Cooperation, Specialization and Patenting in German Technology Regions

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Abstract

We investigate cooperative behavior within technology regions in patenting activities. Case studies of local innovation systems point out certain characteristics fruitful to innovation and regional growth but often pronounce historical singularities as major influence. We provide evidence on the same theoretical basis in an econometric study. Based on a theoretical discussion of research cooperation hypotheses are derived which relate a regions technological characteristics to that regions account of research cooperation. Patent data are used to define the technological specialization of German regions and identify cooperations within and between them. Most cooperations tend to take place in modestly specialized regions, indicating a need for similar technological capabilities between partner firms.

Keywords: Research Cooperation, Technological Specialization, Local Innovation Systems.

JEL Classification: L29, O31, R12

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1 Introduction

Scholars of the economics of innovation and technological change largely agree on innovation as an interactive and highly systemic process with many actors from different parts of the economy involved (e.g. Nelson 1993, Lundvall 1992). The density of innovation networks as well as the openness towards external knowledge of the relevant actors, amongst other factors, have been identified as necessary conditions for the performance of local innovation systems (Breschi and Malerba 2001).

In this paper we focus on the technological knowledge of a region and the patterns of cooperative behavior of the actors within that region as a means of transferring this knowledge. Of course there are many ways by which information between economic actors may be exchanged, one of the empirically more traceable is the formal R&D cooperation. The theoretical literature on R&D cooperation has largely focused on the social benefits of R&D cooperations as a means of internalizing positive spillovers generated through R&D (e.g. D'Aspremont and Jacquemin 1988, Kamien, Muller, and Zang 1992). Since the firms in those models are symmetric with respect to their technological capabilities, cooperation and its consequences is solely dependent on different product market and spillover conditions. These conditions are not questioned here, rather it is assumed that cooperation is favorable to innovation. Taking a step back from that discussion we rather investigate firms decision to cooperate or not when they are technologically heterogeneous and how this relates to a quite similar pattern of cooperative activities on a regional level.

The main research question within this paper is concerned with the relationship between the knowledge and/or the degree of specialization within a region, its propensity to cooperate and the kind or pattern of this relationship. In particular we are interested whether the kind and level of sophistication of technologies applied in a region, the technological diversity of that region as well as the relative technological position of that region with respect to other regions have a significant influence on the intensity and kind of cooperative behavior in research of the firms within a region.

The major results of our analysis are as follows: First, we find that regions which are technologically not too specialized show the highest number of research cooperations. Second, the higher a regions technological specialization the more cooperation will take place with partners inside the same region compared to cooperation with partners outside that region. Third, technologically more diverse regions show more internal cooperations whereas for regions which are less diverse we find a higher number of external cooperation.

The paper proceeds as follows: First, in section 2 we present the theoretical background for the hypotheses we want to test empirically. Here we introduce the conceptions of technology gap, of technological diversity, of internal and external cooperations, and of the tech-region as main building-blocs. Section 3 is devoted to the description of our database and the construction of the various variables we use. Section 4 reports on our estimation results and gives appropriate interpretations. Section 5 concludes the paper by summarizing and pointing on further research required.

2 Theoretical Background and Derivation of Hypotheses

In order to develop testable hypotheses on the specific regional pattern of firms cooperative behavior in this section we present the theoretical background. In particular, we first aim at the knowledge based incentives of firms for engaging in the exchange of know-how on a cooperative basis. In a second step we extend the arguments on the firm level to the regional level. In a third step we derive from this three hypotheses on the relationship between a region's technological characteristics and the pattern of its firms cooperating in research.

2.1 Collective invention

Theories on innovation networks, such as local innovation systems or technological systems, tell us that quite regularly new know-how is to be considered as the collective rather than an individual outcome of knowledge generating activities. This collective dimension is based on the conscious (but also sometimes unconscious) exchange of information and knowledge between specific actors which differ in the *kind* of knowledge and capabilities they hold and master as well as in the *level* of their respective technological competence. Knowledge exchange taking place among such heterogeneous agents may lead to a new combination or recombination of specific knowledge and competencies which then via so-called cross-fertilization leads to new know-how and new capabilities. Consequently, the resulting achievements are a collective outcome and had not been possible by the knowledge generating activities of a single isolated actor.

2.2 Local innovation systems and technology systems

Whenever this exchange of knowledge is taking place on more frequent and even regular terms, whether formalized or not (von Hippel 1987), the resulting structure of relationships can be described by a system or network of actors. Those systems reduce the cost of exchanging know-how and information and thus let the benefits of cross-fertilization be reaped more easily. Based on this aspect, networks for know-how exchange can be observed on different levels. Whenever geographical proximity enables and eases know-how exchange, a regional or local system of innovation (Saxenian 1994, Cooke 1998) may show up (e.g. Jena, where a number of different technologies co-exist such as optics, biotechnology etc.). Is the ease of knowledge exchange directly related to proximity in technological know-how, so-called technological systems (Carlsson and Stankiewicz 1991) may be observed which are characterized by a nevertheless broadly defined core technology (such as “automobiles” where a small number of sub-technologies such as combustion engines, electronics, safety-technologies etc. come together). Of course, firms can be “member” of both kinds of systems.

2.3 Know-how exchange and technology structure

So far, classifying network based exchange of know-how has been based on the degree of accessibility and the related transaction costs. In addition to that, and maybe even more important than sheer (cost dependent) accessibility is the degree to which exchange of knowledge is beneficial to both or all sides involved. As mentioned above the knowledge a firm is endowed with at a certain point in time has at least two dimensions, the kind of knowledge on the one side and its level or degree of sophistication on the other side. For any two (or more) actors willing to exchange know-how these two aspects are of importance.

Consider first that the specific kinds of knowledge are substitutive instead of complementary. Consequently, the actors will not get into exchanging know-how. Alternatively, considering the case where the specific knowledge endowments are neither substitutable nor complementary exchange of know-how will not benefit any of the parties. Third, of course, with complementary knowledge know-how exchange is likely to benefit all actors involved.

With respect to the level of knowledge consider actors whose knowledge by all means is complimentary but who differ considerably in the level of technological sophistication, that is there are high-tech actors as well as low-tech actors. In such cases the difference in just these technology levels, the so-called technological gap[1], may determine whether a cooperation is beneficial for all exchanging parties. For two actors which are rather different, the technological gap between both is relatively large, and therefore the exchange of know-how may be beneficial for the technological laggard only. In that case an exchange of know-how or a cooperation will not be established[2]. Alternatively, when the technological gap between two actors is rather low the exchange of know-how is beneficial to both, in which case a know-how exchange or cooperation is likely to become established.

This idea is graphically represented in figure 1 where the probability of a cooperation between two firms A and B is highest for a technological gap of zero while the probability declines with the difference in the level of capabilities. Note that this holds for complimentary knowledge only.

[1] The technology gap here is to be considered as a multidimensional conception when different knowledge components make up the technology level of an actor. An appropriate measure should take account of differences in technological levels in the aggregate.

[2] We abstract from the possibility of financial compensation for the technological leader. Even though we see cooperations between for example newly founded biotechnology firms (the leader) with large pharmaceutical companies (the laggard) where this compensation is practiced to the extreme case of a merger.

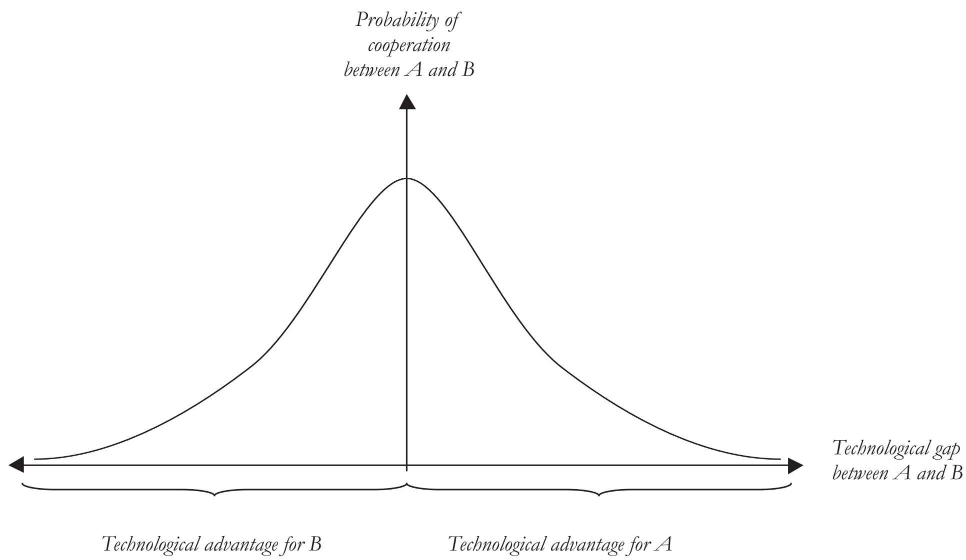

Figure 1: Probability of cooperation depending on the technological gap between two firms.

A consequence of this dependence of cooperation on technology gap structures is that technologically highly sophisticated firms might even be unable to find appropriate cooperation partners. Take, for example, the only and far ahead technology leader in a certain sector for whom the likelihood to find a partner is relatively low - in the case of a monopolistic situation even zero.

In addition to these last arguments one might also ask whether high-tech firms or rather low-tech actors are more interested or engaged in cooperation. On the assumption that low-tech know-how usually has diffused already and thus is public, it is high-tech knowledge which is supposed to be less easily accessible and will be only exchanged (and thus diffuses) in an cooperative arrangement. Consequently, high tech-firms tend to be more engaged in cooperation than low-tech actors.

2.4 Cooperation and relative technological position

Based on these arguments we want to establish the following: Assume that the actors considered are never identical with respect to their kind of knowledge and the specific level of technological capabilities. Assume also that the actors attempting to exchange know-how face all the same transaction costs in getting access to other know-how or using the network. The engagement of these actors in cooperation and know-how exchange then depends on their respective technological position within the overall technology structure resulting from the specific knowledge endowments of the heterogeneous actors. The technological position is defined in a relative way, as an actor's technological gap towards other actors (lagging or leading) as well as the degree of complementarity of the specific knowledge endowments (complementary, substitutive or non-related).

2.5 Regional focus and tech-regions

Before we derive hypotheses that can be tested empirically we want to switch the perspective and consider the actors as part of certain geographical region. In order to take into account the various technologies performed in a certain region we define so-called *tech-regions*. A tech-region ij consists of the firms located in region i and engaged in technology class j. For example the optic firms Zeiss and Jenoptik belong to the technology class "optics" and are located in the region of "Jena". This tech-region is potentially part of the local innovation system of Jena as well as potentially part of the technological system of the optics industry in Germany (or even world wide).

Looking at a specific tech-region ij one may be interested in the following questions: (a) Are firms belonging to tech-region ij engaged in know-how exchange or research cooperation? (b) If there is cooperation to be observed for tech-region ij, what are the determinants for such cooperative arrangements on the tech-regional, regional, and technological level? (c) What kind of network-relationships or know-how exchange relationships are the firms engaged in? That is, are they integrated in a local system of innovation and/or in a technological system. In the former case the cooperation is called *internal* to the region, in the latter case we have cooperation which is *external* to the region.

In order to argue on the level of tech-regions the above used concepts of *technology gap* and *kind of technology* have to be adjusted. For the former, we use the degree of technological specialization of a region i in technology

j. The higher this degree the more specialized is region i in generating new technological know-how and the higher the level of technological sophistication in technology j. For the latter, the degree of technological diversity describes an upper boundary for possible technological complementarities faced by the actors within region i.

2.6 Hypotheses

On the basis of this regional or local perspective we can formulate hypotheses about the cooperative endeavors of firms:

Hypothesis 1 *Comparing different tech-regions the number of cooperations is highest for some intermediate degree of specialization.*

This hypothesis follows directly from the idea that as long two actors have complementary knowledge the technological gap must not be too large for them to both benefit by cooperating.

Hypothesis 2 *If firms located within one specific tech-region are assumed to be rather similar in technological level, tech-regions which are more specialized will show a higher number of internal cooperations relative to external cooperations.*

A tech-region being highly specialized implies that the knowledge generated therein makes up a large quantity of the new knowledge of the whole technological system. The probability of finding an appropriate partner for mutual beneficial knowledge exchange within the region rises compared to finding one outside.

For a third hypothesis consider the following. Firms have closer contacts to other firms belonging to the same local or technological innovation system than to firms outside either system. Those existing contacts provide the basis for possible cooperations. On the one hand, diversity of the region provides easily accessible knowledge for diversifying or broadening firms knowledge bases. On the other hand, specific knowledge to the own field might rather be found within the technological system. Based hereon we can now state:

Hypothesis 3 *Tech-regions within technologically more diverse regions show a higher level of internal cooperations, while those within less diverse regions cooperate more externally to their location.*

3 Data

3.1 Patent level

For the empirical analysis we use German patent data as provided by the German patent office (Patos® 2001). The patents in the database were disclosed between 1995 and 2001 and were assigned by at least one assignee located in Germany. We use information about the assignee(s), the inventor(s), and the IPC main classification of each patent.

Each patent is characterized according to its cooperative nature, technological class, location, and whether one of the assignees is a university or other public research institution. A patent is considered a cooperation if the number of assignees is greater than one (co-assigned). In our view this assumption leads to an underestimation rather than an overestimation of cooperative research. Since two organizations that decide to assign a patent together will have to had cooperated on that project and on the other hand, not every research cooperation will lead to a co-assigned patent if the partners find other ways to compensate each other.

A co-assigned patent is counted as an *internal cooperation* if it is a cooperation in the sense above and all inventors are located in the same region, an *external cooperation* is a cooperation where at least two of the inventors are not co-located. The reason for this classification scheme lies in the patenting conventions of large organizations. Big firms (e.g. Siemens) or research institutes like Max-Planck or Fraunhofer assign their patents in their headquarters no matter where the research leading to the patent was conducted. Therefore cooperations between such large patentees and smaller ones in other regions will almost always be counted as external cooperations even if they were actually within a region. Based on this procedure 12,549 of the 231,720 patents in our sample are considered as cooperations with 3,421 internal and 9,128 external to regions.

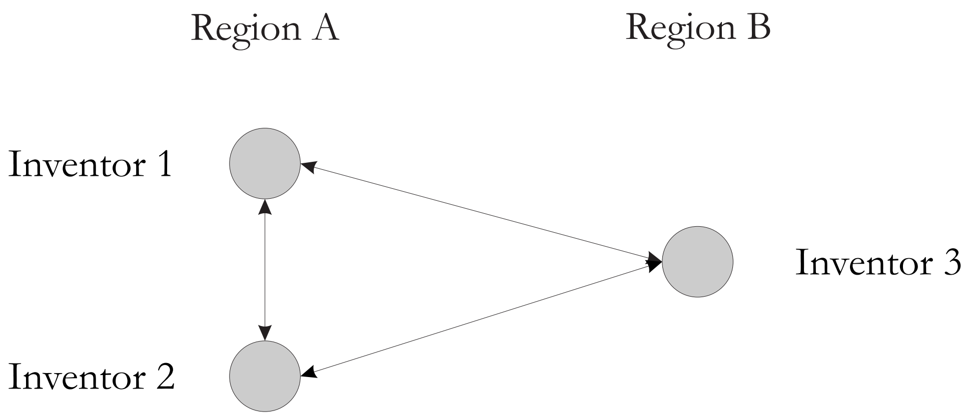

Figure 2: Three inventors from two different regions work together on one patent. For region A this constellation leads to one internal link and two external ones, whereas region B has no internal links but two external ones.

Since this paper is about interaction, network analysis seems to be a natural methodology for describing linkages between regions. The way internal and external links are calculated so far, can only be an approximation to real connections of actors within and between regions, since it is a zero/one variable for each patent. Figure 2 shows how an alternative measure of internal and external interaction is computed. This figure gives a graphical representation of a network of innovators on one patent, with inventors 1 and 2 from region A and inventor 3 from region B. To get an account of cooperative research done we count the cooperative linkages each inventor of a particular patent has, distinguish by this external and internal linkages and aggregate for the tech-regions with respect to the patent just considered. The variable $INLINK$, taking account of cooperations internal to a region, will then have a value of 1 for region A and 0 for region B. The variable $EXLINK$, measuring external cooperation, will be 2 for regions A and B.

3.2 Technology region level

Since our level of analysis is the tech-region, we aggregate the variables to the level of the technological region.[3] For the technological aggregation

[3]e.g. KO in the new dataset is the sum of KO on patent level for technology j in region i.

patents have been classified according to a technology-oriented classification that distinguishes 5 industries and 30 technologies based on the International Patent classification (IPC). This classification has been elaborated jointly by the Fraunhofer-Institut für Systemtechnik und Innovationsforschung (FhG-ISI), the Observatoire de Sciences et des Techniques (OST), and the Science and Technology Research Policy Unit of the University of Sussex (SPRU). Its most updated version is reported in table 5. The observation unit is then a technological class located in a region, according to the first five digits of the German "Kreisgemeindeschlüssel" which make up the German "Kreise", of the first assignee mentioned on the patent. Resulting from this procedure we end up with 9648 observations consisting of 434 regions and 30 technological fields.[4]

To characterize the tech-regions several variables as presented in table 1 are used. We measure, or rather approximate, the regional competence in a certain technology by the degree of specialization of that tech-region. We presume, that in the long run a region will not follow a technological path if it is not successful in those technologies and therefore assume technological competence and specialization to be positively correlated. We follow Patel and Pavitt (1991) and Soete (1981) by employing the index of Technological Revealed Comparative Advantage (TRCA), originally used in a moderately different form in trade theory[5]. This *specialization* index uses the number of patents (P_{ij}) of region i in technology field j and is defined as a regions share of all patenting in a technological field, relative to its share in all patenting in all fields:

$$TRCA_{ij} = \frac{P_{ij}/\sum_i P_{ij}}{\sum_j P_{ij}/\sum_{ij} P_{ij}}$$

A value above unity indicates a comparative advantage of region i in the technological field j. Calculated in this fashion, this index is not symmetric[6] and is therefore not an appropriate measure of specialization to be used in econometric models. (Laursen 1998) suggests the following transformation

[4]Of course not all regions patent in all technological fields.

[5]Namely Balassa's (1965) Index of Revealed Comparative Advantage.

[6]its values range from zero to $max(\frac{\sum_{ij} P_{ij}}{\sum_j P_{ij}}, \forall i)$. In the extreme case, where one region only patents in one technological class $P_{ij} = \sum_j P_{ij}$ and therefore cancel out.

to this measure:[7]

$$RSCA_{ij} = \frac{TRCA_{ij} - 1}{TRCA_{ij} + 1}$$

The $RSCA$ is symmetric and bounded between -1 and +1 with no specialization indicated by a value of 0. Our expectations about the coefficients of this variable are discussed at length in section 2.

The role of diversity in cities or regions has been discussed in the literature. Glaeser, Kallal, Scheinkman, and Shleifer (1992) test three different models of knowledge spillovers according to their impact on the growth rate of cities. They find clear evidence in favor of the model by Jacobs (1969) where she argues that the most important sources of knowledge spillovers are external to the industry in which the firm operates and that cities are the source of innovation because diversity is greatest in cities. We therefore include a simple measure of *diversification* of the **region**. Duranton and Puga (2000) applied the inverse of a Hirshman-Herfindahl index, which translates for our purposes to summing the square of each sector's share in local patents for each region over all technologies. Formally the Hirshman-Herfindahl index or diversity index is given by

$$DI_i = 1/\sum_j p_{ij}^2 \ ,$$

where p_{ij} is the patent share of technology j in region i.

If patenting activity in the region under consideration is fully concentrated in a technology, we find $DI = 1$, and this index increases as activities in this region become more diverse. A positive coefficient of diversity would speak in favor of Jacobs's (1969) argument.

To account for differences between tech-regions in terms of the *concentration of patentees* we also calculated the Herfindahl Index for every observation unit ij as below:

$$HERF_{ij} = \sum_k \left(\frac{P_k}{\sum_k P_k} \right)^2$$

[7] The $RSCA$ is similar to the hyperbolic version of the TRCA suggested by Grupp (1994) but discriminates better between high values of the $TRCA$.

P_k is the number of patents assigned by organization k in tech-region ij. The expected impact of the concentration of patentees on the number of internal cooperations is clear. In the extreme case of a single inventor of the tech-region there is no possibility of internal cooperation, so the influence should be negative. For the number of external cooperations this coefficient should be positive if we assume that the "monopolist inventor" searches for external partners if he does not find them locally.

The *regional concentration of technology j* is measured again with the Herfindahl index

$$HERFTECH_j = \sum_i \left(\frac{P_{ij}}{\sum_i P_{ij}} \right)^2$$

The *ideal type* local innovation system is specialized in a technology which is geographically concentrated with many local innovators. We should therefore see more internal cooperations in those concentrated technologies, while for external cooperations there could be two effects, pushing into different directions. If the technological system is dense, external cooperations could be expected to rise with concentration. On the other hand in the extreme case of a single innovating region in that technology we can - by definition - observe no external cooperation.

The regional statistics of the "Statistisches Bundesamt" (as published in Statistische Ämter des Bundes und der Länder 2002) provide further information to characterize the regions. $BEV00$ represents the size of the region in terms of inhabitants in the year 2000 while $BETRGR$ is the average working force of firms within the specific region (data from 1999). This variable indicates differences in industrial structure between the regions but is only a very rough measure since it is only available on the regional and not also the technological level and it gives only one measure of the distribution of firm size within the region.

With those variables at hand we proceed with the regressions and their analysis in the following section.

Table 1: List of variables and descriptive statistics

	Description	Level	Mean	Std.Dev.	Minimum	Maximum	NumCases
Dependent Variables							
KO	No. of co-assigned patents	Tech-region	1.30	4.19	0	147	9648
KOINT	No. of internal cooperations	Tech-region	0.35	1.31	0	49	9648
KOEXT	No. of external cooperations	Tech-region	0.95	3.47	0	142	9648
KOEXANT	Share of external cooperations (KOEXT/KO)	Tech-region	0.71	0.39	0	1	4098
EXSHARE	Share of external linkages	Tech-region	0.82	0.22	0	1	8721
Regressors							
RSCA	Specialization index	Tech-region	-0.08	0.41	-0.98	0.97	9648
RSCA2	—"— squared		0.17	0.19	0.00	0.96	9648
UNI_EV	No. of patents with at least one Public R&D agency as assignee	Tech-region	0.51	6.17	0.00	320	9648
PAT	No. of patents	Tech-region	24.02	113.76	1.00	4213	9648
PAT2	—"— squared		13516.90	$3.12E{+}05$	1.00	1.77E+07	9648
DI	Technological diversity of region i	Region	10.58	3.45	1.99	19.39	9648
DI2	—"— squared		123.83	73.62	3.96	375.972	9648
HERF	Concentration of innovators in a tech-region	Tech-region	0.47	0.33	0.01	1.00	9648
HERF2	—"— squared		0.33	0.39	0.00	1.00	9648
HERFTECH	Regional concentration of technology j	Technology	0.05	0.05	0.01	0.27	9648
HERFTECH2	—"— squared		0.01	0.01	0.00	0.07	9648
BEV00	Inhabitants of the region in 2000 (thousand)	Region	213.41	244.98	40.20	3384.14	9648
BETRGR	Average size of business in year 1999 (workers per firm)	Region	134.94	113.67	44.21	1615.06	9648
SEC1-5	Dummies for the 5 major technological sectors						9648

4 Empirical Analysis

In this section we present the empirical test of the hypotheses presented in section 2. The theoretical considerations predict that between tech-regions the number of cooperations is highest for some intermediate degree of specialization. Firms within a less specialized region lack the know-how to be a partner for other firms and when they are too specialized they have difficulties finding a partner from whom to benefit through cooperation. We also analyze if there are any differences between factors influencing internal and external cooperations. If firms located within one specific tech-region are assumed to be rather homogeneous, in terms of level of know-how, our model predicts a higher number of cooperations within tech-regions (internal cooperations) relative to external cooperations.

4.1 Overall regression

Since the dependent variable - the number of cooperations within a tech-region - is a count variable, we specify a negative binomial regression (NB) to estimate the influence of technological specialization and the other variables on cooperation. Throughout all regressions in this paper the test for overdispersion speaks in favor of the NB model.[8]

In table 2 the results of five regressions, labelled A to D, on the total number of cooperations in a tech-region are presented. In column A the

[8]The NB arises as an extension of the Poisson regression model, which is characterized by the equality of the conditional mean and variance (defined as equidispersion). The overdispersion parameter α indicates the degree of deviance of the variance from the mean. For the interpretation of the coefficients it is helpful to note that in the NB model the exponential conditional mean is

$$E[y_i|\mathbf{x}_i] = exp(\mathbf{x}'_i\beta)$$

and therefore

$$\frac{\partial E[y_i|\mathbf{x}_i]}{\partial x_{ij}} = \beta_j exp(\mathbf{x}'_i\beta).$$

The coefficient β_j equals the proportionate change in the conditional mean if the j^{th} regressor changes by one unit. For example, if $\hat{\beta}_j = 0.2$ and $exp(\mathbf{x}'_i\hat{\beta}) = 2.5$, then a one-unit change in the j^{th} regressor increases the expectation of y_i by 0.5 units. For a detailed discussion of count data regressions see Cameron and Trivedi (1998).

number of cooperations is regressed on the specialization index $RSCA$ and its square.[9] The coefficients of $RSCA$ and $RSCA2$ are significant and show the expected signs, so that hypothesis 1 cannot be rejected, i.e. an intermediate degree of specialization is favorable to a high level of cooperative research. Universities and public research laboratories might be more cooperative since appropriability or secrecy is neither important to them - in contrary - nor wished for by the state[10] and joint projects with the industry serve as a way of financing research. We therefore included the number of patents in a tech-region, where at least one assignee is a public financed organization (UNI_EV). A positive coefficient would affirm the above argument. Dummies for the five sectors (SEC1-5) were also included[11] to account for systematic differences between technologies.

In regression B of table 2 two new variables with the respective squared terms are included. The absolute number of patents (PAT and $PAT2$) is included to control for differences in size between the tech-regions. Since this measure also approximates the know-how level of a tech-region the argument regarding the expected coefficients is the same as for the specialization index. The diversity index DI is included to account for differences in the technological structure of the regions. If higher technological diversity of a region leads to more cross-fertilization of the actors with different technological background this variable should show a positive coefficient. When cooperations rather take place between actors with the same kind of know-how (as assumed in the theoretical discussion) this coefficient should be negative. The patent terms, PAT and $PAT2$, confirm our expectations and the coefficients of the diversity index imply that - in spite of a decline for low values of DI - cooperations in patenting are more frequently observed in diverse regions as compared to specialized ones.[12] The qualitative interpretation of the other variables ($RSCA$, $RSCA2$, UNI_EV) remains unchanged while values of the coefficients drop sharply compared to model A.

[9]Cubic terms did not prove to be significant.

[10]Except perhaps defense related R&D and alike.

[11]Coefficients for the sectoral dummies are not reported since differences between technologies are not the focus of this paper.

[12]For large values of DI, within the range of observed values, the positive coefficient of $DI2$ outweighs the negative coefficient of DI.

Table 2: Negative binomial regressions of the number of cooperations in patenting on regional and technological characteristics over all sectors

	Model			
	A	B	C	D
RSCA	1.0439	0.4371	0.5776	0.7333
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RSCA2	−0.6723	−0.7550	−0.0032	0.1630
	(0.0000)	(0.0000)	(0.9667)	(0.0043)
UNI_EV	0.1005	0.0088	0.0049	0.0008
	(0.0000)	(0.0001)	(0.0034)	(0.1643)
PAT		0.0123	0.0089	0.0032
		(0.0000)	(0.0000)	(0.0000)
PAT2		−0.0000	−0.0000	−0.0000
		(0.0000)	(0.0000)	(0.0000)
DI		−0.0997	−0.1291	−0.0308
		(0.0000)	(0.0000)	(0.0357)
DI2		0.0075	0.0068	0.0019
		(0.0000)	(0.0000)	(0.0028)
HERF			−4.6085	−4.6280
			(0.0000)	(0.0000)
HERF2			2.1970	2.0389
			(0.0000)	(0.0000)
HERFTECH			3.1901	1.2865
			(0.0003)	(0.0502)
HERFTECH2			−11.8681	−8.5158
			(0.0014)	(0.0029)
BEV00				0.0005
				(0.0000)
BETRGR				0.0011
				(0.0000)
ALPHA	2.1957	1.2458	0.8052	0.4391
LR-Index	0.0491	0.1222	0.1746	0.1537

N = 9648; Five Sector-dummies are included
p-values in parentheses

In models C and D the path of our theoretical considerations is left in favor of more explanatory power of the econometric model. An important issue of the theoretical discussion above was the matching of cooperation partners when there is a sufficiently large number of possible partners, namely firms or organizations performing research in the same technology. The concentration of innovators within a tech-region ($HERF$ and $HERF2$) is a measure of the availability of local cooperation partners. If there is only one innovator in the respective technology, the possibility of - at least - internal cooperations is clearly lower as if there were several organizations involved in that technology. If this technology is in addition concentrated in few regions as measured by $HERFTECH$ the number of cooperations will have to be very low.

As expected, the concentration of innovators ($HERF$) affects the number of cooperations in a negative while decreasing way. Regarding the coefficients of the regional concentration terms ($HERFTECH$), we find the highest degree of cooperation in moderately concentrated technologies. Controlling for these concentration variables changes the picture we had about the relationship between specialization and cooperation. While the other coefficients remain qualitatively unchanged, the square of the specialization term becomes insignificant. This could be explained by the relationship of specialization and regional concentration: Highly specialized tech-regions imply that a great part of innovation of the technology takes place in that region. Therefore the technology has to be concentrated rather than evenly spread across the nation. So if we control for regional concentration, the effect of specialization diminishes.

Size ($BEV00$) as well as the average size of firms ($BETRGR$) within regions both positively affect the number of cooperations.

4.2 Internal vs. external cooperation

To analyze differences between tech-regions in the way they make use of internal (to the region) or external knowledge through their cooperations we perform the same specifications as in table 2 with internal and external cooperations as dependent variables. While in section 4.1 we were interested in answering the question if specialized tech-regions cooperate more than others in general, we now want to identify the characteristics influencing the pattern of cooperation, that is, we want to discriminate between factors related to cooperation at all and the ones related to internal or external cooperation.

The results presented in table 3 indicate that the number of patents has a positive but declining influence on the number of internal as well as the external cooperations. In models E and F for internal cooperations as well as I and J for external ones the specialization index ($RSCA$) is positive and significant, with the quadratic term ($RSCA2$) being negative and significant. Comparing regressions E (internal) and I (external), we do not find the influence of specialization being much different for external and internal cooperations. This comparison does not seem to be appropriate for testing hypothesis 2 since it is about the relative importance of local partners. Small differences between internal end external cooperations appear for the regional diversity ($DI, DI2$), where the (negative) coefficient is twice as high for external cooperations. This result indicates a relatively stronger use of local know-how for actors located in diverse regions compared to actors in regions which are focussed on few technologies. Comparing models G and H with K and L shows that the regional concentration of the technology ($HERFTECH$) does not seem to influence the degree of local interaction, but the one for external cooperations (as in table 2). Another variable which shows a differentiated influence on the type of cooperation is the average business size ($BETRGR$): Looking at model H compared to L, larger companies clearly raise the degree of external linkages, which is similar to findings on the role of multi nationals (MNC) in local innovation systems as connectors of different regions.

The results in table 3 raise an interest to investigate the different influences on the density (internal) and openness (external) of tech-regions in more detail. As explained in section 3 we create two variables that represent the relative importance of external linkages in a tech-region: $KOEXANT$ as the share of external cooperations and $EXSHARE$ as the share of external linkages of a tech-region. Since these shares are bounded between 0 and 1 we transform them by $\theta = ln(s/(1-s))$, to be unbounded, where s is the original share.

In the first two regressions of table 4 (M and N) the dependent variable is $KOEXANT$. Since this variable can only be computed for tech-regions with at least one co-assigned patent ($KO > 0$), the number of observations reduces to 4098, with only cooperating tech-regions left. In the last two columns (O and P), $EXSHARE$ is to be explained by our econometric model. In our view this variable provides a better measure of the openness

Table 3: Negative binomial regressions of the number of internal and external cooperations in patenting on regional and technological characteristics over all sectors

Dep. Var.	Internal Cooperations				External Cooperations			
	E	F	G	H	I	J	K	L
RSCA	0.9961	0.6279	0.6954	0.8012	1.0904	0.3793	0.6039	0.6888
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RSCA2	−1.2060	−0.8109	0.2434	0.3746	−0.6094	−0.7585	0.1501	0.0920
	(0.0000)	(0.0000)	(0.1022)	(0.0009)	(0.0000)	(0.0000)	(0.0113)	(0.1470)
UNI_EV	0.0838	0.0096	0.0079	0.0015	0.0963	0.0081	0.0009	0.0007
	(0.0000)	(0.0236)	(0.0059)	(0.3374)	(0.0000)	(0.0011)	(0.0833)	(0.2395)
PAT		0.0089	0.0053	0.0028		0.0124	0.0040	0.0033
		(0.0000)	(0.0000)	(0.0000)		(0.0000)	(0.0000)	(0.0000)
PAT2		−0.0000	−0.0000	−0.0000		−0.0000	−0.0000	−0.0000
		(0.0000)	(0.0000)	(0.0000)		(0.0000)	(0.0000)	(0.0000)
DI		−0.0584	−0.0995	−0.0199		−0.1245	−0.1470	−0.0315
		(0.0950)	(0.0019)	(0.3881)		(0.0000)	(0.0000)	(0.0644)
DI2		0.0063	0.0055	0.0009		0.0086	0.0079	0.0021
		(0.0000)	(0.0001)	(0.3338)		(0.0000)	(0.0000)	(0.0041)
HERF			−6.8782	−6.5607			−4.7682	−3.8555
			(0.0000)	(0.0000)			(0.0000)	(0.0000)
HERF2			3.5876	3.3819			2.3211	1.4412
			(0.0000)	(0.0000)			(0.0000)	(0.0000)
HERFTECH			−0.1044	−1.0174			2.2320	2.0377
			(0.9410)	(0.3521)			(0.0032)	(0.0087)
HERFTECH2			2.0893	0.8797			−11.8591	−11.3945
			(0.7197)	(0.8500)			(0.0005)	(0.0009)
BEV00				0.0006				0.0004
				(0.0000)				(0.0000)
BETRGR				0.0001				0.0013
				(0.6595)				(0.0000)
ALPHA	3.7643	2.4543	1.2956	0.3295	2.6158	1.3819	0.6098	0.5776
LR-Index	0.0465	0.0937	0.1644	0.1527	0.0480	0.1280	0.1335	0.1415

N = 9648; Five Sector-dummies are included; p-values in parentheses of tech-regions since it distinguishes internal and external connections for every patent and not only for the ones classified as cooperations.

In the first two regressions there is no linear relationship between specialization and the share of external cooperation as is put forward by hypothesis 2. Neither university patenting nor the number of patents influence the type of cooperation. For models O and P the picture is somewhat different. There is a strong negative relationship between specialization and the share of external linkages, thereby confirming hypothesis 2.

One explanation would be that highly specialized tech-regions have difficulties in finding appropriate partners elsewhere while compensating this through relatively more internal partnerships. Interpreting this finding form a technological system point of view means that in highly specialized tech-regions a large quantity of research relevant for the technological system is performed in one tech-region and capable partners are rather found inside this region.

Concerning the influence of regional diversity on the cooperative structure, the results reject our theoretical argument. Under hypothesis 3 we expect a negative coefficient for regional diversity but the overall influence (models M and O) is insignificant and positive. Inclusion of the squared term leads to a U-shaped influence in regression N and no significant influence is observed in regression P.

The finding that the concentration of local innovators leads to a higher share of external connections is the most robust - and not very surprising - result from this exercise. The geographical concentration of technologies ($HERFTECH$) has no significant influence on either measure of external connections.

Technologies within large regions, in terms of inhabitants, show a higher share of internal connections, which makes sense, since the availability of human capital is thought of as a major agglomeration force in the literature.

Table 4: OLS regressions of the share of external connections through joint patenting on regional and technological characteristics over all sectors

Dep. Var.	Share of **external cooperations**		Share of **external linkages**	
	M	N	O	P
RSCA	0.008	−0.093	−1.309	−1.325
	(0.972)	(0.703)	(0.000)	(0.000)
RSCA2	—	0.440	—	−0.601
		(0.400)		(0.001)
UNI_EV	−0.006	−0.006	−0.002	−0.003
	(0.547)	(0.536)	(0.709)	(0.593)
PAT	0.000	0.001	−0.001	−0.003
	(0.550)	(0.218)	(0.079)	(0.000)
PAT2	—	0.000	—	0.000
		(0.268)		(0.000)
DI	0.041	−0.265	0.014	0.069
	(0.118)	(0.023)	(0.170)	(0.126)
DI2	—	0.015	—	−0.003
		(0.005)		(0.193)
HERF	1.552	4.743	1.748	4.291
	(0.000)	(0.000)	(0.000)	(0.000)
HERF2	—	−3.161	—	−2.157
		(0.005)		(0.000)
HERFTECH	4.010	6.217	−0.243	1.423
	(0.061)	(0.234)	(0.743)	(0.446)
HERFTECH2	—	−14.572	—	−8.070
		(0.517)		(0.295)
BEV00	−0.001	−0.001	−0.001	−0.001
	(0.005)	(0.002)	(0.000)	(0.000)
BETRGR	0.003	0.002	0.000	0.000
	(0.000)	(0.001)	(0.099)	(0.628)
R^2	0.027	0.032	0.089	0.095
Adjusted R^2	0.025	0.028	0.088	0.094
N	4098	4098	8721	8721

Five Sector-dummies are included
p-values in parentheses

5 Summary and Conclusions

Providing an analysis of cooperative behavior in research which takes into account findings from the innovation systems literature and acknowledges firms difficulties in finding appropriate partners for such endeavors, we were able to deduct hypotheses on research cooperations on the level of the technology region. Our empirical results imply with respect to our hypotheses that: (i) tech-regions which are intermediately specialized show the highest number of research cooperations, (ii) the higher a tech-regions technological specialization the higher its share of internal cooperation compared to co-operation with partners outside that region. In contrast to a previous study (Cantner and Graf 2003) we could not find evidence for the hypothesis that technologically more diverse regions show more internal cooperations in relation to external ones.

Larger cities/regions that are specialized in relatively few technologies, relying on its core competencies seem to be most conducive to dense local networking. A higher share of external linkages is found in regions with high diversity, a higher degree of concentration of local innovators and large firms.

To put the empirical analysis into perspective we have to admit that our definition of the region is very ad hoc, the local system might easily consist of more than one region according to our definition. Often firms settle close to a city but this locality might belong to a different political region. The problem of the patenting practice of large patentees was already addressed. Large, diversified regions therefore get a higher share of the patents, but since we don't know if those patents have systematically different characteristics in terms of cooperations, we cannot assess the influence of this problem.

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A Appendix

Table 5: Concordance between IPC and technology codes

	Industry Technology	IPC-Code
I. Electrical engineering		
1.	Electrical machinery and apparatus, electrical energy	F21;G05F; H01B,C,F,G,H,J,K,M,R,T; H02; H05B,C,F,K
2.	Audiovisual technology	G09F,G; G11B; H03F,G,J;H04N-003,-005,-009,-013,-015,-017,R,S
3.	Telecommunications	G08C; H01P,Q; H03B,C,D,H,K,L,M;H04B,H,J,K,L,M,N-001,-007,-011,Q
4.	Information technology	G06; G11C; G10L
5.	Semiconductors	H01L, B81
II. Instruments		
6.	Optics	G02; G03B,C,D,F,G,H; H01S
7.	Analysis, measurement, control technology	G01B,C,D,F,G,H,J,K,L,M,N,P,R,S,V,W; G04; G05B,D; G07; G08B,G;G09B,C,D; G12
8.	Medical technology	A61B,C,D,F,G,H,J,L,M,N
9.	Nuclear engineering	G01T; G21; H05G,H
III. Chemistry, pharmaceuticals		
10.	Organic fine chemistry	C07C,D,F,H,J,K
11.	Pharmaceuticals, cosmetics	A61K, P
12.	Biotechnology	C07G;C12M,N,P,Q,R,S
13.	Agriculture, food chemistry	A01H; A21D; A23B,C,D,F,G,J,K,L; C12C,F,G,H,J; C13D,F,J,K
14.	Materials, metallurgy	C01; C03C; C04; C21; C22; B22, B82
15.	Surface technology, coating	B05C,D; B32; C23; C25; C30
16.	Macromolecular chemistry, polymers	C08B,F,G,H,K,L;C09D,J
17.	Chemical industry and petrol industry, basic materials chemistry	A01N; C05; C07B; C08C; C09B,C,F,G,H,K; C10B,C,F,G,H,J,K,L,M;C11B,C,D
IV. Process engineering, special equipment		
18.	Chemical Engineering	B01B,D (without -046 to -053),F,J,L; B02C; B03; B04; B05B; B06; B07; B08; F25J; F26
19.	Materials processing, textiles, paper	A41H; A43D;A46D; B28; B29; B31; C03B; C08J; C14; D01; D02; D03; D04B,C,G,H;D05; D06B,C,G,H,J,L,M,P,Q; D21
20.	Handling, printing	B25J; B41; B65B,C,D,F,G,H; B66; B67
21.	Agricultural and food machinery and apparatus	A01B,C,D,F,G,J,K,L,M; A21B,C; A22; A23N,P; B02B; C12L; C13C,G,H
22.	Environmental technology	A62D; B01D-046 to -053;B09; C02; F01N; F23G,J
V. Mechanical engineering, machinery		
23.	Machine tools	B21; B23; B24; B26D,F; B27; B30
24.	Engines, pumps, turbines	F01B,C,D,K,L,M,P; F02; F03; F04; F23R
25.	Thermal processes and apparatus	F22;F23B,C,D,H,K,L,M,N,Q; F24; F25B,C; F27; F28
26.	Mechanical elements	F15; F16; F17; G05G
27.	Transport	B60; B61; B62; B63B,C,H,J; B64B,C,D,F
28.	Space technology, weapons	B63G; B64G; C06; F41; F42
29.	Consumer goods and equipment	A24; A41B,C,D,F,G; A42;A43B,C; A44; A45; A46B; A47; A62B,C; A63; B25B,C,D,F,G,H; B26B;B42; B43; B44; B68; D04D; D06F,N; D07;F25D; G10B,C,D,F,G,H,K
30.	Civil engineering, building, mining	E01; E02; E03; E04; E05; E06; E21