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Cooperation and the efficiency of regional R&D activities

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This paper investigates the relationship between the cooperative behaviour of manufacturing establishments in a region and the efficiency of their R&D activities, using data for 11 European regions. Some significant differences in the attitude towards R&D cooperation as well as with regard to the efficiency of R&D activities between the regions can be found. However, these two issues appear to a large degree to be empirically unrelated. Therefore, the role of R&D cooperation in regional innovation systems remains unclear.

Key words: Innovation, R&D cooperation, Regional innovation systems
JEL classifications: D21, L6, O32, R30

1. Introduction

Cooperative relationships in the field of R&D play a significant role in the literature on innovation processes. They are deemed particularly important in some recent concepts that aim to explain differences in the performance of innovation activities between regions. This article analyses R&D cooperation and the efficiency of R&D activity in a number of European regions. The guiding question of this investigation is how far interregional differences in co-operation behaviour can contribute to explaining divergent efficiency of R&D activities. Does a relatively high degree of cooperation in the field of innovation lead to correspondingly high efficiency of regional innovation processes, as is frequently suggested in the literature?

The paper is organised as follows. Section 2 gives an outline of basic hypotheses about the relationship between cooperation and efficiency of R&D activity and summarizes the respective empirical evidence obtained so far. The database is introduced in Section 3 and the results of the empirical analysis are presented in Section 4. Finally, some conclusion for an explanation of regional differences of R&D activity are drawn (Section 5).

2. The potential stimulating role of regional cooperation in a division of innovative labour

There exists no standard definition of cooperation in the literature. Broadly defined, any incompletely specified exchange relationship that leaves room for opportunistic behaviour

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by the parties may be regarded as cooperation. Such incomplete contracts are often termed 'relational' (MacNeil, 1978). Relational contracts are exchange relationships that are positioned in the spectrum between the two extreme cases, the spot-market and the hierarchy. In a spot-market relationship, the terms of the contract are unambiguous and can be enforced at low cost. Therefore, exchange could take place even if transaction partners were totally anonymous. Incompletely specified, relational contracts, however, leave room for opportunistic behaviour by one of the parties and necessitate some confidence that the exchange partner will not exploit these possibilities. Hence, in order to be able to develop some trust, actors cannot be completely anonymous to each other. They must be 'linked' (Kranton and Minehart, 2001), i.e., the relational exchange has to be embedded in a longer-term relationship.

In general, a link between partners results from actor-specific transaction costs. These costs may be incurred while identifying a suitable transaction partner, when establishing an appropriate interface for the exchange relationship, and/or by building up some reputation and trust in order to reduce the danger of opportunistic behaviour to a reasonable level. Once spent, this irreversible investment generates a 'lock-in' effect, i.e., an incentive to keep the relationship over a longer period of time, because abandoning it would imply that the respective actor-specific effort is sunk. Such lock-in effects have two important implications for individuals' behaviour. First, actors involved in such a type of relationship will tend to prefer 'voice' over 'exit' if dissatisfaction or conflict occurs. Second, being interested in a long-term relationship may limit the danger of opportunistic behaviour, since both sides may suffer from sunk costs in the case where one of the exchange partners abandons the link owing to a feeling of being treated unfairly.

If economic actors deem investment in actor-specific transaction costs necessary or desirable, this indicates their belief that the respective exchange cannot be carried out in the same manner on a spot market. Therefore, the alternative to cooperation is to make the respective good or service internally. Links allow economic actors to out-source a task that otherwise had to be carried out within the hierarchy of the firm if only a spot market existed. Thus, cooperation leads to a higher degree of labour division between different organisations (e.g., firms, research institutions). Assuming that a division of labour yields efficiency gains, the establishment of cooperative relationships may result in higher productivity and an increase in welfare.

Cooperative relationships are particularly relevant for a division of innovative labour or R&D.[1] The main reason is that, by its very nature, the result of an innovation process is unknown in advance and cannot be predicted. Owing to this uncertainty, the respective contracts have to be incompletely specified. Hence, to benefit from the advantages of a division of innovative labour, some sort of cooperation according to the definition given above is unavoidable. Another reason why a division of innovative labour may necessitate investment in actor-specific transaction costs is that the inputs needed often tend to be highly specialised, and are not commonly traded in large markets. Indeed, markets for skills and resources that are important for an innovation process may well be rather 'thin', with only very few suppliers available and transactions taking place rather infrequently. Because suppliers are rare, an immense amount of search costs could be required to identify a suitable transaction partner. Moreover, if only few transactions occur it may hardly be possible to identify a market price clearly, so that negotiations about the price and further

[1] The main subject of innovation activity is the commercialisation of new knowledge, the invention. R&D expenditure may be directed to generating an invention as well as to its commercialisation.

conditions of an exchange tend to be rather costly. Another potential advantage of R&D cooperation discussed in the literature is that it tends to be characterised by relatively 'open' exchange of information, and that such open information flows may be stimulating for R&D activity.[1] This may particularly pertain to the transfer of 'tacit' knowledge that is not completely codified. Many authors suggest that not only formalised cooperative relationships such as joint ventures or contract research are important for such knowledge transfers, but that informal relationships such as 'information trading' (reciprocal exchanges of information between personnel of competing firms) often play a significant role in stimulating innovation activity (e.g., von Hippel, 1987; Saxenian, 1994).

Although the importance of R&D cooperation for a division of innovative labour has been widely recognised in the literature, many open questions remain. Three of these issues that pertain to the spatial dimension of cooperation and innovation activity will be investigated empirically in this paper. Does, as some literature suggests, R&D cooperation behaviour differ between regions? Are there interregional differences with regard to the quality or efficiency of regional innovation systems? And can interregional differences in the efficiency of innovation activities be explained by corresponding variation in cooperation behaviour? The assertion that such a positive impact of cooperation on innovation activity exists constitutes a main hypothesis in the literature on industrial districts (cf., Porter, 1998; and the contributions in Pyke *et al.*, 1990), innovation networks (cf., Camagni, 1991; Grabher, 1993), and innovative milieux (Aydalot and Keeble, 1988; Crevoisier and Maillat, 1991; Ratti *et al.*, 1997). In this literature, it is argued that regional differences in cooperation behaviour are to a considerable extent responsible for differences with regard to innovation activity, particularly the efficiency of R&D. One main reason given for such a positive effect of cooperative relationships on R&D is that cooperation may work as an important medium for knowledge spillovers. In a wide definition of the term, knowledge spillovers denote all kinds of knowledge transfers between individual persons or institutions (e.g., firms, research institutes) be it by market transaction or by other kinds of interaction (for a review see Breschi and Lissoni, 2001; Feldman, 1999). Knowledge spillovers play a significant role in recent approaches to growth theory (cf., Krugman, 1991; Romer, 1994) as well as in the concept of (national or regional) innovation systems (cf., Lundvall, 1992; Nelson, 1993; Edquist, 1997; Cooke *et al.*, 1997).

The empirical picture of the regional dimension of R&D activity and cooperation behaviour is still largely unclear. The strongest piece of evidence we have so far is that innovation activities in a certain technological field tend to be clustered regionally (Almeida and Kogut, 1997; Baptista and Swann, 1998, 1999; Feldman, 1994; Audretsch and Feldman, 1996; Porter, 1998). This clearly suggests that there are advantages in spatial proximity for innovation activity. One such possible advantage of being located in a cluster of innovation activities in a similar field is a well-developed regional supply of certain inputs, such as differentiated markets for labour and innovation-related services, spatial proximity of institutions for education and research in the respective field, as well as easy availability of relevant knowledge. Another advantage could be a relatively close proximity to potential partners for R&D cooperation. If frequent face-to-face-contacts are necessary for cooperation, spatial proximity may be conducive to establishing and maintaining such a relationship (Nohria and Eccles, 1992). Some regional case studies suggest, however, that spatial clustering does not necessarily lead to a relatively high level of cooperation between the firms or research institutions in the respective region. But if

[1] See for example Axelsson (1992), Lundvall (1992) and Powell (1990).

intensive cooperation emerges, this may have a great effect on the level as well as on the efficiency of R&D activity (e.g., Sabel *et al.*, 1989; Saxenian, 1994). Finally, it has been shown that knowledge spillovers generated by innovation activity are concentrated in the area around the respective source (cf., Acs *et al.*, 1992; Anselin *et al.*, 1997; Jaffe *et al.*, 1993). Spatial proximity to many such sources in a densely populated area or a cluster, therefore, enables actors to benefit from a higher level of spillover than in regions with relatively low density of R&D activity or at a more remote location (Krugman, 1991). Nearly nothing is known, however, about the media of such spillovers, particularly the importance of cooperative relationship for information transfer.

These advantages of spatial clustering correspond to a well-established hypothesis, which states that the level as well as the success or efficiency of innovation activity should be higher in easily accessible locations and densely populated regions—the centre—than in more remote areas or regions that are characterised by a relatively low degree of agglomeration—the periphery (for a brief review of the literature see Fritsch, 2000, pp. 410f.).[1] There is, however, next to no empirical evidence available that shows a significant effect of location on R&D activity of firms or establishments (for a brief review see Fritsch, 2000).

3. Data

The empirical analyses reported here are based on data gathered by a postal inquiry of manufacturing enterprises in 11 European regions (Figure 1). This inquiry was carried out in two phases between 1995 and 1998, and resulted in approximately 4,300 usable questionnaires which constitute the data set. The questions concentrated on innovation-related issues, but also gathered general information on each enterprise, such as the number of employees, the amount of turnover, characteristics of the product programme, etc. (for a more detailed description of the data set, see Sternberg, 2000).

Four of the 11 regions in which the inquiry was carried out are dominated by large cities of international importance. These regions are Barcelona, Rotterdam, Stockholm and Vienna, with the latter two cities serving as national capitals. Two of the regions in our sample, Saxony and Slovenia, were under socialist regimes until 1990/1991 and are faced with the need to more or less completely reorganise their innovation system. Baden, one of the two West German regions in the sample, is said to have a relatively well-functioning innovation system (Cooke, 1996; Heidenreich and Krauss, 1998). In the other West German region of Hanover, there is a relatively high share of large-scale industries (e.g., automobiles, steel) while the proportion of employment in new innovative industries tends to be comparatively low. The French border region of Alsace, which is adjacent to the Baden region in Germany, represents a relatively rural area. The second French region, Gironde, has a significant share of employment in high-tech industries, most of which are well-integrated into the global division of labour. Finally, South Wales represents an old industrialised region that has experienced a considerable employment shift from 'old' declining industries to 'new' high tech industries in recent years (cf., Cooke, 1998). Owing to the great variety with regard to economic development and locational

[1] In a broad sense, a region in the 'centre' may be defined as an easily accessible location characterised by relatively high density of population and economic activity. A centre has a relatively high rank in the spatial hierarchy. In contrast, regions in the 'periphery' are lacking these properties. They are characterised by relatively low density, poor accessibility and rank relatively low.

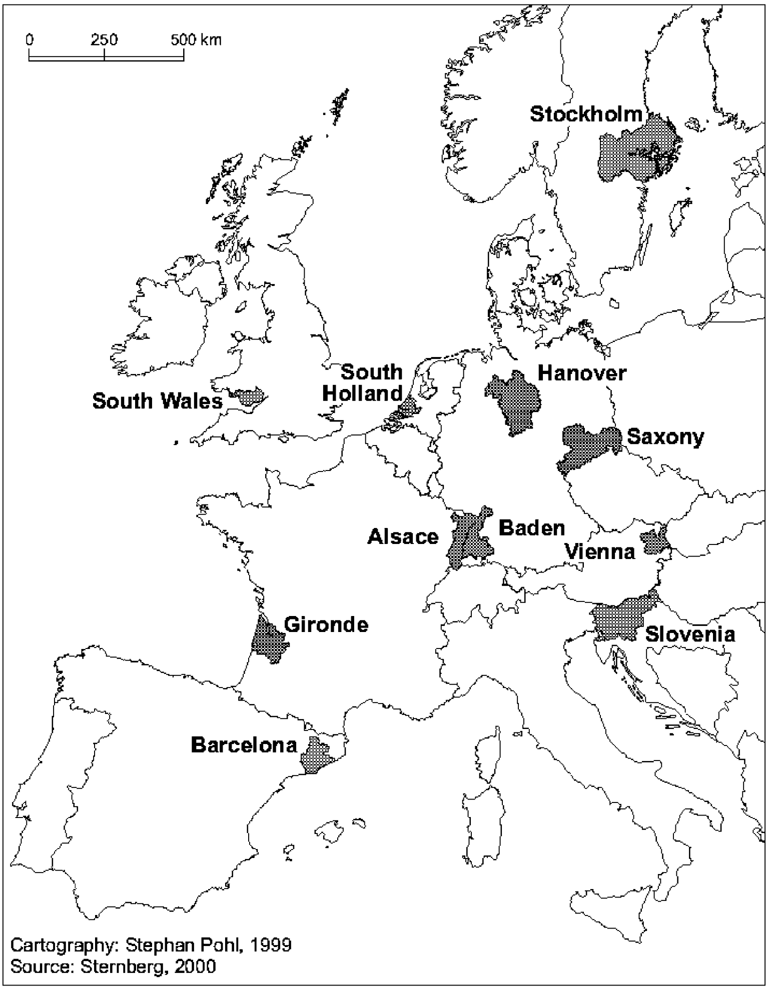

Fig. 1. *Case study areas.*

conditions in the regions of our sample, we may expect to find an impact of location on R&D activity.[1]

4. Empirical tests

There are three main questions involved in the analysis of the relationship between R&D cooperation and the efficiency of R&D activity in a region:

First, do significant differences between regions with regard to their cooperation behaviour exist?

[1] For an overview of economic conditions and innovation activities in the different regions, see Fritsch (2000). The delineation of the case-study areas accounted for the borders of administrative spatial units. Size of regions was also influenced by the number of establishments located there. Accordingly, the relatively densely populated regions in the sample were chosen relatively small owing to the limited resources available for the inquiry. In contrast, rural areas tended to be relatively large in order to have enough cases for the analysis. Definition of sub-regions would, at least in some of the case-study areas, result in a number of cases that is not sufficient for applying multivariate analysis.

Second, can significant differences in the efficiency of R&D activities between regions be found?

Third, are the interregional differences of cooperation behaviour and R&D efficiency somehow related?

Each of the following three subsections is devoted to one of these questions.

4.1 Interregional differences in cooperation behaviour

Information on R&D cooperation with different types of partners was gathered through a number of questions. These question tried to assess whether or not the respective enterprise had maintained a cooperative relationship focused on innovation activity with a certain type of partner in the preceding three years. The respective question was asked for five kinds of partners separately. These types of cooperative partners were:

customers

manufacturing suppliers

suppliers of business services[1]

'other' firms and

publicly funded research institutions.

The research institutions comprised the universities[2] and publicly funded non-university research institutions.[3] The 'other' firms were non-vertically related businesses, particularly including competitors. There are clear indications that most of the relationships to 'other' firms were horizontal in nature. Cooperation with suppliers or customers was defined as a relationship which went beyond 'normal' business interaction. This included issues such as casual contact for information purposes, organised exchange of information and experiences, involvement in planning and operation of projects as well as pilot use of an innovation.[4] With regard to 'other' firms and publicly funded research institutes, all kinds of relationships were assumed to be cooperative. For each kind of partner, we know the

[1] Main fields were software development, tax and legal examination, auditing, business consultancy, market research, advertising, engineering and planning services, check and test services, architecture, etc. For some of the regions, Alsace, Baden, Hanover and Saxony, information about cooperative relationships with suppliers of business oriented services was not raised in the same way as the information on cooperation with other partner types. Therefore, relationships with suppliers of business services had been left out in analyses that were focused on these regions (Fritsch and Lukas, 1999, 2001; Fritsch, 2001A).

[2] In Germany, this included the *Fachhochschulen* (universities with a particular focus on applied studies in engineering, business and other subject areas).

[3] E.g., institutes of the Max-Planck and the Fraunhofer Society.

[4] These forms of cooperation with suppliers or customers were given as categories in the questionnaire used in the three German regions and in Alsace. For the assessment of cooperative relationships with 'other' firms, the final two 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 categories for the type of relationship were 'use of equipment or laboratories', 'research contracts', 'joint R&D projects' and 'collaboration with regard to thesis'. While most of the respondents named 'casual contact for information purposes' as a form of cooperation, more substantial modes such as 'research contracts' and 'involvement in planning and operation of projects' were also mentioned quite frequently. For an overview of the incidence of different modes of cooperative relationship with the different partner types, see Fritsch and Lukas (2001, p. 299) and Fritsch (2001, p. 300). The way the data were gathered allows for different definitions of a cooperative relationship. Since the resulting indicators for cooperation behaviour are closely correlated, these definitions lead to about the same results in the type of analysis conducted here. Therefore, the precise definition of cooperation does not seem to be a very critical issue here. There was some divergence between the case study regions concerning the questions used to gather information on cooperative relationships. As a consequence, some part of the information is not comparable for all 11 regions.

number of cooperative relationships within different spatial categories ('within the region', 'rest of the country', 'abroad').

Suppliers of business-oriented services have been most frequently named as partners for R&D cooperation. Of all manufacturing enterprises, 67.3% maintained cooperative relationship with this type of partner. Also, more than half of the respondents, 58.2%, claimed to have R&D cooperation with their customers. The share of establishments with at least one cooperative relationship with their manufacturing suppliers amounted to 45.4%, while R&D cooperation with public research institutions (30.0% of all enterprises) and with 'other' firms (25.9%) was less common. There are remarkable differences between the case study areas with regard to R&D cooperation behaviour. Looking at the share of enterprises that maintained at least one cooperative relationship to a certain kind of partner (Figure 2), we find above average values, particularly in Baden, Hanover, Saxony and in Slovenia. Conversely, these shares are relatively low in Stockholm and in Vienna. In regions characterised by a relatively high (low) share of establishments with cooperative relationships with a certain type of partner, the propensity to have R&D cooperation with another kind of partner was also relatively high (low). This indicates that cooperativeness tends not to be limited to a certain type of partner (e.g., customers), but is a more general attitude, quite likely involving various kinds of actors.

Identifying some variance between regions with regard to the share of enterprises that maintained a cooperative relationship with a certain type of partner is, however, not sufficient to conclude that there are different propensities to cooperate. The reason is that a relatively high share of establishments with such cooperative relationships in a region could simply be the result of a correspondingly high proportion of establishments that possess the characteristics of businesses that are likely to maintain R&D cooperation (e.g., firms that are relatively large or have a relatively high share of R&D employees). In order to identify interregional differences in the propensity to cooperate, one has to control for the effects of such characteristics in cooperating establishments. Therefore, multivariate models for the propensity to maintain at least one cooperative relationship, as well as for the number of such relationships, were estimated. These models included the relevant characteristics of the establishments as explanatory variables, and also dummy variables for location in a certain region. A statistically significant coefficient for a regional dummy variable indicates that the establishments in the respective region show a higher or lower propensity to cooperate (depending on the sign of the respective coefficient) than the establishments located in Baden that were chosen as control group. This method of analysis ensures that the regional differences identified are not caused by interregional variance with respect to the establishment characteristics controlled for in the multivariate approach.

For the multivariate analysis, a two-stage count-data hurdle model was applied that consisted of two parts. The first part was a logit model aiming to explain whether or not the respective enterprise had at least one cooperative relationship with a certain type of partner. The second part was restricted to those enterprises that had overcome this 'hurdle' of having at least one cooperative relationship with a certain kind of partner, and analysed those factors that determine the number of such contacts. Assuming that the number of cooperative relationships results from a Poisson-like process, Poisson-regression analysis may be used as the estimation method. However, negative-binomial (negbin) regression was applied here because it is based on somewhat more general assumptions than Poisson regression.[1]

[1] Negative binomial regression allows for a greater variance in observations than is assumed for a Poisson process (cf., Greene, 1997, pp. 931–9).

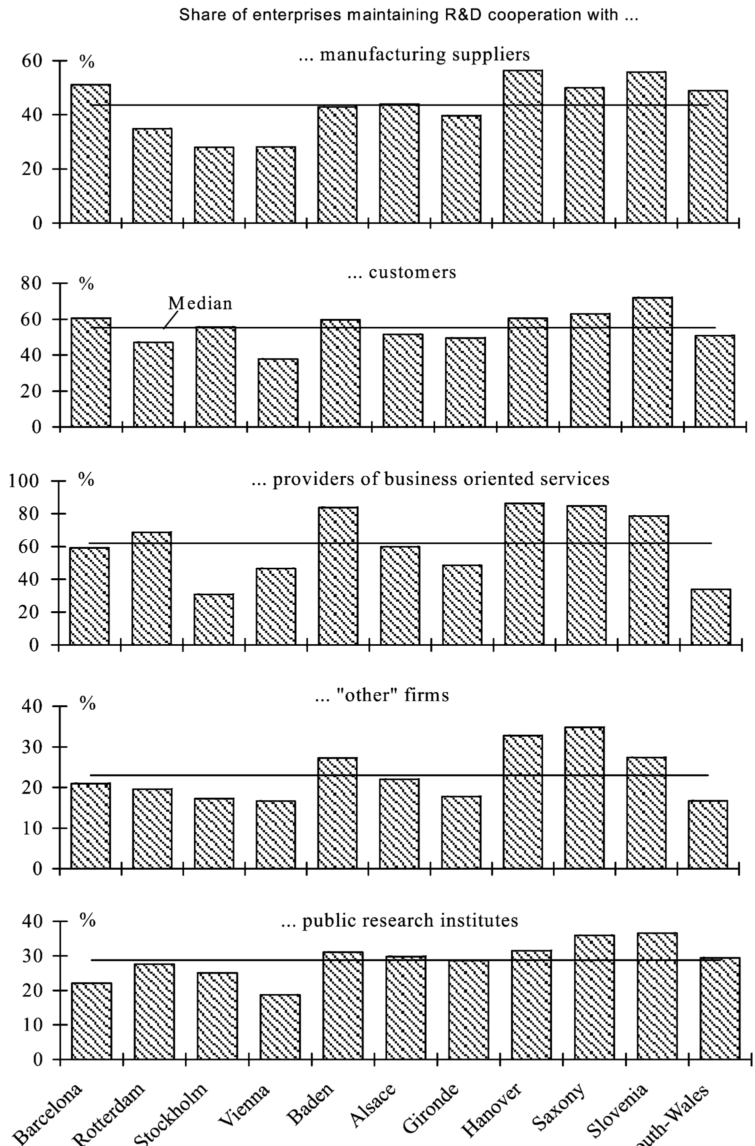

Fig. 2. *Propensity to cooperate in the case study areas.*

The main characteristics of the establishments that proved to have a significant impact on cooperation behaviour and that were controlled for in the empirical analysis are establishment size (measured as the natural logarithm of the number of employees) and the share of R&D employees. The larger the respective enterprise and the greater its share of R&D employees, the higher the propensity to have at least one cooperative relationship and the larger the number of cooperation partners. The influence of these two variables was more or less the same in cooperative relationships with all the different partner types (see Fritsch and Lukas, 2001, for details). This corresponds to the observation that R&D cooperation tends

Table 1. *Regional differences of cooperation behaviour: results for regional dummy variables*

	Cooperative relationships with:									
	Customers		Manufacturing suppliers		Service firms		'Other' firms		Research institutes	
Region	Yes/No	No.	Yes/No	No.	Yes/No	No.	Yes/No	No.	Yes/No	No.
Barcelona	−0.09	+0.67**	+0.28	−0.16	−1.23**	−0.44*	−0.47*	−0.81**	−0.39*	+0.25
Rotterdam	−0.60**	−0.52*	−0.47*	−0.62**	−0.53*	Contr.	−0.64**	−0.36	−0.31	+0.16
Stockholm	−0.05	−1.04**	−0.58**	−1.47**	−2.51**	−1.09**	−0.54**	−0.66**	−0.20	−0.13
Vienna	−0.83**	+0.17	−0.73**	−0.44	−1.81**	−0.57**	−0.72**	−0.16	−0.84**	+0.32
Alsace	−0.19	+0.71**	+0.09	−0.01	−1.27**	n.a.	−0.2	−0.26	+0.04	−0.01
Gironde	−0.11	−2.32**	−0.01	−1.64**	−1.53**	−0.72	−0.43	−0.48	+0.412	−0.58
Hanover	−0.12	−0.3	+0.37*	−0.37*	+0.05	n.a.	+0.15	+0.04	−0.44*	n.a.
Saxony	+0.25*	−0.44**	+0.32**	−0.33*	+0.2	n.a.	+0.45**	−0.11	+0.46**	−0.15
Slovenia	+0.44**	−0.12	+0.32*	−0.16	−0.5**	+0.14	−0.13*	−0.2	−0.03	−0.13
South-Wales	−0.43*	−0.21	+0.23	−0.23	−2.36**	−0.58*	−0.57**	−0.00	−0.08	+0.37*

* Statistically significant at the 5%-level; ** statistically significant at the 1% level; n.a.: no data available; Contr.: The region is the control group in the respective estimate.

to be a phenomenon that is not restricted to one type of partner. Eleven industry dummies were included in the models to control for industry-specific effects.[1]

The results for the regional dummy variables in both stages of the model are shown in Table 1 (for the complete model see Fritsch, 2003). Information concerning Barcelona, Rotterdam, Stockholm and Vienna, the four regions that are dominated by large urban areas, is grouped in the upper part of the table to make identification of the special characteristics of these regions easier. There are remarkably many significant differences in cooperation behaviour between the regions. A relatively high share of those dummy variables that prove to be statistically significant show a negative sign. This confirms the hypothesis that enterprises located in Baden (the reference group in the estimates) are characterised by a relatively cooperative attitude. The two regions in our sample that were formerly under socialist regime, Saxony and Slovenia, are striking exceptions to this pattern. Many of the coefficients of the dummy variables for these two regions assume highly significant positive values in the first part of the model (yes/no). One could have expected negative signs here, because the transformation to a market-driven system in these regions has led to the destruction of many of the 'old' networks there, so that many relationships, often based on personal contacts, had to be established anew (cf., Albach, 1994, for a detailed analysis). However, the dummy variables for these transforming regions often show a negative sign in the second part of the model concerning the number of cooperative relationships. This may serve as an indication of the problems and costs that are involved in establishing new network relationships. Another remarkable result of the analysis is that most of the coefficients for location in regions that are dominated by large cities (Barcelona, Rotterdam, Stockholm and Vienna) have a negative sign. This suggests that being located in a region that provides a rich supply of intra-regional contact opportunities alone is not particularly stimulating for R&D cooperation.

4.2 Interregional differences in R&D efficiency

Careful analysis of the data has revealed a number of significant differences with regard to the extent and the efficiency of innovation activities between the regions under inspection here (see Fritsch, 2000, for details). A comprehensive measure of R&D efficiency is the output elasticity of R&D input that can be derived by estimating knowledge production functions for the different regions (see Fritsch, 2002, for detailed exposition). The basic assumption underlying the concept of the knowledge production function is that the output of the innovation process represents a result of R&D capital or investment, that is

$$R\&D\,output = f(R\&D\,input) \qquad (1)$$

Taking the Cobb–Douglas production function as a framework, the basic relationship is

$$R\&D\,output = a\,R\&D\,input^{b} \qquad (2)$$

[1] A further variable that tends to be positively related with cooperation behaviour is the existence of a 'Gatekeeper', who screens the environment relevant for the innovation activity. Establishments maintaining R&D cooperation are also often characterised by the relatively high aspiration level of their R&D activities. Furthermore, some types of cooperation seem to result in a relatively low share of value added to turnover in the cooperating firms, indicating the externalisation of certain tasks that would otherwise have to be fulfilled within the enterprise itself. For details see Fritsch (2001A) and Fritsch and Lukas (2001). These variables were omitted here for two reasons. First, some of them were only available for a subsample of establishments. Second, a relatively high aspiration level of innovation activity, a low share of value added to turnover as well as the existence of a gatekeeper may represent not a cause, but a result of R&D cooperation and should therefore, not be used as control variables.

with the term *a* representing a constant factor and *b* giving the elasticity by which R&D output varies in relation to the input to the R&D process. If the elasticity value equals one, a 100% increase in R&D expenditure would lead to a doubling in innovative output. An elasticity value lower than one indicates that R&D output does not rise in proportion to R&D input. Taking the natural logarithms of both sides leads to

$$\ln(R\&D\,output) = \ln a + b \ln(R\&D\,input) \quad (3)$$

This equation can be estimated by standard regression methods.

The output elasticity of R&D input may be interpreted as a measure of the productivity of the inputs to the innovation process indicating the efficiency of innovation activity and, thereby, the quality of the innovation system in a region. In particular, this elasticity should increase as the quality of inputs to the R&D process is improving and the spillovers stemming from the R&D activities of other actors in the region (whether they are public research institutions or private sector firms) become more pronounced. The output elasticity is dimensionless and, therefore, cannot be affected by differences in price levels between the regions or by the exchange rates in the case of an international comparison if the input and/or output to the innovation process is measured in monetary terms.

The indicator for R&D output was the number of inventions that were registered for patenting during the preceding three years. To avoid problems of having 'too many' zero-values in the model,[1] the estimations were restricted to those enterprises that had registered at least one invention for patenting during the preceding three years. A patent is only granted for a significant invention that is new on a world-wide scale. For this reason, counting only firms that have patent applications in the sample implies that the estimations are based solely on information from enterprises which are performing near the technological frontier. This approach has the great advantage that R&D output is to a certain extent standardised, and that results of about the same level of novelty are compared. The key input factor to the innovation process, knowledge, tends to be cumulative in character, so that innovation is based on a stock of knowledge capital. In practice, this knowledge stock can be measured only incompletely. The best that we might know is the R&D effort, i.e., the investment into the knowledge stock within a certain time period, which may, however, not cover all the relevant flows. In particular, information about R&D investment made long ago is hard to obtain. Assuming that innovation effort is fairly constant over time, even incompletely measured R&D input may serve as a good proxy for knowledge capital. The data set provides information on R&D employment and R&D expenditure during the preceding three years. Because R&D expenditure includes inputs to the innovation process that are purchased from other firms, it represents a more comprehensive measure than the number of R&D personnel. Interregional differences have been assessed by estimating a knowledge production function with dummy variables testing for regional deviations.[2] Six dummies control for the influence of the different industries which the firms belong to.

[1] A distribution of observations that is characterised by a relatively large number of cases at one end violates the basic assumptions underlying most standard estimation procedures.

[2] As an alternative approach, the model was estimated for each of the regions separately (see Fritsch, 2000, 2002). However, no statistically significant estimates of a region-specific knowledge production function could be found for Gironde and for Slovenia, presumably owing to the relatively small number of observations that our sample provides for these regions. Because both approaches to estimating regional innovation output elasticities with regard to R&D input lead to quite similar results, only the estimates derived from a knowledge production function for all regions are reported here.

Because the dependent variable in the model, the number of patents, assumes the character of a count variable, negative-binomial regression has been applied as estimation procedure. As in the analyses of interregional difference in cooperation behaviour (cf., Section 4.1), Baden is taken as the reference region for assessing the statistical significance of differences. Two types of regional dummy variables were included to test for interregional differences. Dichotomous variables have the value 1 if the respective firm was located in a certain region and the value 0 if not indicated differences with regard to the constant term of the knowledge production function.[1] The coefficients for an interaction of these dummies with a firm's R&D input (R&D expenditure or R&D employment, respectively) reflect differences in the slope of the knowledge production function pointing to diverging output elasticity or productivity of innovation processes.

Looking at the estimated dummy coefficients for divergent regional output elasticities of R&D input, we find many negative signs indicating a lower efficiency of innovation activity than in Baden. This confirms many judgments found in the literature that emphasize the relatively good quality of the innovation system in this region (e.g., Cooke, 1996; Heidenreich and Krauss, 1998; Sabel *et al.*, 1989). The highest output elasticity is found for Vienna (cf., Table 2). While the elasticities for Rotterdam and for Stockholm are not significantly different from the value for Baden (the reference region), the coefficient for Barcelona estimated on the basis of R&D employment as input measure indicates significantly lower productivity than in Baden. By far the lowest values for output elasticity of R&D input are found for Gironde and Slovenia.[2] For many of the other regions, the dummies measuring differences of R&D output elasticities have a negative sign, indicating lower productivity of R&D activities than in Baden. These differences are not statistically significant, but if a region such as Barcelona, Gironde or Slovenia had been taken as reference, much more significant regional effects would have been found. As could have been expected, the estimates of the regional dummies based on R&D expenditure differ to some extent from the estimates using R&D employment as indicators for R&D input; however, these differences are within reasonable limits.

On the whole, the results suggest that being located in a large agglomeration tends to be relatively conducive for R&D activity as compared with location in less densely populated or more peripheral regions.[3]: However, there are also some relatively high values of output

[1] The interpretation of the constant term of the knowledge production function is somewhat ambiguous. If the number of inventions is used as an indicator of the success of R&D activities, the constant term denotes how many inventions have been generated without a corresponding R&D input on behalf of the enterprise during the period for which R&D input was measured. Assuming that the generation of inventions necessitates some R&D input, there are two possible explanations for the existence of a positive constant term. One explanation could be that the respective invention was entirely the result of knowledge spillovers from other sources without any R&D effort on the part of the firm that is supposed to have generated it. In this case, the constant term of the knowledge production function represents those inventions that are 'falling from heaven' on a certain firm. A second possible explanation has to do with the measurement of the input to the innovation process. The constant term of the knowledge production function may reflect incomplete measurement of R&D input. Such a misspecification of R&D input may occur particularly if an invention is not based on current R&D investment but on the existing stock of 'old' knowledge; in such a case, this part of the relevant input could not be measured appropriately.

[2] However, estimates for these regions are based on relatively few observations, so it might be argued that they do not reflect the conditions in the respective regions correctly. The number of usable observations for Gironde was 13 (model with R&D expenditure as input variable) and 11 enterprises (model with R&D employment as input variable). The estimates for Slovenia were based on 31 and 35 cases, respectively.

[3] A number of interregional differences with regard to the constant term of the model can be found that are not in accordance with a centre–periphery scheme. These differences are neglected here because of their unclear interpretation.

Table 2. *Results of negbin-regressions of a knowledge production function with regional dummy variables*

	No. of patents with respect to R&D expenditure	No. of patents with respect to R&D employment
Constant	1.83** (15.78)	0.79** (5.14)
R&D expenditure (ln)	0.51** (7.44)	–
No. of R&D employees (ln)	–	0.50** (9.46)
Industry dummies		
Food, beverages, tobacco	0.59 (1.83)	0.51 (1.46)
Textiles, clothing, leather	−0.18 (0.049)	−0.35 (1.01)
Wood, paper, printing, publishing	−0.21 (1.33)	−0.09 (0.60)
Mineral oil, chemicals, rubber, plastics, stone etc.	0.16 (1.27)	0.37** (3.12)
Metal products, recycling	0.44** (3.15)	0.67** (4.87)
Mechanical engineering, vehicles	0.15 (1.38)	0.17 (1.66)
Regional dummies for absolute term		
Barcelona	0.58** (3.48)	0.56** (2.83)
Rotterdam	−0.15 (0.71)	−0.39 (1.41)
Stockholm	−0.34* (2.31)	−0.66** (2.92)
Vienna	0.04 (0.23)	−0.57 (1.82)
Alsace	−0.52* (2.29)	−0.06 (0.20)
Gironde	−0.77* (2.20)	0.49 (1.42)
Hanover	−0.07 (0.51)	−0.03 (0.14)
Saxony	−0.30* (2.10)	−0.61** (2.91)
Slovenia	−0.82** (3.48)	0.02 (0.06)
South-Wales	0.03 (0.12)	−0.13 (0.37)
Regional dummies for R&D elasticity		
Barcelona	−0.10 (1.11)	−0.20* (2.20)
Rotterdam	−0.07 (0.55)	0.05 (0.36)
Stockholm	0.01 (0.18)	0.14 (1.54)
Vienna	0.20* (2.10)	0.48** (4.11)
Alsace	−0.07 (0.50)	−0.12 (0.95)
Gironde	−0.61** (5.77)	−0.56** (3.53)
Hanover	−0.12 (1.41)	−0.13 (1.68)
Saxony	−0.07 (0.74)	−0.01 (0.09)
Slovenia	−0.43** (3.37)	−0.40** (2.84)
South-Wales	−0.14 (1.15)	0.02 (0.10)
Alpha	0.73** (16.71)	0.73** (16.62)
Pseudo R^2	0.134	0.127
Probability chi^2	0.00	0.00
No. of cases	705	707

* Statistically significant at the 5%level. ** statistically significant at the 1% level.; asymptotic *t*-values of the coefficient in parentheses.

elasticity in less urbanised areas (e.g., Saxony, South-Wales) indicating that R&D may also be conducted quite efficiently in these locations. Other measures for innovation activity point in about the same direction, but the regional pattern is less clear (cf., Fritsch, 2000). At the very least, there are no indications in the data that the peripheral areas or regions with low population density have a clear advantage over the centres with regard to R&D.

4.3 Is there a relationship between R&D cooperation and efficiency of R&D activity?
Having shown that significant differences with regard to cooperation and the efficiency of R&D activity exist among regions, the relationship between these two issues will now be investigated. Does a relatively high level of R&D cooperation of the enterprises in a region correspond to efficiency of R&D activity in that region?

Figures 3 and 4 show the combinations of two regional dummy variables for the propensity to maintain R&D cooperation (cf., Table 1) and the estimates of regional output elasticity with regard to R&D expenditure (Table 2). These two graphs with the dummy variables for the propensity to have cooperative relationship with customers and with 'other' firms are fairly representative examples for the other indicators of regional cooperation behaviour. Clearly, the relationship between cooperation behaviour and R&D efficiency in these cases is rather diffuse. As a statistical measure for this relationship, rank correlation coefficients for the different combinations of indicators of regional cooperation behaviour and the efficiency of R&D activities have been calculated (Table 3). In addition, Table 3 shows correlation coefficients for the relationship between the cooperation variables and two less sophisticated indicators for regional innovation behaviour, the share of establishments that have introduced at least one innovation or have registered at least one invention for patenting in the preceding three years. That many of these correlation coefficients assume negative values clearly indicates that there is no strong overall positive relationship between cooperation behaviour and efficiency of innovation activity in the data. Positive signs on the correlation coefficients can be found mainly for those indicators of regional cooperative behaviour that are based on estimates of the number of cooperative relationships. In almost all these cases, however, the correlation coefficient has a negative value when using the respective cooperation indicator based on the propensity to have at least one cooperative relationship. That only some of these coefficients proof to be statistically significant at the 5% or 10% level is to some degree a consequence of the relatively small number of cases (regions) in the sample.

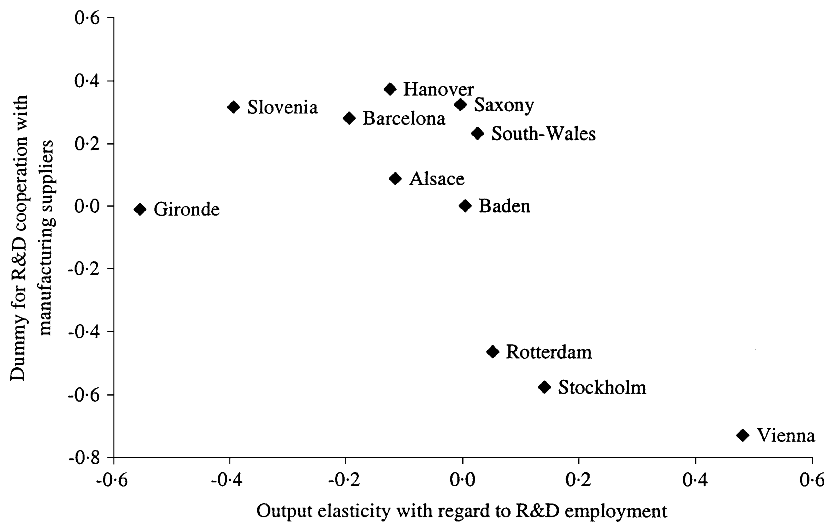

Fig. 3. *Combinations of values of regional dummy variables for cooperation with manufacturing suppliers and output elasticity with regard to R&D employment.*

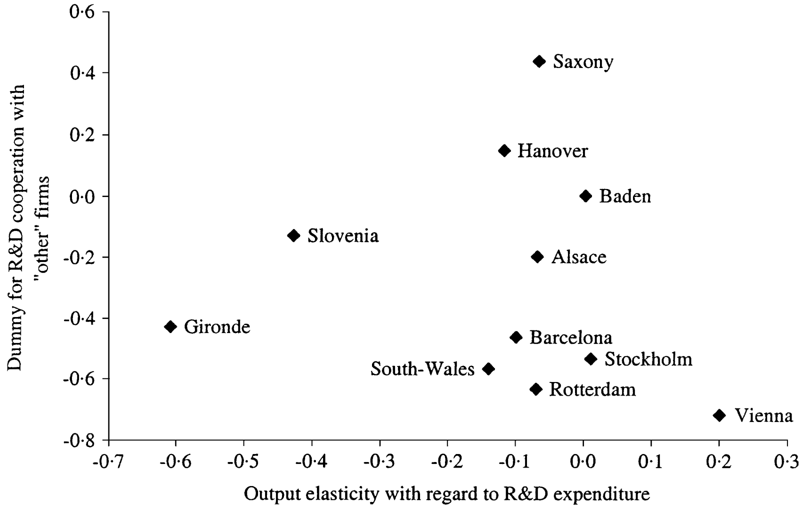

Fig. 4. *Combinations of values of regional dummy variables for cooperation with 'other' firms and output elasticity with regard to R&D expenditure.*

Table 3. *Spearman rank correlation coefficients for the relationship between indicators for regional R&D cooperation behaviour and efficiency of R&D activities*

	Indicators for innovation activities			
Indicators for regional cooperation behaviour	Output elasticity with regard to R&D expenditure	Output elasticity with regard to R&D employment	Having introduced at least one innovation	Having registered at least one invention for patenting
Propensity to cooperate with				
customers	−0.184	−0.464	−0.246	−0.283
manufacturing suppliers	−0.551*	−0.609**	0.236	−0.046
service firms	−0.138	−0.382	0.118	−0.055
'other' firms	−0.257	−0.564*	−0.218	−0.078
research institutes	−0.275	−0.391	−0.282	−0.470
Number of cooperative relationships with				
customers	0.220	−0.018	0.000	0.055
manufacturing suppliers	0.028	−0.200	−0.036	0.041
service firms	−0.107	−0.179	0.226	−0.451
'other' firms	0.009	0.127	0.055	0.475
research institutes	0.215	0.479	0.467	0.553*

* Statistically significant at the 10% level; ** statistically significant at the 5% level.

Excluding outlying regions such as Gironde, Slovenia or Vienna from the analysis does not lead to a much clearer pattern such as would confirm the hypothesis that there is a positive relationship between cooperation and R&D activity. If such a relationship exists, it is obviously not adequately measured by the indicators used here or it is perhaps overlaid by other influences. The results are also robust with regard to alternative definition of what is a cooperative relationship.

5. Conclusions

The empirical analyses conducted here revealed pronounced regional differences with regard to the propensity to maintain cooperative relationship. The reasons for this variation remain unclear and deserve further investigation. Significant differences between regions were also found with regard to the efficiency of R&D activities. These differences correspond to some degree to the centre-periphery hypothesis proposed in the literature. The results of a simple correlation analysis provide no support for the suggestion that cooperation or a relatively pronounced cooperative attitude in a region is conducive to innovation activity. Our sample of regions contains impressive counter-examples to such a hypothesis, i.e., regions that are characterised by a relatively low/high propensity to cooperate on R&D and high/low efficiency of innovation activities (e.g., Vienna, Slovenia, Gironde).

It may be argued that the type of analysis that has been presented here is inadequate for investigating the relationship between cooperation and innovation activity. One may object that the main effects of R&D cooperation are long-term in character and cannot be assessed on the basis of cross-section data. Moreover, the impact of cooperation on R&D may be strongly influenced by certain characteristics of the local network[1] which are only insufficiently described by the indicators used here. If, however, even such a more sophisticated analysis did not reveal a significant positive relationship between cooperation and the efficiency of R&D, this would leave us with the unanswered questions of the role of cooperation in innovation systems. Such a result would suggest particularly that R&D cooperation is not important as a medium for knowledge spillovers. In fact, respective tests of our data suggest that regional R&D spillovers are effective, largely independent of cooperative relationships (Fritsch and Franke, 2004). Our result throws some doubt on recent concepts aimed at explaining regional difference of R&D activity in which cooperation is supposed to be an important element.

But if R&D cooperation does not play such an essential role in the division of innovative labour and as a medium for knowledge spillovers, which are the important factors? One such factor that has not been accounted for in our analysis is mobility of labour between firms. Significant spillovers may occur when members of the workforce change employers or start their own businesses. Particularly spin-offs from incumbent firms could be an important force in the process of innovation and regional development (Klepper, 2001; Sorensen and Audia, 2000). Another significant source of spillovers could be the education system, especially the universities that are supplying the labour market with their graduates. In addition, perhaps 'normal' market relations to suppliers and customers play a much bigger role in the division of innovative labour than is commonly assumed. Unfortunately, there is no information about these issues in the data set. And to gather such data which is comparable across the regions of the sample would hardly be possible,

[1] E.g., the structure of the network, the extent of redundancies in relationships etc. (c.f. Fritsch, 2001B).

given the different definitions and concepts of statistical systems. Owing to such problems of comparability, a sample of regions from only one nation may be much more suitable for a more comprehensive analysis.

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