incentive or

the need for cooperation would increase with the R&D intensity of the respective enterprise. R&D intensity may also be interpreted as an indicator for the absorptive capacity of an enterprise, i.e., its ability to identify and use relevant external knowledge for its own innovation activities (Cohen and Levinthal, 1989; 1990). Our measure of R&D intensity is the percentage of R&D employees.

The literature suggests that the existence of a 'Gatekeeper', i.e., a person who systematically monitors external information that could be relevant for a firm's innovation activities, may be necessary or at least conducive to R&D cooperation (cf. Allen, 1967; Tushman and Katz, 1980). Therefore, we may hypothesize that the existence of such a 'Gatekeeper' increases the probability of R&D cooperation. Our 'Gatekeeper' variable has the value 0 if no such person exists. If there is a 'Gatekeeper', the effect may vary according to the extent that he or she is systematically transferring information to the relevant department or person inside the firm. For enterprises with a 'Gatekeeper' who is not systematically transmitting this information, the variable has the value 1; if such a transfer occurs only occasionally, the value is 2 and if such transfer is routine, the value of 3 is assigned.<sup>8</sup>

A main motive of R&D cooperation could be to increase the degree of specialization by outsourcing parts of the innovation process. In this case the cooperation constitutes a substitute for internal R&D activities and we may expect that the higher level of specialization leads to a lower share of value added to turnover in those firms that maintain R&D cooperations. Therefore, a negative value of the coefficient for the share of value added to turnover would indicate the importance of specialization as a motive or a result of cooperation on R&D. If the share of value added to turnover is higher for firms that cooperate, this may reflect a need for additional

<sup>7</sup> See Fuschfeld and Haklisch (1985), Katz (1986), Katz and Ordover (1990), Link and Bauer (1987), Link and Rees (1990), D'Aspremont and Jacquemin (1988), Marjit (1991), Brockhoff (1992), Brockhoff et al. (1991), Kamien et al. (1992), Kleinknecht and Reijnen (1992), Teece (1992), König et al. (1994), Vonortas (1997).

<sup>8</sup> The question was formulated as follows: "Is external information that may be relevant for innovation projects in this business systematically monitored and collected?" Response categories were "No", "Yes — transfer of this information to the relevant department or person is routine", "Yes — the information is passed on internally only on occasion" and "Yes — but there is no systematic internal distribution of the information collected".

internal effort to build up some absorptive capacity in order to identify and use the knowledge of the cooperation partner for a firm's own purposes.

Our data set provides a number of variables on the objectives and on certain features of R&D activities. With respect to product innovation, respondents were asked to indicate on a three-grade scale the degree to which innovation activities were aimed at generating completely new products in contrast to product modification, i.e., a further development of products that are already part of their product program. Assuming that product modification in many cases involves 'only' incremental innovation, an emphasis on completely new products may be regarded as an indication of a relatively high aspiration level of product innovation activities. We also asked respondents for an assessment of the importance of different objectives of process innovation activities on a three-grade scale. The answers to the response category "reduction of total production time" may be interpreted as an indication of the emphasis placed on rationalization effects in process innovation activities.<sup>9</sup>

The importance of a number of other possible motives for R&D cooperation discussed in the literature, such as the internalization of positive spillovers of innovation activities (Katz, 1986; Katz and Ordover, 1990; König et al., 1994), the chance to overcome internal bottlenecks or the opportunity to share costs by conducting R&D projects jointly (Brockhoff et al., 1991; Teece, 1992) cannot be analyzed in our empirical investigation because the data set provides no information on these issues. The impact of market structure, of a firm's market share or of certain features of the relevant technology (e.g., a need for multi-disciplinary research) can be tested

by including market concentration indicators at a two- of three-digit industry code level or with dummy variables for the 13 industry groups the enterprises belong to.<sup>10</sup> Regional dummy variables for location in Baden and in the Hanover–Brunswick–Göttingen region are included to test for regional differences in the propensity to cooperate on R&D.<sup>11</sup>

The few empirical analyses on characteristics of firms engaged in R&D cooperation did not arrive at a clear pattern of variables or factors that appear to be conducive to entering into cooperative relationships.<sup>12</sup> According to these studies, firms that cooperate on R&D tend to be relatively large, have high market shares and are characterized by a high R&D intensity.<sup>13</sup> There are some hints that characteristics of the output market and of the respective technology may also play a role in explaining R&D cooperation.<sup>14</sup>

<sup>10</sup> The control group was the medicine technology and optical instruments industry. The industry groups were based on the German two-digit classification, which has 22 industries in manufacturing. We had to aggregate some of these industries in order to secure a sufficient number of cases in each industry group.

<sup>11</sup> For a detailed analysis of regional differences in cooperation behavior see Fritsch (1999) as well as Fritsch and Lukas (1999).

<sup>12</sup> Fusfeld and Haklisch (1985), Link and Bauer (1987), Brockhoff et al. (1991), Marjit (1991), Kleinknecht and Reijnen (1992), König, Licht and Staat (1994), Vonortas (1997).

<sup>13</sup> König et al. (1994) find that the propensity to cooperate increases with firm size (number of employees) but that the impact of R&D intensity is hardly significant. In the analyses by Vonortas (1997, p. 151), firm size (measured by sales) also has a statistically significant positive impact on the propensity to maintain R&D cooperation while the impact of R&D intensity turns out to be statistically significant with a positive sign in only one of the five industry groups under inspection. Link and Bauer (1987, p. 253) show that the probability of having an R&D cooperation is positively related to size (sales) as well as with absolute R&D expenditure. Based on their empirical investigation, they conclude that a firm's market power is the principal determinant that steers involvement in cooperative research. In the multivariate analyses by Kleinknecht and Reijnen (1992), size and R&D intensity only matter for cooperation private firms have with public research institutions but not for relationships with other private firms. However, the information on the percentage of firms which cooperate on R&D in different size classes given by Kleinknecht and Reijnen (1992, p. 349) shows clearly that the share of firms that maintain at least one R&D cooperation increases with size (number of employees).

<sup>14</sup> Cf. Kleinknecht and Reijnen (1992), König et al. (1994).

<sup>9</sup> On a firm or enterprise level, cost savings are very frequently the result of a reduction of production time which represents a good indicator for many kinds of rationalization effects (see Ewers et al., 1990 for a detailed analysis of this issue). The other response categories were "reduction of negative effects on the environment", "increased flexibility of production", "reduction of unit labor costs", "improvement of product quality", "reduction of energy or materials input" and "improvement of working conditions". None of these variables proved to be significant when introduced in addition to "reduction of total production time" into the model.

#### 4. Overview of forms, numbers and combinations of R&D cooperation

Generally, we find that R&D cooperation is a quite widespread phenomenon. Slightly more than 60% of the manufacturing enterprises in our sample have cooperative relationships with their customers, nearly 49% maintain cooperation with their manufacturing suppliers, 33% with publicly funded research institutions and about 31% cooperate with “other” enterprises (Table 1).

Looking at the different kinds of cooperative relationships with suppliers, customers and “other” firms, casual contacts for information purposes have the highest share. For cooperation with vertically related firms, the involvement in planning and operation of innovation projects constitutes the second important type followed by an organized exchange of information and experiences. About 30% of enterprises which maintain cooperative relationships with their customers stated that these customers act as pilot users of their new products. Looking at the different kinds of relationship with suppliers, we find that 21.4% of our enterprises act as pilot users for their suppliers’ innovation. In the relationships with “other” firms, an organized exchange of information and experiences (19.3%) is the second important

form of cooperation followed by joint R&D projects (14.6%) and joint use of equipment or laboratories (12.8%). In relationships with publicly funded research institutions, joint R&D projects (22.2%) and thesis collaboration (18.8%) play the most prominent roles, followed by use of equipment or laboratories (16.5%) and contracted research (14.9%).

If we take only those enterprises that maintain at least one relationship with a certain kind of partner and look at the median number of cooperative relationships these enterprises have with partners of this particular type, we find that this number is highest for the cooperative relationships with customers and lowest for the cooperative relationships with publicly funded research institutions (Fig. 1). Particularly for cooperations with customers and manufacturing suppliers, the number of relationships increases with size. This size effect is not at all surprising because, due to the relatively high level of economic activity in larger firms, we can assume that large firms also have a greater number of external ties than small firms do. However, looking at the cooperative relationships with public research institutions and “other” firms, we find that the median number of such relationships is much less shaped by the size of the respective enterprise. In fact, the median number of cooperative relationships with research institutions is

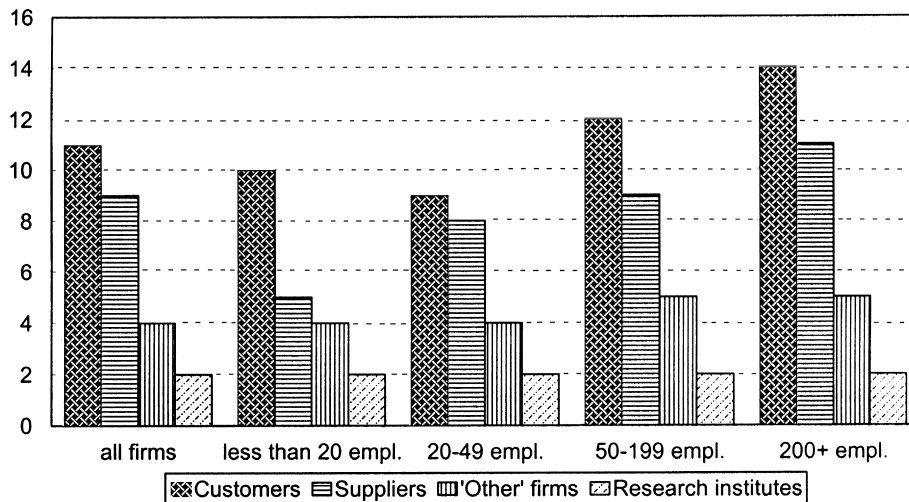


Fig. 1. Median number of cooperative relationships with different kinds of external partners in different enterprise size categories.

Table 2  
Combinations of cooperative relationships with different kinds of partners\*

Firms which cooperate with...	... also cooperate with (in percent)			
	Customers	Suppliers	“Other” firms	Research institutions
Customers	–	66.1 (33.5)	39.7 (22.1)	41.9 (23.9)
Suppliers	82.0 (33.1)	–	39.7 (22.1)	43.4 (28.4)
‘Other’ firms	75.1 (21.9)	60.4 (22.0)	–	45.3 (34.0)
Research institutions	76.3 (23.8)	64.1 (29.5)	43.6 (34.1)	–
Propensity to cooperate in the overall sample	61.6	49.5	32.5	33.8

\* Deviation from the overall share of enterprises with a cooperative relationship with the respective partner (Table 1) in percent given in parentheses.

the same in all enterprise size categories. Based on the mean number of cooperations,<sup>15</sup> we also find a positive relationship between the number of cooperations with research institutes and size. Investigating the bivariate relationship between the number of cooperative relationships with a certain type of partner and size, we find that this number tends to rise less than proportionally with increasing employment for all types of partners.

Enterprises that have a cooperative relationship with one kind of partner are more likely to also maintain a cooperative relationship with another type of partner (Table 2). For example, 66.1% of enterprises that cooperate with their customers are also engaged in R&D cooperation with suppliers compared to 49.5% of enterprises that have a cooperative relationship with suppliers in the overall sample. This result corresponds to the so-called “chain-linked” model of the innovation process (Kline and Rosenberg, 1986, pp. 289–294)<sup>16</sup>. The chain-linked model stresses that inputs from the science sector, information about customers needs and possible inputs, etc., may be important during the whole innovation process and not only at certain stages as the “linear” model would suggest. This implies that innovation processes may be characterized by R&D cooperations not only with one type of partner but

with different types at the same time or stage (cf. Rothwell, 1991). Accordingly, we may explain our finding by the positing that a certain threshold to engage in an R&D cooperation exists, and that once this hurdle is overcome, firms find it easier to start such cooperation with other types of partner. This would imply that we should find empirically more or less the same determinants for the propensities to cooperate with different kinds of partner. Indeed, this is one result of our multivariate analyses (cf. Section 5.2).

## 5. Multivariate analyses

### 5.1. Estimation approach

In our empirical model, we assume that the observed behavior with regard to cooperation may be interpreted as the result of a two-stage decision-making process. The first stage of this process is the decision to cooperate at all on R&D with a certain partner. Because this decision determines the manner in which the innovation process will be organized, we suspect that it is rather strategic in character and strongly shaped by long term considerations. The second stage of the decision-making process concerns the number of external cooperative links and the choice of cooperation partners. We assume that these kinds of decision, in contrast to the first stage, are more operative in nature and are mainly determined by short-term requirements and possibilities. Due to the different characteristics of decision processes at the two stages, we expect to find differ-

<sup>15</sup> We report the median number of cooperative relationships in Fig. 1 because median values are largely robust with regard to extreme values.

<sup>16</sup> For a rather similar view of the innovation processes, see Rothwells (1993, pp. 36–39) description of the “systems integration and networking model”.

Table 3

The propensity to cooperate — logit-poisson hurdle models including all enterprises<sup>a</sup>

	Cooperation with			
	Customers		Suppliers	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Number of employees (ln)	0.324 ** (6.24)	0.249 ** (43.89)	0.406 ** (8.08)	0.243 ** (31.68)
R & D-intensity (share of R & D employees)	2.317 ** (3.96)	−0.616 ** (9.83)	1.751 ** (3.55)	0.984 ** (15.91)
Share of value added to turnover (in percent)	0.003 (1.06)	0.006 ** (15.82)	−0.10 ** (3.17)	−0.008 ** (13.48)
Dummy for location in Hanover region	−0.258 (1.17)	0.625 ** (37.33)	0.070 (0.61)	0.664 ** (28.24)
Dummy for location in Baden	−0.265 (1.90)	0.860 ** (53.40)	−0.312 * (2.27)	1.043 ** (44.72)
<i>Industry dummies:</i>				
Food, beverages and tobacco	−0.871 ** (2.80)	0.885 ** (30.40)	−0.316 (1.04)	−0.111 (1.77)
Textiles, clothing, leather	−0.248 (0.82)	−0.059 * (1.96)	−0.091 (0.31)	0.491 ** (10.17)
Wood (excluding furniture)	−0.548 (1.60)	−0.703 ** (12.93)	−0.228 (0.67)	0.250 ** (3.74)
Paper, printing, publishing	−0.492 (1.65)	−0.207 ** (6.32)	−0.071 (0.24)	−0.180 ** (3.32)
Furniture, jewelry, musical instruments, toys	−0.490 (1.49)	0.041 (1.14)	−0.216 (0.67)	1.096 ** (20.32)
Mineral oil, chemicals	0.066(0.19)	0.663 ** (22.39)	−0.172 (0.52)	0.702 ** (12.20)
Rubber and plastics	−0.201 (0.64)	−0.156 ** (4.83)	0.112 (0.37)	0.595 ** (11.67)
Stone, ceramics and glass	−0.133 (0.43)	0.995 ** (37.88)	0.021 (0.07)	−0.261 ** (4.22)
Metal products, recycling	−0.290 (1.13)	−0.306 ** (11.76)	−0.193 (0.78)	0.342 ** (7.58)
Mechanical engineering	0.083 (0.31)	−0.519 ** (19.67)	0.094 (0.38)	0.551 ** (13.23)
Vehicles	0.291 (0.73)	−1.486 ** (25.86)	−0.051 (0.144)	0.236 ** (4.12)
Data processing, electrical and electronic equipment	0.409 (1.30)	−0.690 ** (20.73)	0.142 (0.49)	0.728 ** (16.91)
<i>Model summary:</i>				
$\chi^2$ for covariates	109.58	16489.29	121.95	5022.03
Significance $\chi^2$	0.000	0.000	0.000	0.000
Pseudo $R^2$ adj.	0.053	0.200	0.057	0.187
Number of cases	1 546	511	1 540	449
	Cooperation with			
	'Other' firms		Research institutions	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Number of employees (ln)	0.190 ** (3.87)	0.192 ** (11.35)	0.843 ** (13.56)	0.163 ** (5.32)
R & D-intensity (share of R & D employees)	1.845 ** (3.82)	−0.091 (0.56)	5.173 ** (8.57)	1.731 ** (6.43)
Share of value added to turnover (in percent)	0.003 (1.01)	0.014 ** (10.58)	0.007 * (2.18)	−0.008 ** (4.66)
Dummy for location in Hanover region	−0.246 (0.67)	0.124 * (2.43)	−1.070 ** (6.18)	−
Dummy for location in Baden	−0.603 ** (4.00)	0.354 ** (6.87)	−0.513 ** (3.18)	0.722 ** (9.38)
<i>Industry dummies:</i>				
Food, beverages and tobacco	−0.285 (0.88)	0.475 ** (3.77)	−0.540 (1.58)	0.066 (0.33)
Textiles, clothing, leather	−0.382 (1.22)	−0.159 (1.12)	−0.495 (1.55)	−0.206 (1.18)
Wood (excluding furniture)	−0.250 (0.67)	0.138 (0.83)	−1.000 * (2.31)	−0.210 (0.81)

Table 3 (continued)

	Cooperation with			
	'Other' firms		Research institutions	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Paper, printing, publishing	0.340 (1.15)	0.231 * (2.05)	-1.025 ** (3.00)	-0.735 ** (3.27)
Furniture, jewelry, musical instruments, toys	-0.382 (1.08)	0.436 ** (3.42)	-0.956 * (2.54)	-0.217 (1.03)
Mineral oil, chemicals	0.093 (0.27)	1.556 ** (14.95)	-0.343 (0.93)	0.645 ** (3.73)
Rubber and plastics	-0.155 (0.48)	-0.269 (1.78)	-0.637 (1.83)	0.165 (0.70)
Stone, ceramics and glass	-0.028 (0.09)	0.168 (1.39)	-0.478 (1.44)	0.065 (0.31)
Metal products, recycling	0.118 (0.46)	0.729 ** (8.13)	-0.726 ** (2.62)	-0.024 (0.18)
Mechanical engineering	0.094 (0.03)	0.408 ** (4.50)	0.029 (0.11)	0.449 ** (4.07)
Vehicles	-0.145 (0.39)	-0.274 (1.51)	-0.278 (0.70)	-0.083 (0.43)
Data processing, electrical and electronic equipment	0.081 (0.28)	0.488 ** (5.05)	-0.574 (1.83)	-0.278 (1.93)
<i>Model summary:</i>				
$\chi^2$ for covariates	59.74	668.51	359.53	232.22
Significance $\chi^2$	0.000	0.000	0.000	0.000
Pseudo $R^2$ adj.	0.030	0.155	0.181	0.126
Number of cases	1539	324	1537	318

<sup>a</sup> Estimated logit/poisson coefficients. Asymptotic/absolute *t*-values in parentheses.

\* Statistically significant at the 5% level.

\*\* Statistically significant at the 1% level.

ences with regard to the factors that govern the two kinds of features or decisions: the existence of at least one cooperative relationship and the number of cooperation partners.

In order to estimate the impact of the exogenous variables on the propensity to cooperate and on the number of cooperative relationships separately, a count data hurdle-model was applied.<sup>17</sup> This model consists of two parts. The first part is a logit model which aims to explain whether the particular enterprise has at least one cooperative relationship with a certain type of partner or not. The second part is restricted to those enterprises that have overcome this 'hurdle' of having at least one cooperative relationship with a certain type of partner and analyzes those factors that determine the number of such contacts. In this second step of analysis, a truncated-at-zero poisson regression-model is applied.

Let  $f_1$  represent the logit-function for overcoming the hurdle to have at least one cooperative relationship with a certain kind of partner;  $f_2$  describes the truncated-at-zero count model for the number of cooperative relationships once the hurdle is passed. If the dependent variable  $Y$  is the number of cooperative relationships with a certain kind of partner, then the probability model of the combined functions is given by

$$P(Y = 0) = f_1(0) \tag{1}$$

$$P(Y = y) = (f_2(y)(1 - f_1(0)) / (1 - f_2(0))) \tag{2}$$

with  $y \in \mathbb{N}$

or

$$P(Y = y) = (f_2(y) A), \tag{3}$$

respectively. The numerator of  $A$  in Eq. (3) is the probability to overcome the hurdle and the denomi-

<sup>17</sup> See Johnson and Kotz (1969) and Mullahy (1986) as well as Winkelmann and Zimmermann (1995) for a detailed description of these kinds of model.

Table 4

The propensity to cooperate — logit-poisson hurdle models including only enterprises with innovations<sup>a</sup>

	Cooperation with			
	Customers		Suppliers	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Number of employees (ln)	0.141* (2.01)	0.119** (18.14)	0.310** (4.79)	0.283** (31.52)
R & D-intensity (share of R & D employees)	0.599 (0.81)	-1.823** (21.52)	1.488* (2.22)	1.459** (20.56)
Share of value added to turnover (in percent)	0.002 (0.53)	-0.005** (13.87)	-0.009* (2.37)	-0.010** (14.55)
Gatekeeper	0.287** (4.38)	0.211** (23.90)	0.221** (3.52)	-0.064** (6.33)
Importance of new products as an objective of product innovation effort	0.206** (2.71)	-0.071** (10.14)	0.044 (0.63)	-0.166** (15.73)
Importance of cost reduction as an objective of process innovation effort	-0.075 (0.70)	0.118** (10.69)	0.212* (2.13)	0.172** (10.59)
Dummy for location in Hanover region	-0.187 (0.93)	0.828** (46.30)	0.055 (0.29)	0.762** (28.77)
Dummy for location in Baden	-0.213 (1.05)	0.401** (19.64)	-0.284 (1.53)	0.987** (37.61)
<i>Industry dummies:</i>				
Food, beverages and tobacco	-0.683 (1.66)	-1.048** (18.08)	0.095 (0.24)	-0.297** (4.23)
Textiles, clothing, leather	-0.091 (0.23)	-0.365** (11.14)	0.228 (0.60)	0.488** (9.54)
Wood (excluding furniture)	0.035 (0.07)	-1.720** (23.24)	-0.129 (0.28)	-0.540** (5.48)
Paper, printing, publishing	-0.074 (0.18)	-0.612** (17.26)	0.231 (0.60)	-0.618** (9.40)
Furniture, jewelry, musical instruments, toys	-0.216 (0.50)	-0.193** (5.11)	-0.286 (0.69)	0.975** (17.34)
Mineral oil, chemicals	-0.119 (0.28)	0.117** (3.71)	-0.324 (0.83)	0.384** (6.09)
Rubber and plastics	-0.038 (0.09)	-1.735** (31.98)	0.289 (0.72)	0.452** (8.245)
Stone, ceramics and glass	0.286 (0.66)	0.691** (23.90)	-0.080 (0.21)	-0.609** (7.92)
Metal products, recycling	0.026 (0.07)	-0.418** (14.73)	-0.106 (0.32)	0.061 (1.21)
Mechanical engineering	0.254 (0.75)	-1.082** (35.16)	0.029 (0.09)	0.337** (7.51)
Vehicles	0.380 (0.72)	-1.851** (29.52)	0.077 (0.15)	-0.268** (4.14)
Data processing, electrical and electronic equipment	0.605 (1.48)	-0.845** (23.82)	-0.081 (0.23)	0.595** (13.02)
<i>Model summary:</i>				
$\chi^2$ for covariates	67.88	14,660.02	81.00	5324.20
Significance $\chi^2$	0.000	0.000	0.000	0.000
Pseudo $R^2$ adj.	0.060	0.246	0.063	0.235
Number of cases	944	362	940	328
	Cooperation with			
	"Other" firms		Research institutions	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Number of employees (ln)	0.162** (2.62)	0.257** (11.61)	0.767** (9.99)	0.177** (4.77)
R & D-intensity (share of R & D employees)	1.766** (2.74)	-0.612** (2.83)	4.858** (5.95)	1.425** (3.96)
Share of value added to turnover (in percent)	0.004 (1.15)	0.019** (11.85)	0.004 (0.33)	-0.003 (1.57)
Gatekeeper	0.105 (1.61)	0.098** (3.84)	0.241** (3.30)	0.037 (0.74)
Importance of new products as an objective of product innovation effort	0.171* (2.42)	-0.008 (0.38)	0.174* (2.24)	0.086 (1.82)

Table 4 (continued)

	Cooperation with			
	'Other' firms		Research institutions	
	yes/no (logit)	no. of relations (poisson)	yes/no (logit)	no. of relations (poisson)
Importance of cost reduction as an objective of process innovation effort	-0.131 (1.32)	-0.218 ** (5.87)	-0.079 (0.07)	0.033 (0.53)
Dummy for location in Hanover region	-0.199 (1.09)	-0.212 ** (3.18)	-1.178 ** (5.56)	
Dummy for location in Baden	-0.439 * (2.31)	0.453 ** (7.58)	-0.532 ** (2.56)	0.166 (1.59)
<i>Industry dummies</i>				
Food, beverages and tobacco	0.029 (0.74)	0.492 ** (3.56)	-0.041 (0.09)	-0.272 (1.15)
Textiles, clothing, leather	0.026 (0.07)	-0.062 (0.40)	-0.123 (0.31)	-0.412 * (1.99)
Wood (excluding furniture)	0.229 (0.49)	0.148 (0.76)	-0.778 (1.45)	-0.235 (0.79)
Paper, printing, publishing	0.639 (1.70)	-0.116 (0.81)	-0.733 (1.72)	-0.840 ** (2.98)
Furniture, jewelry, musical instruments, toys	-0.055 (0.13)	0.632 ** (4.60)	-0.898 (1.94)	0.222 (0.93)
Mineral oil, chemicals	0.361 (0.93)	1.593 ** (14.05)	-0.284 * (0.66)	0.458 * (2.37)
Rubber and plastics	0.079 (0.19)	-0.338 (1.84)	-0.165 (0.38)	0.053 (0.20)
Stone, ceramics and glass	-0.154 (0.39)	-0.119 (0.67)	-0.173 (0.41)	-0.258 (0.99)
Metal products, recycling	0.360 (1.14)	0.620 ** (6.06)	-0.642 (1.83)	-0.201 (1.22)
Mechanical engineering	0.225 (0.73)	0.276 ** (2.69)	0.288 (0.87)	-0.136 (0.97)
Vehicles	0.305 (0.66)	0.083 (0.42)	-0.039 (0.07)	-0.219 (1.01)
Data processing, electrical and electronic equipment	0.258 (0.74)	0.554 ** (5.22)	-0.361 (0.94)	-0.243 (1.47)
<i>Model summary</i>				
$\chi^2$ for covariates	41.84	715.13	240.38	87.60
Significance $\chi^2$	0.002	0.000	0.000	0.000
Pseudo $R^2$ adj.	0.033	0.233	0.187	0.089
Number of cases	939	231	938	240

<sup>a</sup> Estimated logit/poisson coefficients. Asymptotic/absolute *t*-values in parentheses.

\* Statistically significant at the 5% level.

\*\* Statistically significant at the 1% level.

nator normalizes for  $f_2$ .<sup>18</sup> The expected value of the dependent variable is given by:<sup>19</sup>

$$E(Y) = \sum_{i=1}^n (y_i f_2(y_i) A) \quad (4)$$

The logit-poisson model that is applied here has a major advantage over an ordinary poisson model in

that it takes into account the fact that there are 'too many' zero values in our data compared to an ordinary poisson distribution. Our model also allows for differences with regard to the determinants of the decision to cooperate at all with a certain kind of partner and the factors that explain the number of such cooperative relationships.

## 5.2. Results

Tables 3 and 4 show estimates of the logit-poisson hurdle models which try to identify the characteristics of enterprises that maintain cooperative relationship with a certain type of actor. In the first part of the model (logit analysis) the dependent variable

<sup>18</sup> We have to normalize the probability function (2) due to the truncation of  $f_2$  at zero.

<sup>19</sup> The expected value of the whole logit-poisson hurdle model differs from the expected value of the truncated-at-zero model by factor *A*. If we were to use the same poisson function for  $f_1$  and  $f_2$ , the hurdle model would collapse to an ordinary count data model.

has the value 1 if at least one relationship with the respective type of partner exists and it is 0 if there is no such relationship. In the second part of the model (poisson regression) the dependent variable is the number of cooperative relationships if at least one such relationship exists.

Two versions of models have been estimated. In the first version, (Table 3) all enterprises, innovators and non-innovators, were included while the ‘Gatekeeper’ indicator as well as the indicators for the objectives of innovation activities were left out. The second version was restricted to those enterprises that had introduced considerable innovation during the preceding years and accounted for three indicators (Table 4).<sup>20</sup> The reason for the differences between the two versions of our model was that in the questionnaire not all enterprises were asked to answer all of the questions. We suspected that many respondents in enterprises which did not innovate would refuse to answer numerous detailed questions concerning innovation activities which were not relevant to them. Accordingly, after some basic information was gathered, those enterprises which stated they had not introduced any significant product or process innovations during the preceding three years were advised to skip over a number of innovation-specific questions and go on to the questions about cooperative relationships. The issues that were not addressed by the non-innovators included the questions on the main objectives of product and process innovation activities as well as the ‘Gatekeeper’ question.

In all our estimates, the size of the enterprise (number of employees) is statistically significant with a positive sign. In a number of tests with different formulations of the size variable we found that the natural logarithm provides the best approximation of the size effect. For the second stage of our model this indicates that the number of cooperative relationships rises less than proportionately with size.

According to the parameter estimates, the importance of size in the first part of our model is considerably higher for cooperative relationships with research institutions than for cooperation with other types of partners. However, if enterprises have overcome the hurdle of establishing a cooperation with a public research institution, the size of the enterprises seems to be relatively unimportant for explaining the number of such relationships. The coefficient for R&D intensity always assumes a positive sign in the first part of the model (logit analysis) and is — except in one case — statistically significant. In the second part of the model (poisson regression), we also find positive signs for the impact of R&D intensity on the number of cooperative relationships with suppliers and research institutes. However, in regard to the number of cooperative relationships with customers the respective coefficient has a statistically significant negative value that is not in accordance with our expectations. For the number of cooperations with “other” firms, the coefficient also shows a negative sign, but is only statistically significant in the estimates limited to the firms which had introduced innovations (Table 4).

In the estimates for cooperative relationships with suppliers, the coefficient for the share of value added to turnover has a negative sign in both parts of our model. This indicates that cooperation with suppliers in many cases works for many firms as a substitute for their own innovation effort. The estimates on the impact of the share of value added to turnover for other types of cooperation partners do not show such a clear pattern. With regard to cooperative relationships with research institutes, we find a positive coefficient in the first part of the model and a negative sign of the coefficient in the second part. This suggests that maintaining at least one R&D cooperation with research institutes necessitates additional effort, but that a high number of such contacts stimulates specialization at certain stages of the production process. The positive sign for the relationship between the number of cooperations with “other” firms and the rate of value added to turnover can be interpreted as an indication that such horizontal contacts require complementary internal activities and do not lead to the outsourcing of certain steps of the innovation process. Looking at the coefficient for the relationship between the share of value added to

<sup>20</sup> The difference with regard to the number of cases between these two approaches is caused by the omission of non-innovative enterprises in the second version as well as by a relatively high share of missing values for the indicators for main objectives of product and process innovation.

turnover and the number of cooperations with customers, we find opposite signs when running the regressions for the two types of samples. In the estimate limited to those firms that have introduced considerable innovations during the preceding years (Table 4), the negative sign of the respective coefficient indicates that cooperative relationships with a larger number of customers may stimulate an outsourcing of activities. The positive sign for the relationship between the number of R&D cooperations with customers and value added to turnover that we find in the estimate for all firms (Table 3) is due to those firms that had not introduced considerable innovation in the years prior to our inquiry.

The results of our estimates that are restricted to the innovative enterprises (Table 4) confirm the hypothesis that the existence of a Gatekeeper is necessary or at least conducive to cooperative relationships. This seems to hold particularly with regard to cooperations with customers, where we find statistically significant positive signs for the 'Gatekeeper' variable in both parts of our model. The only case where the 'Gatekeeper' variable has a 'wrong' negative sign is in the second part of our model for cooperative relationships with suppliers where we, nevertheless, find a positive sign for this variable in the first stage. While a Gatekeeper is associated with the existence of at least one cooperative relationship with research institutes, it seems to be unimportant in explaining the number of such relationships.

The more intensely product innovation activity is aimed at generating new products instead of the further development of already existing products, the higher the propensity for the existence of at least one R&D cooperation with customers, research institutions or "other" firms. This indicates that firms whose product innovation activity is characterized by a relatively high aspiration level have a special need for obtaining external know-how by means of R&D cooperation. A high aspiration level of product innovation effort, however, produces statistically significant negative signs at the second stage of our model, implying that cooperation on completely new products tends to be concentrated on a relatively small number of partners. An explanation for this finding could be that the generation of completely new products often requires rather special external knowledge that only very few cooperation partners can

provide. A heavy emphasis on rationalization effects for process innovation increases the likelihood for maintaining cooperative relationships with suppliers and is also positively related to the number of such cooperations.

Industry dummy variables turn out to be statistically significant mainly in the second part of our model which relates to the number of cooperative relationships. We find the highest number of industry dummies to be statistically significant in estimates for the relations with customers and suppliers. In most of these cases the industry dummies exhibit a negative sign, indicating that our control group, the medicine technology and optical instruments industry, is characterized by a relatively high propensity for cooperation with these types of partners. In the estimates for the relationships with "other" firms those industry dummies that are statistically significant all have a positive sign; obviously, the degree of horizontal R&D cooperation in our control group is below the average. Introducing concentration ratios for the industries did not significantly contribute to the explanation of R&D cooperation with the different types of partners.

With regard to the regional dummy variables we find a number of interesting results. Enterprises in the two western German regions, Baden and Hanover, tend to show a lower propensity to cooperate with external partners, particularly with public research institutions, than enterprises in Saxony. However, regardless of the lower likelihood of maintaining at least one cooperative relationship in these regions, the number of such relationships tends to be significantly higher once the hurdle of establishing an R&D cooperation with a certain kind of partner has been overcome. The results for the regional dummy-variables are quite surprising because regional innovation systems in Baden and in the Hanover region are well established while the innovation system in Saxony had to undergo radical changes during the transformation from a socialist to a market-driven system in recent years. In this transformation process public research institutions in Saxony have been subjected to drastic reorganization and many of them experienced a severe reduction of personnel. Likewise, almost all of the manufacturing firms that survived the transition experienced fundamental adjustments with respect to the number of employees,

their internal structure and their market relations (Fritsch and Mallok, 1998). Many of the ‘old’ networks have been destroyed by these developments, so that a large proportion of cooperative relationships within Saxony’s innovation system needed to be established anew. In contrast, Baden is said to be characterized by a sophisticated transfer infrastructure and a relatively high level of inter-firm cooperation (Semlinger, 1993; Cooke, 1996). Apparently, the fact that Baden and Hanover have a long established innovation system does not result in a higher propensity to cooperate with a certain kind of partner but in a larger number of cooperative relationships of those firms that cooperate with this type of partner.<sup>21</sup>

The results of the estimates for the different kinds of relationship with a certain type of partner, which are reported elsewhere,<sup>22</sup> agreed with the results of the logit analyses that constitute the first part of our model. In these estimates, the pseudo  $R^2$  tended to be highest for relatively intense forms of cooperation (e.g., “joint R&D projects”) and it was relatively low for those kinds of cooperative relationships that are characterized by an only modest degree of involvement (e.g., “casual contact for information purposes”). The partly significant differences in the results for the two parts of our model apparently indicate that it is appropriate to differentiate between two features of R&D cooperation: the fact that at least one cooperative relationship exists with a certain type of partner, which may be seen as the result of a more strategic decision to cooperate at all with this kind of partner, and the number of cooperative relationships as a consequence of decisions that are more operative in nature.

A number of further variables were tested but did not make a significant contribution. One of these variables was an estimate of the average length of the product life-cycle (based on a three-grade scale) of the main product. Our hypothesis was that the probability of enterprises entering into a cooperative relationship may increase if product life cycles are

relatively short because R&D cooperation can contribute to a reduction of time to market. In addition, no statistically significant impact could be found for the age of the enterprise, the share of exports and for the assessment of the importance of certain inputs for innovation activities.<sup>23</sup> In keeping with our finding that cooperative relationships are not restricted to one type of partner but that firms which cooperate on R&D tend to maintain cooperations with different kinds of partners (Table 2), an indicator for existence of R&D cooperation with other partners adds considerably to the explained variance if included in the model. However, because R&D cooperation with the different types of partners seems to be determined by more or less the same set of variables, including an indicator for the existence of cooperative relationships with other types of partners also introduces multicollinearity. For this reason, this indicator has been omitted in the analyses reported here.

## 6. Conclusions

In contrast to previous studies, we were able to clearly identify a set of variables that distinguish firms that cooperate on R&D from firms that do not. Quite remarkably, this set of variables tends to be more or less the same for cooperative relationships with different types of partners. According to our results, firms that are engaged in R&D cooperation tend to be relatively large, have a comparatively high share of R&D employees, spend resources for monitoring external developments relevant to their innovation activities (‘Gatekeeper’) and are characterized by a relatively high aspiration level of their product innovation activities. Enterprises that maintain cooperative relationships with their suppliers tend to have a relatively low share of value added to turnover, indicating that this type of cooperation tends to be a substitute for internal R&D. We find some differences with regard to the variables that are related to having at least one cooperative relationship with a

<sup>21</sup> For a more detailed analysis of regional differences, see Fritsch (1999) as well as Fritsch et al. (1999).

<sup>22</sup> See the Appendix of the working-paper version of this paper (Fritsch and Lukas, 1998), which may be obtained from the authors upon request.

<sup>23</sup> E.g., “training of personnel”, “analysis of market conditions”, “purchase of licenses or certain components”, “experience with certain technologies”.

certain kind of partner and the variables that affect the number of such relationships. The pronounced differences in cooperation behavior between industries mainly concern the number of cooperative relationships; in regard to the propensity of firms to cooperate on R&D such industry characteristics seem to be much less relevant. We could also identify a number of differences in R&D cooperation behavior between regions concerning the propensity to cooperate as well as the number of cooperation partners.

## Acknowledgements

This paper is based on a joint project with four teams involved in the design of the questionnaires and the collection of the data, all supported by the German Science Foundation (“Deutsche Forschungsgemeinschaft”). The research institutions and the respective project leaders are: Department of Economic Geography at the University of Hanover (Prof. Dr. Ludwig Schätzl), Department of Economic and Social Geography at the University of Cologne (Prof. Dr. Rolf Sternberg), Fraunhofer Institute for Systems and Innovation Research in Karlsruhe (Dr. Knut Koschatzky, Prof. Dr. Frieder Meyer-Krahmer) and the Faculty of Economics and Business Administration at the Technical University Bergakademie Freiberg, Research Unit Innovation Economics (Prof. Dr. Michael Fritsch). We gratefully acknowledge the helpful comments of two anonymous referees.

## References

- Allen, T.J., 1967. Communications in the research and development laboratory. *Technology Review* 70, 31–37.
- Brockhoff, K., 1992. R&D cooperation between firms — a perceived transaction cost perspective. *Management Science* 38, 514–524.
- Brockhoff, K., Gupta, A.K., Rotering, C., 1991. Inter-firm R&D co-operation in Germany. *Technovation* 11, 219–229.
- Cohen, W., Levinthal, D.A., 1989. Innovation and learning: the two faces of R&D — implications for the analysis of R&D investment. *Economic Journal* 99, 569–596.
- Cohen, W., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly* 35, 128–152.
- Cooke, P., 1996. The new wave of regional innovation networks: analysis, characteristics and strategy. *Small Business Economics* 8, 159–171.
- D’Aspremont, C., Jaquemin, A., 1988. Cooperative and non-cooperative R&D in duopoly. *American Economic Review* 78, 1133–1137.
- Ewers, H.-J., Becker, C., Fritsch, M., 1990. The nature of employment effects of new technology. In: Matzner, E., Wagner, M. (Eds.), *The Employment Impact of New Technology — The Case of West Germany*. Avebury/Gower, Aldershot, pp. 23–41.
- Fritsch, M., 1999. Cooperation in regional innovation systems. Freiberg Working Paper 99/10, Faculty of Economics and Business Administration, Technical University Bergakademie Freiberg, Germany.
- Fritsch, M., Franke, G., Schwirten, C., 1999. Innovation in manufacturing — an East–West German comparison. In: Fritsch, M., Brezinski, H. (Eds.), *Innovation and Technological Change in Eastern Europe — Pathways to Industrial Recovery*. Elgar, Cheltenham, pp. 161–184.
- Fritsch, M., Lukas, R., 1998. Who cooperates on R&D? Freiberg Working Paper 98/12, Faculty of Economics and Business Administration, Technical University Bergakademie Freiberg, Germany.
- Fritsch, M., Lukas, R., 1999. Innovation, cooperation, and the region. In: Audretsch, D.B., Thurik, R. (Eds.), *Innovation, Industry Evolution and Employment*. Cambridge Univ. Press, Cambridge, pp. 157–181.
- Fritsch, M., Mallok, J., 1998. Surviving the transition: the process of adaptation of small and medium-sized firms in East Germany. In: Brezinski, H., Franck, E., Fritsch, M. (Eds.), *The Microeconomics of Transition and Growth*. Elgar, Cheltenham, pp. 163–184.
- Fusfeld, H.I., Haklisch, C.S., 1985. Cooperative R&D for competitors. *Harvard Business Review* 63, 60–76.
- Geroski, P., 1995. Markets for technology: knowledge, innovation and appropriability. In: Stoneman, P. (Ed.), *Handbook of the Economics of Innovation and Technological Change*. Blackwell, Oxford, pp. 90–131.
- Heidenreich, M., Krauss, G., 1998. The Baden–Württemberg production and innovation regime: past successes and new challenges. In: Braczyk, H.-J., Cooke, P., Heidenreich, M. (Eds.), *Regional Innovation Systems — The Role of Governments in a Globalized World*. UCL Press, London, pp. 214–244.
- Johnson, N.L., Kotz, S., 1969. *Distributions in Statistics: Discrete Distributions*. Wiley, New York.
- Kamien, M.I., Muller, E., Zang, I., 1992. Research joint ventures and R&D cartels. *American Economic Review* 82, 1293–1306.
- Katz, M.L., 1986. An analysis of cooperative research and development. *Rand Journal of Economics* 17, 527–543.
- Katz, M.L., Ordover, J.A., 1990. R&D cooperation and competition. *Brookings Papers on Economic Activity — Microeconomics*, 137–203.
- Kleinknecht, A., Reijnen, J.O.N., 1992. Why do firms cooperate on R&D? An empirical study. *Research Policy* 21, 347–360.
- Kline, S.J., Rosenberg, N., 1986. An overview of innovation. In:

- Laudan, R., Rosenberg, N. (Eds.), *The Positive Sum Strategy*. National Academy Press, Washington, DC, pp. 274–305.
- König, H., Licht, G., Staat, M., 1994. F&E-Kooperationen und Innovationsaktivität. [R&D cooperation and innovation activity] In: Gahlen, B., Hesse, H., Ramser, H.-J. (Eds.), *Europäische Integrationsprobleme aus wirtschaftswissenschaftlicher Sicht*. Siebeck, Tübingen, pp. 219–242, (in German).
- Link, A.N., Bauer, L.L., 1987. An economic analysis of cooperative research. *Technovation* 6, 247–260.
- Link, A.N., Rees, J., 1990. Firm size, university based research, and the returns to R&D. *Small Business Economics* 2, 25–31.
- Marjit, S., 1991. Incentives for cooperative and non-cooperative R&D in duopoly. *Economics Letters* 37, 187–191.
- Mullahy, J., 1986. Specification and testing in some modified count data models. *Journal of Econometrics* 33, 341–365.
- Rothwell, R., 1991. External networking and innovation in small and medium-sized manufacturing firms in Europe. *Technovation* 11, 93–112.
- Rothwell, R., 1993. The fifth generation innovation process. In: Oppenländer, K.H., Popp, W. (Eds.), *Privates und staatliches Innovationsmanagement*, ifo-institut für wirtschaftsforschung, pp. 25–42, München.
- Schasse, U., 1995. Produkt- und Prozeßinnovationen in Niedersachsen. [Product and process innovation in Lower Saxony] In: Schasse, U., Wagner, J. (Eds.), *Erfolgreich produzieren in Niedersachsen*. Niedersächsisches Institut für Wirtschaftsforschung, Hanover, pp. 61–82.
- Semlinger, K., 1993. Economic development and industrial policy in Baden-Württemberg: small firms in a benevolent environment. *European Planning Studies* 1, 435–463.
- Teece, D.J., 1986. Profiting from technological innovation — implications for integration, collaboration, licensing and public policy. *Research Policy* 15, 285–305.
- Teece, D.J., 1992. Competition, cooperation and innovation — organizational arrangements for regimes of rapid technological progress. *Journal of Economic Behavior and Organization* 18, 1–15.
- Tushman, M.L., Katz, R., 1980. External communication and project performance: an investigation into the role of gatekeepers. *Management Science* 26, 1071–1085.
- Vonortas, N.S., 1997. *Cooperation in Research and Development*. Kluwer Academic Publishers, Boston.
- Winkelmann, R., Zimmermann, K.F., 1995. Recent developments in count data modelling: theory and application. *Journal of Economic Surveys* 9, 1–24.