Searching Near and Far: The Spatial Dimension of University Linkages

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Abstract

This study analyzes the spatial pattern of university linkages to private actors as well as to other universities and non-university public research organizations. The importance of a set of individual, institutional and regional factors is tested. Among others, these factors include physical distance, previous contacts and networks, R&D intensity and size of the partner, age, university affiliation etc. The contribution of this study is twofold. First, the spatial dimension of knowledge spillovers is explained, and by doing so, second, important factors are identified that influence university connections to external actors. Concluding, possibilities to improve the (regional) knowledge base are discussed.

JEL-Classification: O31, O33, O38, O32, L3, H4

Keywords: Public research; R&D co-operation, Knowledge flows; Innovation, Proximity; Local knowledge spillovers

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1. The problem

In the modern economy innovative activities are crucial determinant of competitiveness and economic success. The development of new and improved products or methods of production requires an active process of searching for new or recombination of existing sources of knowledge and technology (von Hippel, 1988). However, as the complexity of problems to be solved increases permanently over time, agents increasingly rely on external knowledge sources. Since, public academic institutions, in particular universities, are considered as one important source of economically relevant knowledge (see Pavitt 1991, Dasgupta and David 1994 and Rosenberg and Nelson 1994 for theoretical considerations as well as Salter and Martin 2001 and Siegel and Zervos 2002 for excellent overview of empirical studies), economists as well as policy makers increasingly focus on knowledge flows from university in order to foster innovation and economic growth. Till date a number of studies emerged that analyze the interactions of universities with other actors in the system of innovation. However, significantly lower number of studies focuses on the spatial dimension of university linkages. Assuming the knowledge spillovers are seriously constrained by physical space and that location matters for innovative activities, studying the spatial pattern of university linkage appears important issue in the debate on regional development.

Mansfield and Lee (1996) tracked R&D spending of private firms for universities in the US. They found that the proportion of private R&D expenditures for universities less than 100 miles away is more than double for universities located 100-1000 miles away, and more than triple for universities more than 1000 miles away. Adams (2002) applied similar approach in order to analyze the spatial scope of university-industry spillovers in the US. He found the strongest knowledge spillovers from universities at a distance up to 200 miles.

Fritsch and Schwirten (1999, 2002) studied the linkages between private sector actors and public research organizations (Regular Universities, University of Applied Sciences and non-university public research institutions) as well as between public research organizations in three German regions. Regarding linkages between public research organizations and private actors the authors found significant number of local connections: on the average about 40 per cent of the connections were to local companies, about 45 per cent to companies located in other German regions and about 15 per cent to companies in foreign countries. Fritsch and Schwirten (1999 and 2002) found, however, significantly larger geographical scope of university linkages to other public research organizations: about 35 per cent of the connections were to local partners, another 35 per cent to partners located elsewhere in

Germany and 30-35 percent to partners abroad. According to these studies, there were also significant differences between the different types of public research organizations, with Regular Universities and public research labs having much large geographical scope of connections than Universities of Applied Sciences. Fritsch (2003) found for eleven European regions that more than half of the university-industry linkages were local.

In order to asses the spatial dimension of university-industry linkages, Beise and Stahl (1999) surveyed 2.300 German companies that have introduced innovations which would not have been developed without the support of public research organizations. The authors found remarkable spatial coincidence between innovating firm and the particular public research organization cited as a knowledge source: about 80 (90) per cent of Universities of Applied Sciences, about 50 (65) per cent of the Regular Universities and about 58 (68) per cent of the public research labs that have been cited by innovating firms were located at a distance up to 100 (200) km around firm's location.

However, most of these studies restrict themselves to the description of the spatial pattern of university linkages, while only few attempt further investigation. Moreover, keeping in mind the importance of academic knowledge for industrial R&D, the spatial pattern of university-industry linkages is mostly addressed from the private sector side. However, comparatively less is known about the university perspective. This study relies on Mansfield and Lee (1996) and Adams (2002) in focusing mainly on the university perspective. Moreover, not only university interactions with private sector actors but also with other universities and non-university public research organizations[1] are considered. How does the spatial pattern of university linkages look like? What are the main driving factors? Do the distance and partner's characteristics play a role? These are the issues addressed here.

This study is organized as follows. The next section introduces the data used in this study. Section 3 describes the spatial distribution of university linkages to private sector actors as well as to other universities and non-university public research organizations. Section 4 deals with the factors that determine the connections of university professor to partners at certain locations. The results of the analysis of the spatial pattern university linkage to private sector actors are presented in subsection 4.1, while subsection 4.2 focuses on the explanation of the spatial pattern of university linkages to other universities and non-university public research organizations. Section 5 discusses the findings of this study and presents the conclusions.

[1] Non-university public research institutions are all those research institutions that are funded (at least partially) by public authorities (federal as well as at the state level). Such non-university public research institutions include among others the institutes of the Max-Planck-Society, Fraunhofer-Society, Gottfried-Wilhelm-Leibniz-Society, Helmholtz-Association.

2. Data sources

The analysis in this study is based on survey from seven East German universities - four Regular Universities and three Universities of Applied Sciences. These are the Technical University Dresden, the University of Applied Sciences Dresden (*Hochschule fuer Technik und Wirtschaft Dresden*), the Friedrich-Schiller-University Jena, the University of Applied Sciences Jena (*Fachhochschule Jena*), the Martin-Luther-University Halle/Saale, the University of Applied Sciences Merseburg (*Fachhochschule Merseburg*) and the University of Rostock. The survey was performed in 2005 by means of standardized questionnaire by post. Questionnaires were sent only to university professors conducting research in engineering, natural sciences, agricultural science and forestry, human medicine, and business administration/economics. These are proven to be the academic disciplines with the most straightforward impact on innovative and economic performance of the economy (Fritsch and Slavtchev 2005; Mueller 2006). Academic disciplines such as languages, cultural studies, sports science, science of arts, law, social science or administrative science are excluded from the analysis since these appear to be more relevant for the public sector rather for the private ones. There were 1,323 questionnaires sent, from which 540 came back. Table 1 shows the distribution of responded professor across universities and academic disciplines.

Table 1: Distribution of responded professors across universities and disciplines

Academic discipline	Univ. Rostock	Univ. Halle	UAS Merseburg	Univ. Jena	UAS Jena	TU Dresden	UAS Dresden	Total [%]
BA/Econ.	13	8	4	4	11	17	7	11.85
Natural science	29	51	6	52	-	45	13	36.30
Human medicine	6	8	-	21	-	16	-	9.44
Agricultural/Forestry	17	12	-	-	-	9	7	8.33
Engineering	17	-	15	-	23	83	46	34.07
Total [%]	15.19	14.63	4.63	14.26	6.30	31.48	13.52	100.00

Note: Missing values are due to the fact that the respective university does not provide the particular discipline.

The questionnaire consists of several sections. In the first part university professors were asked about personal and institutional characteristics. In the second and third sections, professors were asked about their linkages to private sector actors and non-university public research institutions, respectively. How many partner of a certain type they have? Where are these partners located? The interviewed persons could answer either numerically or at the Likert scale of zero to three.

For the purpose of the econometric analysis performed in this study, secondary data are used. Data on the private sector R&D employment are taken from the establishment file of the German Social Insurance Statistics as described in Fritsch and Brixy (2004). Secondary university data are taken from the German University Statistics available from the German Statistical Office.

3. The spatial dimension of university linkages

This study considers both university interactions with private companies as well as with other universities and non-university public research institutions. In order to get detailed insights into the spatial dimension of university linkages, university professors were asked about the number of respective co-operation partner in five different spatial categories: in the same Planning Region (*Raumordnungsregion*) where the university is located in, in the same Federal State (except the respective planning region), in other Federal States in East Germany, in Federal Sates in West Germany and in foreign countries. The average number of partners per professor and spatial category is presented in figure 1[2].

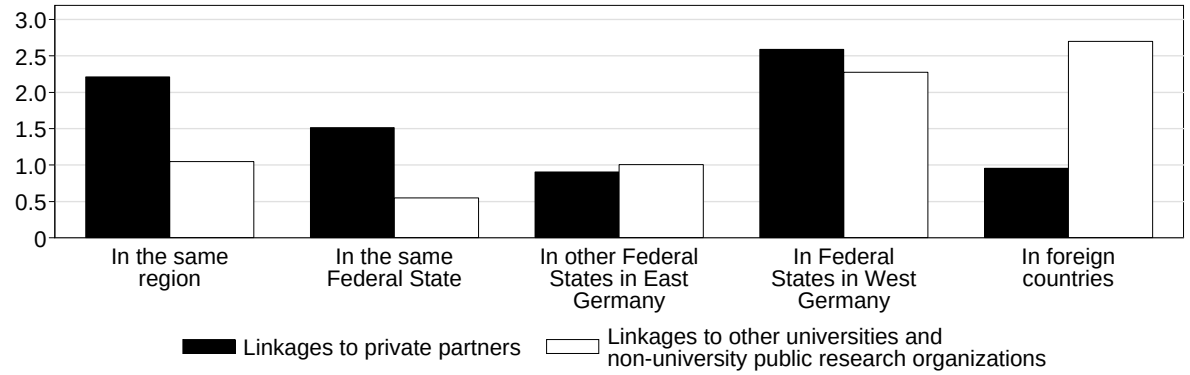

Figure 1: Spatial distribution of university linkages

According to the observed pattern of spatial interactions in figure 1, the proximity between universities and private sector actors appears important for the propensity to co-operate. A significant number of interactions take place between university professors and private firms in the vicinity of the respective university - in the same Planning Region and in the same Federal State. Moreover, as figure 1 clearly shows, interactions between university professors

[2] Since from the 540 university professors in the sample, 391 reported at least one connection to private partner, the information in figure 1 is based on the responses of 391 university professors.

and private sector actors are quite sensitive to the distance between the partners. The average number of linkages to private actors per professor shrinks from somewhat above 2 in the same Planning Region to 1.5 in the same Federal State and declines quite quick with increasing distance from the university. On the average, every university professor has less that one partner in other Federal Sates in East Germany and in foreign countries. This finding fits very well to the previous studies investigating both the spatial scope of university-industry interactions as well as the spatial scope of knowledge spillover from universities in Germany (Beise and Stahl 1999; Fristch and Schwirten 1999 and 2002; Fritsch 2003). As university-industry linkages are assumed to be important vehicle for transfer of academic knowledge in the private sector, the results of this study provide also reasonable explanation for the finding of Fritsch and Slavtchev (2007a) who reported significant knowledge spillovers from both Regular Universities as well as Universities of Applied Sciences at a distance up to 50 km from the university location.

A noteworthy exception to the negative trade-off between distance and the number of university-industry linkages is, however, the remarkably high number of university linkages to private actors located in Federal States in West Germany. The average per professor number of linkages to private partners in West Germany is about 2.5 and therefore higher than the number of university-industry linkages in the same region. A possible explanation for this finding is the lack of proper co-operation partners in the proximity of the respective university. The detailed analysis of the factors that determine the spatial distribution of university linkages is, however, left for the subsequent sections.

When comparing the spatial distribution of university linkages to private sector actors with the linkage to other universities and non-university public research organizations, considerable differences can be observed (figure 1). For university-industry linkages distance appears to be disadvantageous while university linkages to other public research organizations appear non-sensitive to spatial proximity between the partners. Moreover, the number of connections to other public research organizations clearly increases with the distance. The average number of connection is about 1 at the location of university, falls to 0.5 in the Federal State and then increase rapidly and monotonically to about 1 in other Federal States in East Germany, 2.3 in West Germany and 2.7 in foreign countries. This result suggests that distance does not hamper the transfer of knowledge between academic researchers. Moreover, the main result of this section, namely the bipolar nature of university linkages – mainly with far distant public research facilities but predominantly local when it comes to co-operation with private sector actors - suggests that through participating in interregional networks

universities are able to disseminate knowledge that has been generated globally to local private actors (Liebeskind et al. 1994; Zucker, et al. 1998; Fritsch and Schwirten 1999).

4. What drives the spatial pattern of university linkages?

This section analyzes the factors that determine the spatial distribution of university linkages to both private sector actors as well as to other universities and non-university public research organizations. The analysis of the distribution of university connections with private actors is conducted in subsection 4.1, while university connections to other public research facilities are analyzed in subsection 4.2. The main concern of such analyses is to contribute to the better understanding of the spatial pattern of knowledge flows within the public R&D sector as well as between public research facilities and private sector actors. Given the importance of academic knowledge for the innovative and economic performance of private actors, additional contribution of this analysis is the explanation of differences in the innovative and economic performance in space. Last but not least, important implication can be drawn out for public policy that relies on academic knowledge in order to promote regional growth.

4.1 Interactions with private sectors actors

While analyzing the spatial pattern of university linkages to private sector actors in this section, four distinct types of explanatory variables are considered: personal characteristics of co-operating university professors, characteristics of their environment (institutional characteristics), regional characteristics as well as characteristics of the private partner. The factors tested in this study are:

- *Distance*. The influence of the distance on the propensity to have co-operation partner at a certain location is quite straightforward. Both the establishment as well as the maintenance of co-operative activities require substantial amount of resources which can be assumed as a sunk costs (Veugelers 1998). Time and money are required first to find a proper co-operation partner and second to meet him. Distance is assumed to have negative impact on the propensity to collaborate with distant actors as it raises both searching and traveling costs. The importance of distance dwindles, however, if knowledge that has to be transmitted can be codified or its complexity can be reduced (Hippel 1994). Nevertheless, the transfer of knowledge which is not completely codified in texts and/or blueprints requires particular transfer media – often face-to-face interactions – which are sensible to distance (Polanyi 1967; Hippel 1987; Dosi 1988;

Quintas 1992). This can be of particular importance for the spatial scope of university-industry linkages in cases of complex and sophisticated projects. Two alternative measures for distance are included: the average distance from the location of the university professor to particular region in kilometers (DIST [km]) as well as the same distances measured in minutes travel time by car (DIST [min]).

- *Previous/existing networks and familiarity*. There are at least two reasons why contacts and networks created in the past as well as information about certain locations and their endowment with potential co-operation partners can influence the spatial scope of subsequent university linkages. First, a kind of path dependency in the co-operation behaviour of agent, namely a significant attitude to rely on previous partners or location instead of looking for new ones can be explained by the possibility to save a significant amount of resources that otherwise have to be spent for finding other appropriate co-operation partner (Gulati 1995; Veugelers, 1998). Second, experience and knowledge about nature and attitude of the respective partner can straighten mutual recognition and reduce monitoring costs, uncertainty and initial distrust between the actors (Ireland et al. 2002; Nooteboom 1999; Dodgson 1993; Gulati 1995). With respect to this, most scholars agree that even tacit and/or complex knowledge can be transferred over large distances when the lack of spatial proximity can be substituted by organizational, cognitive and social proximity (Hippel 1994; Rallet and Torre 1999; Breschi and Lissoni 2003). Using the same data as here but in a more general approach, Slavtchev (2007) showed that the university professors' experience with previous linkages to private sector actor is positively correlated with the propensity for subsequent co-operation. In order to control for possible effect of previous experience and networks, the location of obtaining PhD degree of university professors (West vs. East Germany, PhD_WEST) is included in the model[3].

- *University affiliation* (UNI). The university affiliation is included in order to control for differences between the two main types of universities in the German Education System, namely between Regular Universities (*Universitaeten*) and the Universities of Applied Sciences (*Fachhochschulen*). There are at least three reasons for such differences. First, the German Universities of Applied Sciences have been set up in order to meet the demand of the local economy. Accordingly, they are mainly supposed to provide

[3] University professors were surveyed in 2005, about 15 years after the German Reunification in 1990. Therefore, since the average age of professors in the sample is between 45 and 54 years, it appears reasonable to assume that the location of achieving doctoral degree is also largely related to the professor's place of origin.

undergraduate education (bachelor degree) as well as some technical services in market related fields requested by local economy. This in turn may reduce the visibility of the Universities of Applied Sciences to the region they are located in. Second, professors at Universities of Applied Sciences are clearly inferior to their University colleagues in terms of financial equipment, which may be crucial for spatial scope of their linkages. Third, universities in general are supposed – in addition to teaching and research – to participate in interregional networks in order to absorb globally generated knowledge and to circulate it locally (Liebeskind et al. 1994; Zucker, et al. 1998; Fritsch and Schwirten 1999). However, due to larger scale and higher absorptive capacity, Regular Universities have distinct advantage over Universities of Applied Sciences.[4]

- *Firm size* (SMALL, MEDIUM and LARGE). The size of the private partner may affect the spatial scope university-industry linkages. Financially powerful large firms may have advantages over small firms in having more distant partners due to the sunk costs character of the effort spent to find a proper co-operation partner and to travel in order to meet him (Arundel and Geuna 2004). Additionally, large firms are more likely to have specialized R&D department (Acs and Audretsch 1990; Kleinknecht 1987; Pavitt et al. 1987) and therefore to monitor the present state of science and technology at a larger geographical scale (Arundel and Geuna 2004). The lack of a R&D department may explain the finding in Kleinknecht (1989) according to whom small firms are in general less informed about the ongoing academic research than large firms. Mansfield and Lee (1996) and Adams (2002) found the negative impact of distance on the propensity to have a connection to public research institutions less pronounced for large firms than for small ones.

- *Age* (AGE). The age of the professor is included in order to control for possible relationship with the spatial scope of the university professors' linkages to private firms.

- *Initiator of co-operation* (TTO_INI, FIRM_INI). When explaining the spatial scope of university linkage, we control for the possibility that co-operations are initiated by the technology transfer office (TTO_INI) as well as the private partner (FIRM_INI). This is done in order to analyze the attitude of these three agents towards distance. Although mutual averseness to distance can be expected for all possible initiators of particular relation, the relative importance of distance may, however, differ for different agents. It appears reasonable to expect private firms to be sensitive to (travel) costs and therefore

[4] According to Cohen and Levinthal (1990) internal R&D is important precondition for the appropriation of external knowledge. In Germany, R&D stills largely domain in the Regular Universities.

to distance. In Germany, the TTOs are supposed not only to support university researchers in administrative problems regarding co-operation but are also often asked to find and to offer a proper collaboration partner in a self-governed way (to act as a broker). However, nothing is known about the spatial scope they operate at.

- *Professors' research excellence* (STAR). There are at least three possible reasons why research excellence may impact the spatial scope of university linkages. First, research excellence may indicate pronounced prestige and therefore geographically wider scope of visibility. Second, R&D intensive professors are more likely to be part of excellence networks the geographical scope of which is hardly believed local (Liebeskind et al. 1994; Zucker et al. 1998). Additionally, according to Zucker et al. (2002) excellent researchers are supposed to have exceeding scientific skills. Such skills may allow them to transfer even tacit or complex knowledge over long distance. The research excellence is measured as the share of external research funds gained from the German Science Foundation (*DFG*). Funds from the German Science Foundation are designated according to relatively strong competitive procedure to high quality basic research and according to Hornbostel (2001), there is a pronounced correspondence between indicators that are based on external research funds and bibliometric indicators for high quality research such as SCI publications.
- *R&D intensity of the partner* (CONC_RD_PRIV). According to Cohen and Levinthal (1990) in-house R&D is a necessary precondition for building up absorptive capacity that in turn allows to identify and to appropriate externally generated knowledge. Therefore, R&D intensive firms should be more likely to co-operate with universities than other firms that conduct less research (Arundel and Geuna 2004; Veugelers and Cassiman 2005; Belderbos et al. 2004; Fritsch 2003). Also from the university perspective, firms that conduct R&D might be more attractive as a co-operation partner than less R&D intensive firms. Therefore, if R&D intensity of firms is important criterion for the partner selection, the spatial distribution of R&D intensive firms can be expected to influence the spatial scope of university connections to private actors. In particular, a significant number of connections can be expected to locations that are characterized by relatively pronounced concentration of R&D intensive firms. Moreover, the geographical concentration of private R&D activities of industries with which university professor usually collaborate may strengthen the visibility not only of the entire region but also of particular firm located there. Baptista and Swan (1998) showed that firms located in clusters and strong industrial regions tend to be more innovative

than firms located outside such locations. Beaudry and Breschi (2003) showed that this is particularly true for firms located in clusters densely populated by other highly innovative firms.[5] Hence, location in a cluster with high R&D activity may signal significant R&D intensity and economic success and therefore may increase the propensity with which professor chooses collaboration partner from that particular location.

- *University Spin-Offs*. The majority of such university-based firms can be assumed to be knowledge intensive firms, the business and the economic performance of which depends on the academic knowledge. Frequent linkages to the (parental) university are the logical consequences. Therefore the number of university spin-offs is included in the analysis in order to test for the possibility that the spatial pattern of university-industry linkages is also driven by university linkages to spin-off companies. An excellent example for such linkages can be found in Audretsch and Stephan (1996), who found that about 60 per cent of university-based biotech firms in the US were found within the region of parental university. More important in the context of the analysis here, Audretsch and Stephan (1996) also showed that American biotech firms with at least one academic founder are more likely to have linkage to local university than linkages to universities outside the region.

The importance of the different factors is tested by means of multivariate regression. The information about the spatial distribution of university linkages is based on the number of connections to private sectors that university professors report for five different spatial categories: in the same Planning Region where the university is located in, in the same Federal State (except the respective planning region), in other Federal States in East Germany, in Federal Sates in West Germany and in foreign countries. From the 540 university professors in the sample, 391 reported at least one connection to private partner. Therefore, the total number of observation is 1.955. As there are no data on the worldwide private sector R&D intensity available to the author, part of the analysis is based on 1.564 observations. According to the count character of the data, negative-binomial regression technique appears appropriate (Greene 2003). Additionally, fractional logit estimator is applied on the share of connections to partners in each of the five spatial categories in order to test the robustness of the results (Papke and Wooldridge 1996). Since every professor reports the number of

[5] The higher innovative performance of clustered firms is mainly explained by externalities of Marshall-Arrow-Romer type. Such types of advantages can arise due to availability and price of inputs, knowledge spillovers, aggregated demand etc. (for overview Beaudry and Breschi 2003; Fritsch and Slavtchev 2007b).

connection in each of the five spatial categories, the standard errors of the estimated coefficients are adjusted for intragroup correlation; the number of clusters equals the number of individuals (391). Explanatory variables that are no attributes of location are interacted with binary dummy variables for the respective spatial categories (Rabe-Hesketh and Skrondal 2005). Descriptive statistics and construction of all variables is reported in table A1 in the appendix. The estimation results for the determinants of university linkages to private actors when distance is measured in terms of kilometres are reported in table 3 while the results when distance is measured in minutes of travel time by car are shown in table A2 in the appendix.

Table 3: Determinants of the spatial distribution of university-industry linkages

	Dependent: share of connections in the respective spatial category			Dependent: number of connections in the respective spatial category		
	Fractional logit			Negative-binomial		
	(1)	(2)	(3)	(4)	(5)	(6)
DIST [km]	-0.003**	-0.003**	-0.002*	-0.003**	-0.003**	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
STAR*REG	-0.008*	-0.008*	-0.008*	-0.009**	-0.009**	-0.008**
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
STAR*FSTATE	-0.008*	-0.008*	-0.009*	-0.011**	-0.011**	-0.009*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)
STAR*EAST	0.001	0.002	-0.001	-0.006	-0.005	-0.005
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
STAR*WEST	0.006*	0.006*	0.006*	0.007**	0.008**	0.004*
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)
STAR*FOREIGN	0.008*	0.009*		0.006*	0.007*	
	(0.004)	(0.004)		(0.003)	(0.003)	
UNI_SPIN_OFF	0.250*	0.229*	0.231*	0.349**	0.393**	0.190*
	(0.110)	(0.110)	(0.112)	(0.101)	(0.099)	(0.088)
PhD_WEST*REG	0.076	0.055	0.060	-0.066	-0.099	0.010
	(0.132)	(0.131)	(0.130)	(0.127)	(0.123)	(0.131)
PhD_WEST*FSTATE	-0.373*	-0.344*	-0.356*	-0.556**	-0.577**	-0.476**
	(0.151)	(0.149)	(0.151)	(0.167)	(0.163)	(0.152)
PhD_WEST*EAST	-0.755**	-0.716**	-0.709**	-0.773**	-0.827**	-0.745**
	(0.205)	(0.207)	(0.201)	(0.207)	(0.200)	(0.204)
PhD_WEST*WEST	0.310*	0.292*	0.272*	0.003	0.061	0.004
	(0.137)	(0.133)	(0.133)	(0.117)	(0.110)	(0.105)
PhD_WEST*FOREIGN	0.169	0.191		0.094	0.101	
	(0.192)	(0.190)		(0.197)	(0.211)	
TTO_INI*REG	0.195*			0.181**		
	(0.076)			(0.057)		
TTO_INI*FSTATE	0.025			0.160		
	(0.076)			(0.082)		
TTO_INI*EAST	-0.049			0.065		
	(0.097)			(0.088)		
TTO_INI*WEST	-0.086			-0.184**		
	(0.077)			(0.063)		
TTO_INI*FOREIGN	-0.024			-0.209*		
	(0.093)			(0.093)		
FIRM_INI*REG		0.046			-0.081	
		(0.081)			(0.076)	
FIRM_INI*FSTATE		-0.133			-0.132	
		(0.080)			(0.090)	
FIRM_INI*EAST		-0.411**			-0.151	

		(0.117)			(0.106)	
FIRM_INI*WEST		0.256**			0.160**	
		(0.084)			(0.058)	
FIRM_INI*FOREIGN		-0.146			-0.101	
		(0.117)			(0.113)	
CONC_RD_PRIV			0.074*			0.061*
			(0.037)			(0.025)
SMALL*REG			0.146*			0.222**
			(0.063)			(0.061)
SMALL*FSTATE			0.237**			0.347**
			(0.066)			(0.075)
SMALL*EAST			0.054			0.224*
			(0.099)			(0.088)
SMALL*WEST			-0.335**			0.071
			(0.065)			(0.052)
MEDIUM*REG			0.038			0.179**
			(0.066)			(0.058)
MEDIUM*FSTATE			0.061			0.206**
			(0.073)			(0.069)
MEDIUM*EAST			0.165			0.069
			(0.103)			(0.104)
MEDIUM*WEST			0.006			0.208**
			(0.069)			(0.051)
LARGE*REG			-0.179**			-0.076
			(0.061)			(0.055)
LARGE*FSTATE			-0.292**			-0.059
			(0.068)			(0.067)
LARGE*EAST			-0.345**			-0.144
			(0.094)			(0.083)
LARGE*WEST			0.351**			0.381**
			(0.061)			(0.054)
UNI*REG	-0.731**	-0.748**	-0.593**	-0.401**	-0.396**	-0.368*
	(0.161)	(0.161)	(0.159)	(0.134)	(0.131)	(0.149)
UNI*FSTATE	0.040	0.083	0.204	0.136	0.154	0.258
	(0.162)	(0.165)	(0.163)	(0.192)	(0.200)	(0.169)
UNI*EAST	0.151	0.271	0.168	0.075	0.097	0.091
	(0.197)	(0.213)	(0.215)	(0.199)	(0.206)	(0.187)
UNI*WEST	0.652**	0.564**	0.488**	0.339*	0.349*	0.306*
	(0.183)	(0.183)	(0.183)	(0.154)	(0.157)	(0.138)
UNI*FOREIGN	0.191	0.243		0.035	0.015	
	(0.250)	(0.249)		(0.287)	(0.261)	
AGE*REG	0.307**	0.243**	0.215**	0.238**	0.227**	0.231**
	(0.067)	(0.060)	(0.065)	(0.069)	(0.069)	(0.078)
AGE*FSTATE	-0.111*	-0.044	-0.174**	0.068	0.123	0.004
	(0.054)	(0.054)	(0.057)	(0.083)	(0.079)	(0.081)
AGE*EAST	-0.175*	-0.052	-0.147*	-0.034	-0.045	-0.014
	(0.070)	(0.057)	(0.073)	(0.084)	(0.089)	(0.098)
AGE*WEST	-0.001	-0.053	-0.091	-0.194**	0.154*	-0.095
	(0.054)	(0.058)	(0.060)	(0.068)	(0.074)	(0.064)
AGE*FOREIGN	-0.304**	-0.265**		-0.085	-0.017	
	(0.077)	(0.084)		(0.110)	(0.108)	
Constant	-1.226**	-1.236**	-1.270**	0.479	0.814**	0.068
	(0.149)	(0.150)	(0.157)	(0.289)	(0.260)	(0.276)
Observations	1,955	1,955	1,564	1,955	1,955	1,564
LL pseudo	-711.32	-706.39	-579.01	-3,734.46	-3,737.82	-3,063.65
Wald				412.48**	437.38**	394.74**
LR				314.46**	307.73**	381.41**
AIC	0.756	0.751	0.781	3.850	3.854	3.960
BIC	-13,947.6	-13,957.5	-10,776.9	-7,126.6	-7,119.9	-5,133.2

Note: Robust standard errors in parentheses. * significant at 5% level; ** significant at 1% level.

According to the results of the multivariate regression analysis, the distance to the respective partner plays important role for the propensity to be connected. The negative and statistically significant coefficients for DIST [km] clearly show that the number of connection decrease with the distance. This result is in line with previous studies explaining geographically bounded knowledge spillovers by the (at least partly) tacit nature of knowledge that requires particular transfer channels such as inter-personal face-to-face contacts that are sensitive to distances (Hippel 1994; Audretsch 1998; Krugmann 1998).

The estimated coefficients for research intensive professors (STAR) that is negative and significant when interacted with the regional dummy variable (STAR*REG) but positive and statistically significant when interacted with the dummy variables for West Germany and for foreign countries (STAR*WEST and STAR*FOREIGN) suggest that such excellent professors tend to have more connections to remote private actors than to local ones.

The estimation results indicate that contacts and networks created in the past play important role for subsequent co-operations and by this influence the spatial scope of university linkages. The positive and statistically significant coefficient for UNI_SPIN_OFF indicates that the significant number of connections to locations with firms founded by researchers from the same university. This result is in line with studies that emphasize the great importance of public science for university based firms (Audretsch and Stephan 1996; Zucker et al. 2002). The estimated coefficients for PhD_WEST which are significant and negative for university linkage with private actors located in the same Federal State and in other Federal States in East Germany (PhD_WEST*FSTATE and PhD_WEST*EAST) while significant but positive for linkages to West German firms (PhD_WEST*WEST in models 1-3) indicate that university professors who have obtained their doctoral degree in West Germany, have more co-operation partners in that part of the county. A possible explanation may be that previous contacts or perhaps even networks that have been established during the PhD study and that still are active or can be easily reactivated, influence the subsequent spatial patterns of university professors linkages.

Connections to private sector actors initiated by TTOs appear to be mainly local. The estimated coefficient for the engagement of TTOs in order to establish regional linkages (TTO_INI*REG) is positive and significant, meaning that the number of local linkages increases when TTOs are involved. The coefficient of the TTOs engagement changes, however, its sign to negative when distance increases, and becomes even significant for connections with private sector actors located in West Germany (TTO_INI*WEST in model

4). Obviously, TTOs connect university researchers mainly with local private actors. This result appears reasonable as it is more likely that TTOs are more familiar with the local private sector than with private actors that are far away.

As indicated by the positive and statistically significant coefficient for FIRM_INI*WEST the number of linkages increases when these are requested, respectively initiated by private firms located in West Germany. The coefficients for co-operation requests from firms nearby (FIRM_INI*REG, FIRM_INI*FSTATE) are not significant and negative significant for co-operation requests that have been made by firms located in other East Germany States (FIRM_INI*EAST). This certifies university professors' attitude towards connections to West German companies.

A reasonable explanation for this finding might be the uneven distribution of private partners with particular characteristics that are advantageous for co-operation. Therefore, private actors' R&D intensity (CONC_RD_PRIV) and size (SMALL, MEDIUM, LARGE) at different locations are introduced in the model. The research intensity of private firms appears to be important factor for the selection of co-operation partner. The positive and significant coefficient for CONC_RD_PRIV indicates an increasing number of connections between university professors and firms located in relatively R&D intensive regions. This result and the findings of Hollanders (2006) who provides evidence for significant R&D shortfalls in East Germany, may explain the remarkably high number of connections to West Germany firms. Also the size of the private sector actor appears to be important factor in influencing the spatial scope of university connections to private sector actors. The positive and significant coefficients for SMALL*REG and SMALL*FSTATE and - on the same time - the negative and significant coefficients for LARGE*REG, LARGE*FSTATE and LARGE*EAST clearly suggest significant differences between small and large firms regarding their perception to distance. The results indicate significant part of the local connections to relatively small private partners. Exactly the opposite results are, however, obtained for connections of university professors with firms located in West Germany. The positive and significant coefficient for LARGE*WEST suggests that most of the university linkages to West German firms are to large ones. Obviously, large firms are more likely to have distant university as a co-operation partner than small firms. Hence, the results are in line we our expectation as well as with studies explaining the positive correlation between firm's size and the propensity to have more distant co-operation partner by the firm's financial power and R&D capabilities (Mansfield and Lee 1996; Adams 2002; Arundel and Geuna 2004). The estimated coefficients

for connections to medium size firms (MEDUIM) show no clear pattern when university professors co-operate with such firms.

Regarding professors affiliation to certain type of university (Regular University or University of Applied Sciences), the results certify that Regular Universities have geographically wider scope of co-operation than Universities of Applied Sciences. The estimated coefficient for linkages of professors at Regular Universities with private actors in the same region (UNI*REG) is negative indicating that such professors have less partners in the region than professors at Universities of Applied Sciences. The opposite is true in regard to connections with more distant actors such as firms located in West Germany (UNI*WEST); in this case the estimated coefficient is positive and significant. This result is in line with previous studies investigating the spatial interaction between universities and firms (Mansfield and Lee 1996; Beise and Stahl 1999; Fritsch 2003; Adams 2002).

Considering the estimated coefficients for AGE, there is an evidence that university professors interact increasingly with local actors when age increases. The estimated coefficient is positive and significant for interactions with local actors (AGE*REG), meaning that the number of local connections increases with age. However, the estimated coefficient is significant at the 5 per cent level for interactions with more distant firms. The results indicate a negative relationship between age and the number of linkages with more distant private partners. A possible explanation for this relationship is that with increasing age scholars increasingly focus on activities such as practical education for students as well as teaching (Slavtchev 2007). Both activities can also be assumed to lower the interregional visibility of university professors.

4.2 Interactions with other universities and non-university public research institutions

This subsection analyzes the spatial pattern of university linkages to other universities and non-university public research organizations. While modeling the spatial distribution of university linkages to public research organizations, explanatory variables that are related to characteristics of the public research sector are used instead of attributes of the private sector. Additionally, the research excellent of university professors at a certain location as measured by the amount of external research funds gained from the German Science Foundation per professor (ERF_GSF_PROF) is introduced. If research excellence is important criterion for selecting partner then the distribution of excellence should drive the distribution of university

linkages. Descriptive statistics of all variables used in this subsection is reported in table A1 in the appendix. The estimation results for the determinants of university linkages to public research organizations when distance is measure in terms of kilometers are reported in table 4 while the results when distance is measured in minutes of travel time by car in table A3 in the appendix.

The results of both, the fractional logit estimator as well as the negative-binomial estimator appear qualitatively identical. With regard to the distance a u-shaped relationship is found. This means that the number of public research partners first decrease when distance increase if, however, distance increases over certain level the number of public partners also increase. This relationship was already indicated in figure 1. A possible explanation for such relation between distance and the number of public partners can be found in the spatial distribution of public research organizations in Germany. In particular, universities are characteristic for large cities and urban agglomerations and serve relatively large geographical areas. Hence, the most reasonable interpretation of this result is that distance plays no role.

The estimated coefficients for research intensive professors (STAR) that is negative and significant when interacted with the regional dummy variable (STAR*REG) but positive and statistically significant when interacted with the dummy variable for West Germany (STAR*WEST) suggest that such excellent professors tend to have more connections to remote public research facilities than to local ones. Additionally, the positive and significant coefficient the amount of external research funds gained from the German Science Foundation per professor (ERF_GSF_PROF) suggests that quality matters for the selection of appropriate co-operation partner. Hence, the spatial distribution of university linkage depends on the spatial distribution of research excellence. In particular, this result explains the particular pattern that was found for the spatial scope of university linkages to other universities and non-university public research organizations (figure 1). The higher number of connections to other researchers at public research organizations in West Germany appears related to the higher research intensity in West Germany measured in the amount of external research funds from the German Science Foundation per university professor. The control variable for concentration of potential co-operation partner at a certain location (CONC_RD_PUB) is – as expected – positive and significant.

Table 4: Determinants of the spatial distribution of universities' linkages to other universities and non-university public research organizations

	Dependent: share of connections in the respective spatial category					Dependent: number of connections in the respective spatial category				
	Fractional logit					Negative-binomial				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DIST [km]	-0.004*	-0.004*	-0.005*	-0.005*	-0.006*	-0.005*	-0.004*	-0.005**	-0.006**	-0.006**
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$DIST^2$ [km^2]	0.000*	0.000*	0.000*	0.000*	0.000*	0.000**	0.000**	0.000**	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
STAR*REG		-0.004*			-0.004*		-0.007**			-0.007**
		(0.001)			(0.002)		(0.002)			(0.002)
STAR*FSTATE		-0.005			-0.003		-0.001			0.001
		(0.003)			(0.003)		(0.002)			(0.002)
STAR*EAST		-0.004*			-0.004*		0.002			0.002
		(0.002)			(0.002)		(0.002)			(0.002)
STAR*WEST		0.002*			0.002*		0.003**			0.003**
		(0.001)			(0.001)		(0.001)			(0.001)
STAR*FOREIGN		0.004*					0.005*			
		(0.002)					(0.002)			
ERF_GSF_PROF				0.036*	0.038*				0.057**	0.057**
				(0.018)	(0.017)				(0.011)	(0.011)
CONC_RD_PUB			0.368**		0.394**			0.201**		0.266**
			(0.127)		(0.131)			(0.074)		(0.075)
PhD_WEST*REG	-0.524**	-0.525**	-0.477**	-0.563**	-0.520**	-0.234*	-0.276*	-0.194	-0.311**	-0.299**
	(0.157)	(0.157)	(0.156)	(0.160)	(0.159)	(0.113)	(0.111)	(0.112)	(0.113)	(0.109)
PhD_WEST*FSTATE	-0.722**	-0.704**	-0.706**	-0.657**	-0.626**	-0.552**	-0.544**	-0.531**	-0.430**	-0.420**
	(0.206)	(0.206)	(0.212)	(0.212)	(0.217)	(0.150)	(0.150)	(0.148)	(0.145)	(0.143)
PhD_WEST*EAST	-0.224	-0.204	-0.193	-0.189	-0.162	-0.122	-0.127	-0.083	-0.076	-0.077
	(0.141)	(0.142)	(0.143)	(0.144)	(0.145)	(0.138)	(0.138)	(0.135)	(0.135)	(0.135)
PhD_WEST*WEST	0.418**	0.415**	0.465**	0.452**	0.450**	0.322**	0.312**	0.393**	0.366**	0.356**
	(0.117)	(0.117)	(0.120)	(0.120)	(0.121)	(0.104)	(0.104)	(0.104)	(0.103)	(0.104)
PhD_WEST*FOREIGN	0.310*	0.299*				0.439**	0.433**			
	(0.125)	(0.126)				(0.117)	(0.119)			
UNI*REG	-0.643**	-0.629**	-0.708**	-0.599**	-0.656**	-0.174	-0.335*	-0.230	-0.118	-0.346*
	(0.180)	(0.190)	(0.184)	(0.181)	(0.193)	(0.128)	(0.139)	(0.132)	(0.126)	(0.142)
UNI*FSTATE	-0.913**	-0.821**	-0.677**	-0.832**	-0.553*	-0.372*	-0.352	-0.230	-0.260	-0.136
	(0.209)	(0.216)	(0.222)	(0.226)	(0.225)	(0.176)	(0.182)	(0.176)	(0.202)	(0.187)
UNI*EAST	0.159	0.236	0.232	0.240	0.343	0.489**	0.434*	0.590**	0.619**	0.588**
	(0.183)	(0.191)	(0.187)	(0.188)	(0.198)	(0.171)	(0.174)	(0.178)	(0.180)	(0.182)
UNI*WEST	0.297	0.254	0.333	0.325	0.285	0.664**	0.585**	0.722**	0.696**	0.619**
	(0.167)	(0.176)	(0.177)	(0.176)	(0.186)	(0.157)	(0.160)	(0.168)	(0.165)	(0.167)
UNI*FOREIGN	0.544**	0.482*				0.692**	0.651**			
	(0.194)	(0.199)				(0.171)	(0.181)			
AGE*REG	0.134	0.128	0.128	0.113	0.094	0.036	0.032	0.038	0.086	0.087
	(0.073)	(0.073)	(0.075)	(0.075)	(0.077)	(0.066)	(0.065)	(0.066)	(0.066)	(0.066)
AGE*FSTATE	-0.062	-0.062	-0.089	0.013	-0.020	-0.107	-0.100	-0.110	0.010	-0.018
	(0.066)	(0.066)	(0.069)	(0.069)	(0.071)	(0.068)	(0.068)	(0.066)	(0.071)	(0.066)
AGE*EAST	-0.170**	-0.166**	-0.119*	-0.113	-0.095	-0.161**	-0.161**	-0.097	-0.080	-0.073
	(0.046)	(0.046)	(0.056)	(0.058)	(0.057)	(0.061)	(0.060)	(0.063)	(0.063)	(0.061)
AGE*WEST	0.036	0.036	0.098	0.080	0.085	-0.033	-0.038	0.051	0.020	0.018
	(0.046)	(0.046)	(0.060)	(0.060)	(0.061)	(0.063)	(0.062)	(0.067)	(0.066)	(0.063)
AGE*FOREIGN	-0.016	-0.016				-0.008	-0.013			
	(0.054)	(0.054)				(0.066)	(0.065)			
Constant	-1.123**	-1.091**	-1.507**	-1.695**	-2.225**	0.570*	0.535*	0.422	-0.416	-0.746*
	(0.290)	(0.291)	(0.298)	(0.440)	(0.424)	(0.239)	(0.237)	(0.260)	(0.314)	(0.330)
Observations	2,385	2,385	1,908	1,908	1,908	2,385	2,385	1,908	1,908	1,908
LL pseudo	-873.98	-872.94	-644.36	-645.85	-642.63	3,963.35	-3,953.64	-2,892.19	-2,880.65	-2,866.85
Wald						640.73**	745.86**	617.70**	638.80**	787.22**
LR						590.21**	609.64**	398.72**	421.78**	449.38**
AIC	0.748	0.751	0.692	0.694	0.696	3.340	3.336	3.049	3.037	3.028
BIC	-17614.4	-17577.6	-13703.7	-13700.7	-13669.4	-10473.6	-10454.1	-8499.9	-8523.0	-8,512.8

Note: Robust standard errors in parentheses. * significant at 5% level; ** significant at 1% level.

The results for contacts and perhaps networks that have been made in the past indicate that these play important role for the spatial scope of subsequent linkages. The estimated coefficients for PhD_WEST*REG and PhD_WEST*FSTATE are negative and significant while the coefficients for PhD_WEST*WEST and PhD_WEST*FOREIGN positive and highly significant. This suggests that, in comparison to their East German colleagues, professors obtained their doctoral degree at West German universities have more and more distant connection, in particular to West German public research organizations. Obviously, previous contacts to persons at the location of obtaining doctoral degree are still active or can be easily reactivated, therefore influencing the spatial scope of subsequent linkages.

According to the estimated result for the university affiliation (Regular University vs. University of Applied Sciences, UNI) there are remarkable differences between these two types of research organizations. The negative and statistically significant coefficients for UNI*REG and UNI*FSTATE suggest that professors at Regular Universities have significantly lower number of connection to researchers at other public research facilities located in relative proximity– in the same planning region and in the same Federal State. The positive and statistically significant estimates for UNI*EAST, UNI*WEST and UNI*FOREIGN indicate, however, geographically wider range of researchers at Regular Universities; these have significantly more connections to other researcher in West Germany and in foreign countries than professors at Universities of Applied Sciences.

The results for AGE are somewhat ambiguous. The estimate coefficient for AGE*REG is positive but only weakly significant. It turns out to be negative for AGE_FSTATE and for AGE_EAST is, however, significant only for the later. The coefficient for AGE_WEST is positive but insignificant and the coefficient for AGE_FOREIGN negative insignificant. Overall, there is some evidence for weak negative trade-off between age and the number of remote partners. However, when other factors such as distance and research excellence are considered this relationship is no longer significant. The mixed pattern that is found for AGE suggests that it not important determinant of the spatial scope of university linkages to other universities and non-university public research organizations.

The results of the analysis of the linkages between public research organizations in this study are in line with Fritsch and Schwirten (1999 and 2002) who found basically the same pattern for the spatial dimension of connections between researchers in public organizations. Moreover, the results of this study are useful complementation of Fritsch and Schwirten (1999

and 2002) and Slavtchev (2007) as they focus rather on the motives for such connections than on the possible determinants for their spatial dimension. However, regarding the importance of distance, the results of this study contrast Katz (1994, p. 39) who found for UK, Canada and Australia '… that university-university collaboration decreases exponentially with distance and therefore occurs more frequently with partners who are geographically closer than with those further away'. However, we agree with Katz (1994) that both the characteristics of the space and the spatial distribution of public research institutions influence the linkages between scholars.

5. Discussion and conclusion

The objective of this study is to analyze the determinants of spatial distribution of linkages of university researchers with private sector actors as well as with researchers at other universities and non-university public research organizations. The contribution of this study is, however, twofold. First, the spatial dimension of knowledge spillovers via linkages to universities can be explained, and by doing so, second, important factors are identified that influence university connections to external actors. This, in turn, can help to deepen our understanding about the role of universities in the innovation system as well as to help policy makers and university administrators that rely on knowledge flows from universities in order to stimulate (regional) growth.

The results of the analysis suggest that the proximity between partners is important for successful establishment of connections to private sector actors. Accordingly, the impact of distance is negative, meaning that the number of connections decreases with the distance. However, there is also evidence that the impact of the distance is different for the different type of actors and connections. The results suggest that scholars willing to co-operate accept quite large distances in order to find appropriate partners. Distance appears, however, more important for private sector actors. Connections over large distances take place mainly with financially powerful and R&D intensive large firms. Connections to small firms appear to be mainly local. In that, the results are consistent with previous findings (Mansfield and Lee 1996; Adams 2002; Arundel and Geuna 2004). Connections between university researchers and private actors that have been initiated by university TTOs appear to be regional pointing out the local scope of TTOs' activities.

The negative relationship between the distance and the number of connections to private actors could not be found for linkages within the public research sector. That is, for linkages

to other universities and non-university public research organizations respectively, proximity appears not to be necessary condition for knowledge transfer.

Another important factor that determines the spatial pattern of university linkages is the amount of R&D activities conducted internally by the partner. In this study, a significant number of connections between university professors and firms in R&D intensive clusters is found. That is, the spatial pattern of university linkages depends on the spatial distribution of such appropriate partners. This result explains the high number of connections to West German regions that are relative R&D intensity when compared with East German regions. Here, the results are also consistent with Mansfield and Lee (1996) and Adams (2002) in suggesting that actors bridge even large distances in order to find high quality co-operation partner.

The results of this study point out the importance of contacts that have been made in the past, of previous networks as well as familiarity with people at certain locations or with the locations themselves. Accordingly, university professor obtained their PhD degree at West German universities are found to have more connections to West German partners. On the contrary, university professors obtained their doctoral degree at East German universities tend to co-operate mainly locally. Additionally, there is also evidence for the role of previous contacts made during the occupation in private sector.

The results of this study also provide clear evidence for significant differences between the two main types of German universities – Regular Universities and Universities of Applied Sciences - that reflect their different role in the regional innovation system. Regular Universities are found to have much wider geographical scope of co-operation pointing their importance as a vehicle to absorb globally generated knowledge and to disseminate it locally. Universities of Applied Sciences are geared mainly to the needs of local economy. The age of university researchers is found to impact negatively the geographical scope of collaborations. This means that as age increases scholars tend to co-operate locally while the number of connections to distant partners decreases.

Having in mind the result of section 3, namely that the universities participation in interregional networks allows the absorption of globally generated knowledge that can be disseminated to local private actors, useful implications could be made out of this study. For policy that relies on academic knowledge in order to strengthen the innovative and economic performance of a region, university TTOs appear appropriate strategy to facilitate intraregional knowledge transfer. However, there might be several pitfalls. Using the same

data, Slavtchev (2007) showed that universities' TTOs appear helpful mainly in establishing meeting and workshops with private actors. TTOs appear, however, not sufficient for interaction modes that rely on personal contacts as well as interaction modes associated with intensive transfer of idiosyncratic knowledge. Moreover, university researchers relying on the services of TTOs have on the average lower number of connections to private actors. Additionally, as suggested by the results for spatial pattern of university linkages in this study, the local availability of appropriate private partners is important precondition for the successful establishment of connections. If this precondition is not fulfilled locally, university linkages take place on wider geographical scale. TTOs are not supposed to deal with problem like that. This in turns raises the question about appropriate measures able to increase the intensity of university-industry linkages.

Regarding the interregional scope of university linkages, the results of this study correspond with Lynne Zucker, Michael Darby, Edwin Mansfield, Jeong-Yeon Lee and James Adams who suggested in a number of seminal works that excellent researchers are those who are able to shape the space and make globally generated knowledge available for local actors. Hence, fostering excellent research appears appropriate strategy to improve the regional knowledge base.

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Appendix

Table A1: Descriptive statistics

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
Interactions with private sector actors:						
PART_PRIV [share]	Share of linkages to private actors in the respective spatial category.	1,955	0.2000	0.2523	0	1
PART_PRIV [number]	Number of linkages to private actors in the respective spatial category.	1,955	2.2583	3.5815	0	45
AGE	Liker scale; 1<=35 years old, 2=35-44 years old, 3=45-54 years old, 4>=55 years old.	1,955	3.1841	0.7914	1	4
UNI	Dummy for affiliation at Regular University (1=yes).	1,955	0.7263	0.4459	0	1
PhD_WEST	Dummy for obtaining PhD degree at West German University (1=yes).	1,955	0.4655	0.4989	0	1
SMALL	Frequency of interaction with firms with less than 20 employees. Liker scale; 0=never, 1=sometimes, 2=often, 3=very often.	1,955	1.0384	1.0372	0	3
MEDIUM	Frequency of interaction with firms with less than 20-249 employees. Liker scale; 0=never, 1=sometimes, 2=often, 3=very often.	1,955	1.2174	1.0149	0	3
LARGE	Frequency of interaction with firms with more than 249 employees. Liker scale; 0=never, 1=sometimes, 2=often, 3=very often.	1,955	1.3402	1.1126	0	3
TTO_INI	Frequency of co-operation requests made by TTO. Liker scale; 0=never, 1=sometimes, 2=often, 3=very often.	1,955	0.2813	0.5566	0	3
FIRM_INI	Frequency of co-operation requests made by private firms. Liker scale; 0=never, 1=sometimes, 2=often, 3=very often.	1,955	1.6113	0.8746	0	3
DIST [km]	Avrg. distance between university location and the respective spatial category in kilometres.	1,955	205.096	144.000	25.263	492.100
DIST [min]	Avrg. distance between university location and the respective spatial category in minutes travel time by car.	1,955	170.9005	107.4435	27.2096	369.6844
CONC_RD_PRIV	Share of R&D employees in cooperating industries in the respective spatial category over the total employment share in the respective spatial category.	1,564	0.9631	1.0820	0	13.9161
UNI_SPIN_OFF	Number of university spin-off in the respective spatial category.	1,955	0.0951	0.2935	0	1
STAR	Share of external research funds gained from the German Science Foundation.	1,955	14.5647	24.6398	0	100
Interactions with other universities and non-university public research organizations:						
PART_PUB [share]	Share of linkages to other universities and non-university public research organizations in the respective spatial category.	2,385	0.2000	0.2471	0	1
PART_PUB [number]	Number of linkages to other universities and non-university public research organizations in the respective spatial category.	2,385	1.7174	2.6533	0	50
AGE	see above	2,385	3.1300	0.8036	1	4
UNI	see above	2,385	0.8029	0.3979	0	1
PhD_WEST	see above	2,385	0.5010	0.5001	0	1
DIST [km]	see above	2,385	204.747	143.726	25.263	492.100
DIST [min]	see above	2,385	171.2783	107.0892	27.2096	369.6844
CONC_RD_PUB	Share of university researchers in the same faculty in the respective spatial category over the share of total university researcher in the respective spatial category.	1,908	1.0415	0.4031	0	2.6801
ERF_GSF_PROF	External research fund gained from the German Science Foundation per professor in the respective spatial category [1,000 EUR].	1,908	20.4673	5.9349	5.7939	26.5034
STAR	Share of external research funds gained from the German Science Foundation.	2,385	22.3015	32.1736	0	100

Table A2: Determinants of the spatial distribution of university-industry linkages

	Dependent: share of connections in the respective spatial category			Dependent: number of connections in the respective spatial category		
	Fractional logit			Negative-binomial		
	(1)	(2)	(3)	(4)	(5)	(6)
DIST [min]	-0.002*	-0.002*	-0.002*	-0.002*	-0.002*	-0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
STAR*REG	-0.006*	-0.006*	-0.006*	-0.009**	-0.009**	-0.008**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
STAR*FSTATE	-0.008*	-0.008*	-0.009*	-0.010**	-0.010**	-0.009*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)
STAR*EAST	0.001	0.002	-0.001	-0.006	-0.005	-0.005
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
STAR*WEST	0.006*	0.006*	0.006*	0.008**	0.008**	0.005*
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)
STAR*FOREIGN	0.008*	0.009*		0.004*	0.004*	
	(0.004)	(0.004)		(0.002)	(0.002)	
UNI_SPIN_OFF	0.250*	0.228*	0.232*	0.348**	0.393**	0.187*
	(0.110)	(0.110)	(0.112)	(0.102)	(0.099)	(0.088)
PhD_WEST*REG	0.075	0.054	0.066	-0.087	-0.122	-0.007
	(0.133)	(0.132)	(0.131)	(0.126)	(0.122)	(0.130)
PhD_WEST*FSTATE	-0.372*	-0.343*	-0.356*	-0.568**	-0.591**	-0.485**
	(0.151)	(0.149)	(0.151)	(0.166)	(0.162)	(0.152)
PhD_WEST*EAST	-0.754**	-0.715**	-0.707**	-0.775**	-0.829**	-0.743**
	(0.206)	(0.207)	(0.201)	(0.207)	(0.200)	(0.204)
PhD_WEST*WEST	0.312*	0.295*	0.274*	0.026	0.038	0.019
	(0.137)	(0.132)	(0.133)	(0.118)	(0.111)	(0.106)
PhD_WEST*FOREIGN	0.172	0.194		0.119	0.129	
	(0.194)	(0.191)		(0.196)	(0.211)	
TTO_INI*REG	0.196*			0.175**		
	(0.077)			(0.057)		
TTO_INI*FSTATE	0.024			0.151		
	(0.076)			(0.081)		
TTO_INI*EAST	-0.050			0.065		
	(0.097)			(0.088)		
TTO_INI*WEST	-0.086			-0.197**		
	(0.077)			(0.063)		
TTO_INI*FOREIGN	-0.024			-0.221*		
	(0.093)			(0.092)		
FIRM_INI*REG		-0.045			-0.095	
		(0.081)			(0.076)	
FIRM_INI*FSTATE		-0.133			-0.142	
		(0.080)			(0.090)	
FIRM_INI*EAST		-0.411**			-0.154	
		(0.117)			(0.107)	
FIRM_INI*WEST		0.257**			0.170**	
		(0.085)			(0.058)	
FIRM_INI*FOREIGN		-0.145			-0.090	
		(0.117)			(0.113)	
CONC_RD_PRIV			0.075*			0.060*
			(0.037)			(0.025)
SMALL*REG			0.150*			0.214**
			(0.064)			(0.061)
SMALL*FSTATE			0.237**			0.344**
			(0.066)			(0.075)
SMALL*EAST			0.052			0.230**
			(0.099)			(0.088)
SMALL*WEST			-0.338**			-0.085
			(0.065)			(0.053)
MEDIUM*REG			0.040			0.174**
			(0.066)			(0.058)
MEDIUM*FSTATE			0.063			0.202**
			(0.073)			(0.069)
MEDIUM*EAST			0.164			0.068

			(0.103)			(0.104)
MEDIUM*WEST			0.003			0.215**
			(0.068)			(0.052)
LARGE*REG			-0.177**			-0.070
			(0.061)			(0.054)
LARGE*FSTATE			-0.290**			-0.055
			(0.068)			(0.067)
LARGE*EAST			-0.344**			-0.142
			(0.094)			(0.083)
LARGE*WEST			0.348**			0.388**
			(0.062)			(0.054)
UNI*REG	-0.730**	-0.746**	-0.593**	-0.407**	-0.401**	-0.373*
	(0.161)	(0.161)	(0.160)	(0.133)	(0.130)	(0.147)
UNI*FSTATE	0.039	0.082	0.207	0.131	0.151	0.255
	(0.162)	(0.165)	(0.163)	(0.191)	(0.199)	(0.169)
UNI*EAST	0.151	0.271	0.154	0.112	0.135	0.135
	(0.200)	(0.215)	(0.218)	(0.199)	(0.207)	(0.188)
UNI*WEST	0.650**	0.563**	0.493**	0.304*	0.315*	0.292*
	(0.186)	(0.186)	(0.185)	(0.155)	(0.157)	(0.139)
UNI*FOREIGN	0.189	0.241		0.007	0.051	
	(0.250)	(0.249)		(0.286)	(0.261)	
AGE*REG	0.305**	0.241**	0.225**	0.206**	0.192**	0.208**
	(0.070)	(0.064)	(0.067)	(0.071)	(0.070)	(0.078)
AGE*FSTATE	-0.111*	-0.044	-0.170**	0.049	-0.101	-0.008
	(0.055)	(0.055)	(0.058)	(0.084)	(0.079)	(0.081)
AGE*EAST	-0.175*	-0.052	-0.148*	-0.033	-0.045	-0.009
	(0.070)	(0.057)	(0.073)	(0.084)	(0.089)	(0.098)
AGE*WEST	-0.000	-0.051	-0.101	-0.222**	-0.186*	-0.125
	(0.056)	(0.060)	(0.063)	(0.069)	(0.074)	(0.065)
AGE*FOREIGN	-0.302**	-0.263**		-0.055	-0.018	
	(0.080)	(0.086)		(0.110)	(0.108)	
Constant	-1.207**	-1.218**	-1.343**	0.683*	1.024**	0.225
	(0.205)	(0.203)	(0.201)	(0.306)	(0.274)	(0.283)
Observations	1,955	1,955	1,564	1,955	1,955	1,564
LL pseudo	-711.34	-706.40	-578.93	-3,732.49	-3,735.70	-3,062.76
Wald				423.04**	451.50**	401.00**
LR				318.40**	311.97**	383.20**
AIC	0.756	0.751	0.781	3.848	3.851	3.959
BIC	-13947.6	-13957.5	-10777.0	-7130.5	-7124.1	-5135.0

Note: Robust standard errors in parentheses. * significant at 5% level; ** significant at 1% level.

Table A3: Determinants of the spatial distribution of universities' linkages to other universities and non-university public research organizations

	Dependent: share of connections in the respective spatial category					Dependent: number of connections in the respective spatial category				
	Fractional logit					Negative-binomial				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DIST [min]	-0.006*	-0.006*	-0.006*	-0.009*	-0.008*	-0.004*	-0.004*	-0.006**	-0.009**	-0.008**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$DIST^2$ [min^2]	0.000*	0.000*	0.000*	0.000**	0.000*	0.000*	0.000*	0.000**	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
STAR*REG		-0.004*			-0.004*		-0.007**			-0.007**
		(0.002)			(0.002)		(0.002)			(0.002)
STAR*FSTATE		-0.004			-0.003		-0.001			0.002
		(0.003)			(0.003)		(0.002)			(0.002)
STAR*EAST		-0.004*			-0.004*		0.002			0.002
		(0.002)			(0.002)		(0.002)			(0.002)
STAR*WEST		0.002*			0.002*		0.003**			0.003**
		(0.001)			(0.001)		(0.001)			(0.001)
STAR*FOREIGN		0.005*					0.004*			
		(0.002)					(0.002)			
ERF_GSF_PROF				0.034*	0.039*				0.057**	0.056**
				(0.017)	(0.017)				(0.011)	(0.011)
CONC_RD_PUB			0.353**		0.375**			0.185*		0.244**
			(0.126)		(0.130)			(0.074)		(0.075)
PhD_WEST*REG	-0.524**	-0.522**	-0.469**	-0.567**	-0.515**	-0.226*	-0.272*	-0.181	-0.299**	-0.290**
	(0.155)	(0.155)	(0.155)	(0.158)	(0.157)	(0.115)	(0.113)	(0.113)	(0.115)	(0.110)
PhD_WEST*FSTATE	-0.714**	-0.695**	-0.691**	-0.641**	-0.608**	-0.540**	-0.534**	-0.511**	-0.410**	-0.402**
	(0.205)	(0.205)	(0.211)	(0.212)	(0.217)	(0.150)	(0.150)	(0.148)	(0.145)	(0.144)
PhD_WEST*EAST	-0.217	-0.197	-0.187	-0.179	-0.155	-0.115	-0.120	-0.078	-0.069	-0.071
	(0.141)	(0.143)	(0.143)	(0.144)	(0.145)	(0.138)	(0.138)	(0.136)	(0.136)	(0.136)
PhD_WEST*WEST	0.422**	0.416**	0.459**	0.460**	0.445**	0.323**	0.314**	0.383**	0.363**	0.350**
	(0.116)	(0.116)	(0.119)	(0.120)	(0.119)	(0.104)	(0.105)	(0.104)	(0.103)	(0.103)
PhD_WEST*FOREIGN	0.306*	0.293*				0.435**	0.430**			
	(0.125)	(0.125)				(0.118)	(0.120)			
UNI*REG	-0.630**	-0.616**	-0.682**	-0.570**	-0.619**	-0.160	-0.324*	-0.197	-0.083	-0.306*
	(0.178)	(0.188)	(0.182)	(0.178)	(0.191)	(0.128)	(0.140)	(0.133)	(0.126)	(0.143)
UNI*FSTATE	-0.907**	-0.819**	-0.679**	-0.821**	-0.568*	-0.364*	-0.349	-0.229	-0.253	-0.150
	(0.209)	(0.216)	(0.222)	(0.224)	(0.225)	(0.176)	(0.182)	(0.175)	(0.200)	(0.186)
UNI*EAST	0.164	0.236	0.223	0.255	0.334	0.484**	0.431*	0.572**	0.612**	0.570**
	(0.184)	(0.191)	(0.187)	(0.190)	(0.198)	(0.172)	(0.175)	(0.178)	(0.180)	(0.182)
UNI*WEST	0.284	0.240	0.322	0.322	0.275	0.643**	0.561**	0.710**	0.692**	0.610**
	(0.169)	(0.178)	(0.179)	(0.179)	(0.188)	(0.159)	(0.161)	(0.169)	(0.167)	(0.168)
UNI*FOREIGN	0.540**	0.477*				0.681**	0.641**			
	(0.195)	(0.199)				(0.170)	(0.181)			
AGE*REG	0.123	0.122	0.130	0.090	0.092	0.030	0.032	0.027	0.087	0.082
	(0.074)	(0.074)	(0.075)	(0.075)	(0.077)	(0.067)	(0.067)	(0.069)	(0.068)	(0.069)
AGE*FSTATE	-0.058	-0.055	-0.075	0.022	-0.002	-0.097	-0.092	-0.094	0.022	-0.002
	(0.064)	(0.064)	(0.068)	(0.068)	(0.069)	(0.069)	(0.068)	(0.067)	(0.070)	(0.066)
AGE*EAST	-0.163**	-0.159**	-0.116*	-0.101	-0.090	-0.156*	-0.154*	-0.098	-0.077	-0.072
	(0.047)	(0.047)	(0.056)	(0.058)	(0.058)	(0.061)	(0.060)	(0.062)	(0.062)	(0.061)
AGE*WEST	0.036	0.034	0.089	0.086	0.077	-0.038	-0.042	0.036	0.013	0.008
	(0.046)	(0.046)	(0.060)	(0.060)	(0.060)	(0.061)	(0.061)	(0.063)	(0.063)	(0.061)
AGE*FOREIGN	-0.016	-0.019				-0.015	-0.018			
	(0.054)	(0.054)				(0.065)	(0.064)			
Constant	-1.016**	-1.001**	-1.446**	-1.552**	-2.143**	0.579*	0.576*	0.431	-0.330	-0.656
	(0.329)	(0.330)	(0.336)	(0.459)	(0.440)	(0.265)	(0.262)	(0.286)	(0.328)	(0.345)
Observations	2,385	2,385	1,908	1,908	1,908	2,385	2,385	1,908	1,908	1,908
LL pseudo	-873.85	-872.86	-644.35	-645.54	-642.64	-3,963.07	-3,953.06	-2,893.10	-2,881.18	-2,867.71
Wald						643.26**	749.03**	618.71**	630.07**	775.34**
LR						590.77**	610.79**	396.90**	420.73**	447.67**
AIC	0.748	0.751	0.692	0.693	0.696	3.339	3.335	3.050	3.038	3.029
BIC	-17614.7	-17577.8	-13703.7	-13701.3	-13669.3	-10474.1	-10455.3	-8498.1	-8521.9	-8511.1

Note: Robust standard errors in parentheses. * significant at 5% level; ** significant at 1% level.