The Role of Regional Knowledge for Innovation

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Abstract

We investigate the contribution of different inputs, particularly different knowledge sources, on regional patenting output in the framework of a knowledge production function. The knowledge sources included are R&D employment, size of public research institutions by field of research (number of employees, budget), amount of university external research funds from private firms, public departments, German Science Foundation (DFG) and from other sources. The contribution of these knowledge sources is tested systematically on the level of German districts (Kreise) by including the respective information for the particular region, for adjacent regions and for the national economy. One main finding is that the quality of the university research makes some contribution to regional innovation while the mere size of the universities is unimportant.

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1. Introduction

Empirical research has demonstrated that location matters for innovation activity (Feldman, 1994; Fritsch, 2000, 2002, 2005). Innovation processes have a pronounced regional dimension and conditions for innovative activity differ considerably between geographic areas. A main reason for this impact of location on innovation is the availability of knowledge. A role of location for innovation activity implies that at least part of the relevant knowledge is specific to a certain region and shapes the innovation activities there. Main sources of this knowledge could be private sector firms, universities and public research institutes. The knowledge may stem from inside the respective region, or it may spill over from adjacent regions. The relative importance of these different knowledge sources inside and outside the region is, however, still largely unclear.

This paper analyses the relevance of different types and sources of knowledge for regional innovation output. The framework of a knowledge production function is used to explore the link between different kinds of knowledge inputs and innovation output. The next section (section 2) briefly summarizes the main results of earlier research in this field. Section 3 reports data and indicators used, and in section 4 we describe the regional distribution, particularly the spatial concentration, of different kinds of knowledge and of innovation output (section 4). Based on the discussion of some estimation issues (section 5), the results of the multivariate analysis are presented in section 6. Concluding, we discuss the results of the analysis and derive policy implication (section 7).

2. Regional knowledge and innovation

There is a general agreement among economists and economic geographers that innovation activity is shaped by space and concentrated in certain areas

(Feldman, 1994). Prominent examples of innovative clusters are the Silicon Valley, Route 128 (see Saxenian, 1994) or the Cambridge (UK) technology region (see Athreye, 2004). Bottazzi & Peri (2003) show for Europe, that Northrhine-Westfalia, Bavaria, Baden-Wuerttemberg, Ile de France and East Anglia are responsible for about the half of the total number of EU patents in the 1977-95 period. To understand why such regions experience high levels of innovative activity and rapid technological development whereas other regions do not, we need to understand the forces that govern regional innovation processes.

It is widely accepted nowadays that scientific knowledge plays an essential role for economic development and social welfare. Two main sources of knowledge may be distinguished, university research und research in the private sector. Both knowledge sources are of distinct nature. University research is supposed to primarily generate basic knowledge that cannot be directly commercialized. In contrast to that, industrial R&D is mainly directed to commercial ends, seeking to apply knowledge and transform it into marketable products or methods of production. Accordingly, the basic knowledge that results from university R&D may be an important input for private sector innovation activity. Hence, one can expect that the effect of university R&D on economic development is more indirect in nature than private sector R&D.

In order to capture the effects of different inputs on innovation output Griliches (1979) introduced a knowledge production function that he specified as of a Cobb-Douglas-type (see section 4 for details). Using such a knowledge production function, Jaffe (1989) reports a significantly positive contribution of both private and university R&D to innovation output as indicated by corporate patents at the US state level. According to these estimates, the impact of private R&D is much stronger than that of university R&D (see table 4 for a summary of results of previous studies). At the level of the Metropolitan Statistical Areas (MSA), the impact of university knowledge R&D on patenting is even less pronounced (see Jaffe, 1989, 968). Using the US Small Business Administration innovation count data, Acs, Audretsch & Feldman (1991) find a stronger evidence for the impact of university research activities on innovation at the US State level than Jaffe (1989); at the level of MSAs the impact of private R&D and particularly of university R&D on innovative output is considerably weaker. In both studies, the impact of private sector R&D on innovative output is much stronger than that of university R&D.

Due to its particular character the transfer of certain types of knowledge between actors and regions can be seriously constrained. While a part of knowledge is codified in texts and blueprints, some other types of knowledge are not and remain tacit. Tacit knowledge (see Polanyi, 1967) entails not only simple facts but involves skills and experiences that can not be completely codified. Therefore, a transfer of such tacit knowledge requires direct interaction, often face-to-face contact, between the actors. As maintained by Dosi (1988), the tacidness may result from the specific character of the respective knowledge and from the efficiency of the available transfer media. If transfer of tacid knowledge requires face-to-face contact, the transfer cost will increase with the geographical distance. Therefore, spatial proximity may be rather conducive to tacid knowledge transfer (Audretsch, 1998; Krugman, 1998). Quite a lot of research has been undertaken to identify the spatial dimension of knowledge transfers. Jaffe, Trajtenberg & Henderson (1993) as well as Breschi & Lissoni (2003) find at the level of the US states that patents tend to be cited more frequently within the state from which they originate than elsewhere.

Anselin, Varga & Acs (1997) and Acs, Anselin & Varga (2002) study regional innovativeness at MSA level and find that university R&D in a radius of up to 50 miles has an effect on private sector innovation output. For the more distant universities no such statistically significant influence could be found. R&D in private sector firms has a positive effect on R&D in other private sector firms that are located in spatial proximity. Anselin; Varga & Acs (1997) and Adams (2001) can show that the relevant radius for such spatial knowledge spillovers is larger for university R&D than for private sector R&D. An impact of private sector R&D on university R&D could not be found. Using innovation data disaggregated for industries, Anselin, Varga & Acs (2000) can show that there are considerable differences of the effect of local universities on innovation between different industries. Other studies tried to capture localized knowledge spillovers by investigating the location decisions of firms. Audretsch & Stephan (1996, 1999) explore university-firms relations as a determinant of spatial clustering in the biotechnological sector Audretsch, Lehmann & Warning (2004) and Audretsch & Lehman (2005) show that in the case of Germany, the firm's location decisions depend on the geographical proximity to relevant knowledge sources. Hence, a tentative conclusion from theory and empirical studies is that both factors, local inputs and spatially bounded knowledge spillovers matter and may cause pronounced differences in regional innovation performance. It is, however, largely unclear in which ways such knowledge spillovers become effective.

3. Data and indicators

Our information on the different types of regional knowledge relates to the 327 West German districts (*Kreise*). East Germany is excluded because in this part of the country, the developments in the period of analysis were dominated by peculiarities of the transition process that make it still a rather special case in the period under inspection. Districts provide a relatively fine-grained pattern for the regional analysis that is well suited for investigating the role of geographical distance for knowledge spillovers.

When relating the different kinds of knowledge input to innovation output, we assume a time lag of three years, i.e. we regard the input of year t-3 as the relevant input for innovation output of year t. Hence, while our measure of innovative output, the number of patent applications, relates to the 1995-2000 period the indicators for innovative input are for the years 1992-97. This is done for two reasons. First, patent applications are published only about 12-18 months after submission. This is the time necessary to verify whether the application fulfils the basic preconditions for being granted a patent. Second, R&D activity requires time before a patentable result is attained. Acs et al. (2002) report that US innovation records in 1982 result from inventions made 4.3 years ago. Fischer & Varga (2003) use a two year lags between R&D efforts and patent counts in Austria in 1993. Ronde & Hussler (2005) link the innovative output, the number of French patents between 1997 and 2000, to R&D efforts in 1997. In our data we found the best results when using a three year lag.

The indicators of knowledge sources used in this study are as follows:

- The number of R&D employment in the private sector ($R\&D_{PRIV}$). This information is taken from the establishment file of the German Social Insurance Statistics (*Statistik der sozialversicherungspflichtig Beschäftigten*), as described and documented by Fritsch & Brixy (2004). Employees are classified as working in R&D if they have a tertiary degree in engineering or in natural sciences.

- The number of persons that graduate from the universities in a certain year (*GRAD*). Graduates may be an important medium for knowledge spillovers from the universities, although we do not know how many of them become employed in the same region where they attained their university degree.

- The amount of universities' regular funds (*URF*) in thousands of Euros.

- The amount of external research funds that the universities gained from private sector firms (ERF_{IND}), from the German Science Foundation (ERF_{DFG}), from government departments[1] (ERF_{PUB}) and from other institutions[2] (ERF_{OTHER}), respectively (in thousands of Euro). The total amount of such external research funds is given by ERF_{TOTAL}. The amount of external funds that is attracted can be regarded an indicator of the quality of research. Moreover, funds from private firms indicate university-industry collaboration and should lead to relatively pronounced knowledge spillovers. Although we have no information about the location of the respective private firms, we know from other studies that industry-university cooperation tends to be concentrated in the university's vicinity (Fritsch and Schwirten, 1999).

- The yearly number of patent applications that is available on the level of districts (*Kreise*) for the 1995-2000 period (Greif & Schmiedl, 2002). A patent application indicates that an invention was made that extends the existing knowledge pool. However, using patents as indicator for new knowledge underestimates the results from basic research which cannot be patented. A patent is assigned to the district in which the inventor has his registered main residence at the time of submitting the application. If a patent has more than one inventor, which are located in other districts, the count is divided by the number of the inventors involved. For this reason the number of patents per district is not always whole-numbered. To make

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[1] This comprises external funds from the Federal State as well as from the States (*Laender*).

[2] Other institutions are municipalities, foundations, international organizations, German Federal Labor Office, etc.

the information on the number of patents conform to the negative binomial estimation model that we apply (section 5), these numbers have been rounded up.

All these data are on a yearly basis at the level of districts. To test for spatial spillovers, the respective variables are summed up over all districts that have their geographic center within a 50 km radius around the district under inspection, forming the *first ring*. To test the hypothesis that the intensity of knowledge spillovers decreases with distance, we also form a *second* ring that entails all districts that have their geographic center in a 50 to 75 km distance.

Table 1: Descriptive statistics (pooled yearly values)

Variable	Mean	Std. Dev.	Min	Max	Median
No. of patents	96.13	116.14	2	1,470	61
No. of private sector R&D employees	1,470.83	2790.71	31	30,423	564.5
Universities' regular funds	33,017.59	97,628.93	0	1 201,834	0
External research funds (total)	5,289.83	17,174.97	0	221,675.7	0
External funds from DFG	1,685.16	5,447.81	0	60028.22	0
External funds from private firms	1,420.91	5,689.64	0	91,537.61	0
External funds from government departments (Federal German Government and States Government)	1,382.38	4,817.60	0	60,606.5	0
External funds from other sources	834.90	3,460.76	0	54,348.79	0
No. of graduates from universities	559.97	1,382.28	0	14,813	0
Firm size (district average)	12.05	3.77	6.12	49.94	11.55
Degree of industrialization	1.06	0.21	0.50	1.70	1.07

The descriptive statistics presented in table 1 show high dispersion of the different indicators among regions. Large differences between the median and the mean values point to a rather skewed distribution of the respective variable. The number of patents varies between 2 and 1,470 patents across the West German districts. There is no region, which does not have any patent application at all. Innovation activities seem to be concentrated in the South and South-West of West Germany, where the cities of Munich and Stuttgart take an unequivocal stand with 1,470 and 725 patents in the year 2000, respectively.[3]

4. Regional distribution of innovation input and output

The Lorenz curves for the regional distribution of innovation input and output (figure 1) and the respective Gini coefficients (table 2) show a remarkable degree of concentration.[4] The highest degree of spatial concentration is found for those indicators, which pertain to universities such as regular funds of universities, external research funds as well as for the number of graduates per year. Private sector R&D employment as well as the number of patents is far less concentrated in space. However, the Gini coefficients (table 2) for these indicators are considerably higher than for overall private sector employment indicating a higher level of concentration than is found for economic activity as such. The higher spatial concentration of university related indicators may have at least two reasons. First, only less than half of the districts have a university (155 out of the 327 in the year 2000, i.e. about 47 percent), while R&D employment can be found in every district. A second explanation could be that universities are characterized by higher indivisibilities in terms of minimum efficient size than private sector R&D activity. The relatively high concentration of external R&D funds among the university related indicators results probably from the competitive nature of their allocation procedure. External R&D funds indicate excellence and are, therefore, concentrated at

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[3] For a detailed description of the regional distribution of patents see Greif & Schmiedl (2002).

[4] Audretsch & Feldman (1996) report Gini coefficients for industry innovations, industry value added and employment in the USA of 0.30, 0.56 and about 0.50 respectively.

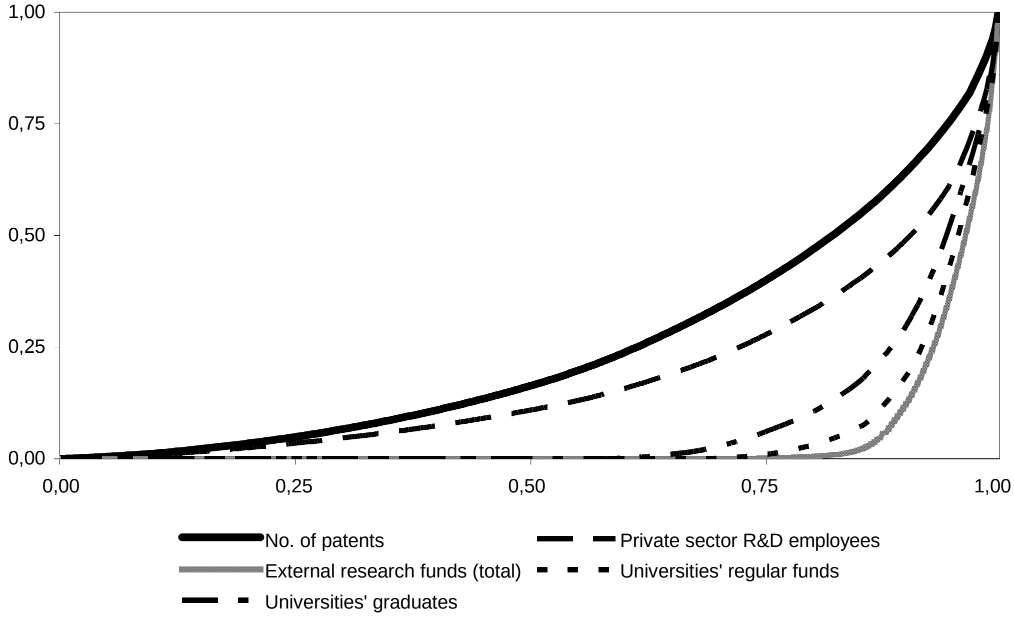
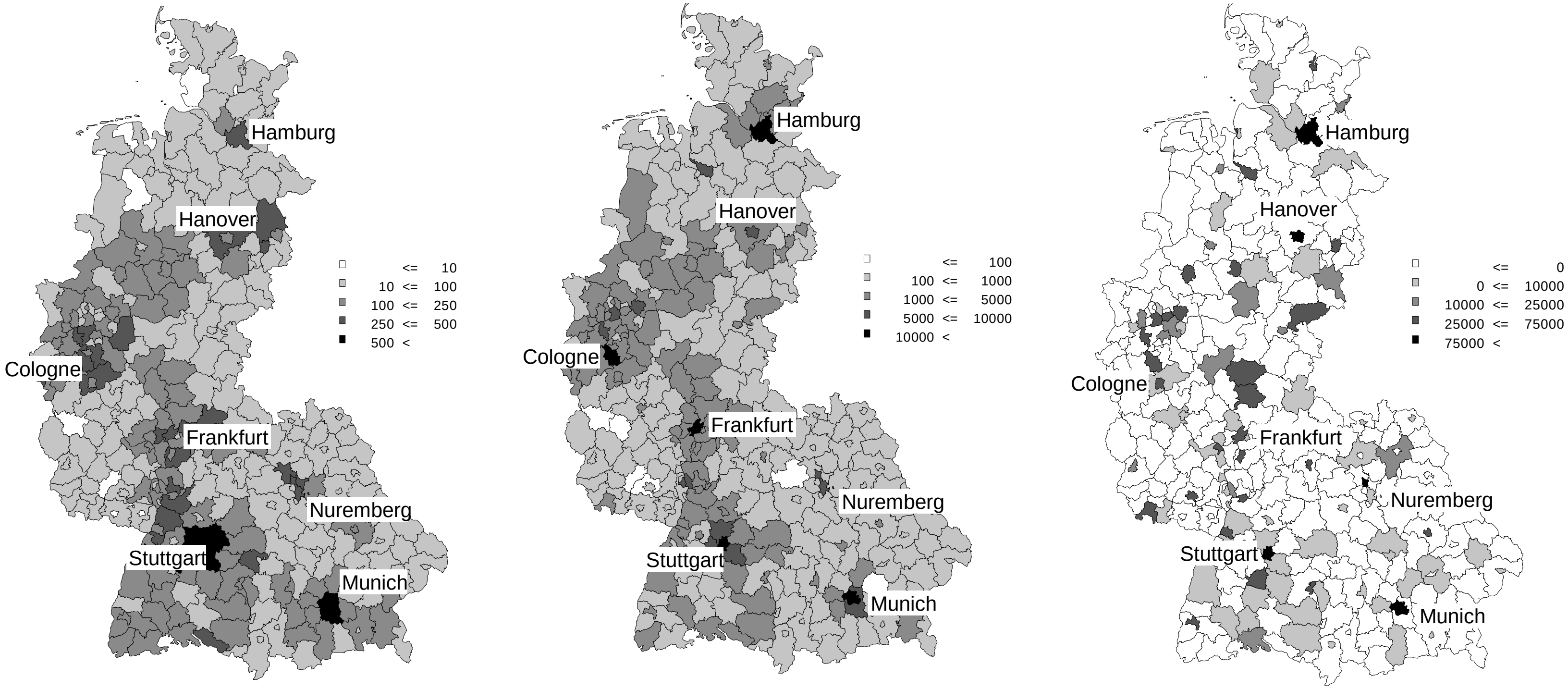


Figure 1: Regional concentration of innovation input and output (average yearly values)

Table 2: Gini coefficients for regional concentration of innovation input and output (average yearly values)

Indicator	Gini coefficient
Number. of patents	0.509
Number of private sector employees	0.427
Number of private sector R&D employees	0.630
Universities' regular funds	0.897
Graduates from universities	0.843
External research funds (total)	0.911
External research funds from German Science Foundation (DFG)	0.917
External research funds from private firms	0.930
External research funds from government departments	0.921
External research funds from other sources	0.923



Number of Patents | Number of private sector R&D employees | External research funds (in 1000 Euro)

Figure 2: Spatial distribution of innovation input and output (average yearly values)

those universities which have the highest quality of research.[5] Distinguishing between different sources of external research funds shows that the resources from private firms and from government departments are somewhat more concentrated than those from other sources, but the differences are not very pronounced.

The spatial distribution of patents and private sector R&D employment is rather similar (figure 2). Regions with a high number of private sector R&D employees also tend to have a relatively high number of patents. Compared to R&D employment and patents, university's external research funds are much more concentrated. A number of regions with a high number of patents (e.g. the two extreme cases Munich and Stuttgart) have a high level of private R&D input plus high quality universities that attract large volumes of external research funds. However, there are also regions that attain a relatively high number of patents without having a university and with an only below average level of private sector R&D. Likewise, having a university with large amounts of external research funds in the region is in no way a guarantee for an equivalent patent output even if there is considerable private sector R&D present. Obviously, there are further factors such as the interplay of the different elements of the regional innovation system (Fritsch, 2004, 2005) that determine the quality of innovation activity in a region. Generally, we find considerably more innovation activity in larger cities than in remote and rural areas. However, the picture is quite manifold. There is at least some innovation activity everywhere and there is hardly any location in which the distance to the next research university is more than 100 km.

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[5] The share of external funds on university finance makes only 22.8 percent. 31.7 percent of external funds stem from the German Science Foundation (DFG), 26.9 is from private sector firms, 26.5 percent from public departments and 15.9 percent is from other sources (municipalities, foundations, international organizations, German Federal Labor Office, etc.).

5. Estimation issues

The regional knowledge production function describes the relationship between innovation input and innovation output (Griliches, 1979; Jaffe, 1989). The basic hypothesis behind the knowledge production function is that inventions do not fall completely ‘from heaven’ but result from R&D activity, i.e.

(1) *R&D output = f (R&D input).*

Adopting the Cobb-Douglas form of a production function, the basic relationship can be written as

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

with the term *a* representing a constant factor and *b* giving the elasticity by which R&D output varies in relation to the input to the R&D process. If the elasticity equals one, a 100 percent increase in R&D expenditure would lead to a doubling of innovative output. An elasticity value that is lower than one indicates that the innovative output does not increase in proportion to the R&D input. Taking the natural logarithms of both sides and adding an index *t* for time (year) we get

(3) $ln\ (R\&D\ output)_t = ln\ a + b\ (ln\ R\&D\ input)_t$.

This equation can be estimated by applying standard regression techniques.

For analyzing the relative contribution of the different types of knowledge source for regional innovation output we include indicators for these knowledge types. Differences in output elasticity *b* for the innovation inputs imply differences in the impact of the respective knowledge source on innovation output. The coefficients of output elasticity are dimensionless so that the estimates for the different knowledge sources can be directly compared with each other. We test for the importance of spatial knowledge spillovers by accounting for innovation inputs in adjacent regions, the first and second ring.

A significantly positive impact of innovation resources located in neighboring districts implies knowledge spillovers between the regions. By separating the different sources of knowledge, we can investigate the impact and the relative importance of the different types of knowledge on regional innovation activity.

The constant term *a* captures inputs which are not represented by the other variables of the empirical model. There are two interpretations of this term (Fritsch, 2002; Fritsch and Franke, 2004). First, due to the cumulative character of knowledge, current period innovations can be a product of the inventor's own R&D effort in previous periods that is not explicitly accounted for in the empirical model. Second, some inventions may 'fall from heaven' in the sense that they partly emerge without any own R&D effort, e.g. as a result of a costless spillover from other sources. Furthermore, the constant term may signify the random character of innovation processes.

Our dependent variable, the number of patents, has the form of a non-negative integer. Assuming that the number of patents is generated by a Poisson-like process, Poisson-regression analysis may be applied. However, we used negative-binomial (negbin) regression because it is based on somewhat more general assumptions than the Poisson regression.[6] General least squares (GLS) estimates of the models are given in the Appendix (table A3) for comparison. Due to the characteristics of the data set, panel estimation techniques may be applied to control for unobserved region specific effects. Random effects estimation presupposes that the unobserved heterogeneity in the production of innovations is randomly distributed across districts. Panel analysis with fixed effects does not appear appropriate because the values of variables under inspection change only slightly over time. To prevent the a

[6] Negative binomial regression allows for a greater variance of observations than is assumed for a Poisson process. For a more detailed description of these estimation methods see Greene (2003, 931-939). Note that we find at least one patent per year for each district in our data so that the problem of having "too many zero values" does not apply.

priori exclusion of districts with no university due to non defined logarithm of zero, we take a logarithm of university related variable plus a unit. As maintained by Feldman (1994), industry presence may promote incentives for innovation activities. In order to capture the effects of industry concentration we control for the location coefficient of manufacturing employment in the region in all models [7] that indicates the degree of concentration in the manufacturing sector. Using alternative indicators for industry concentration like the share of manufacturing employment in the district leads to implausible results. There is quite a considerable correlation between several types of R&D input such as the number of private sector R&D employees, universities' regular and external funds as well as the number of graduates that may cause considerable multicollinearity in the analysis (Table A1 in the Appendix).

6. Results

We find that private sector R&D employment has the strongest impact on patenting of all knowledge sources (table 3). The production elasticity of private sector R&D employment in the same region amounts to about 0.67 while it is slightly above 0.23 for private R&D resources in the first ring (average distance < 50 km) ring. Private R&D activity in the second ring (distance 50-75 km) is not statistically significant. Including private R&D in a third or fourth ring does not lead to significant or plausible estimates so that we conclude that the relevant private sector spillover sources are all located within a radius of about 75 km. The size of these coefficients and the spatial pattern that we found is well in accordance with the results of previous research for other countries. It is rather remarkable that the number of scientific and teaching personnel at universities as well as the size of the regular budget has no significant effect on the regional number of patents. Such a positive impact can, however, be found for the amount of external funds that the universities

[7] This location coefficient is the share of regional employment in manufacturing over the share of manufacturing employment in West Germany as a whole.

attract. This indicates that it is the quality of the research at universities that is important for their contribution to the innovation system, not their mere size. The size of the coefficient for university R&D is considerably smaller than what was found in studies for the US (table 4). In contrast to a recent study for French regions (Ronde & Hussler, 2005), the impact of university R&D is, at least, statistically significant.

Table 3: Determinants of the regional number of patents – results of multiple negbin regressions (panel, random effects)+

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$R\&D_{PRIV}$	0.673***	0.665***	0.672***	0.674***	0.677***	0.676***	0.670***
	(26.56)	(25.77)	(26.76)	(26.97)	(27.21)	(27.14)	(26.61)
$R\&D_{PRIV}$ 0-50km	0.233***	0.233***	0.232***	0.231***	0.230***	0.234***	0.232***
	(8.34)	(8.35)	(8.36)	(8.34)	(8.29)	(8.41)	(8.37)
$R\&D_{PRIV}$ 50-75km	0.018	0.017	0.017	0.017	0.019	0.017	0.017
	(0.72)	(0.67)	(0.68)	(0.68)	(0.74)	(0.66)	(0.68)
ERF_{TOTAL}	0.010 a)	0.008					
	(1.80)	(1.43)					
ERF_{DFG}			0.010**				0.007 a)
			(2.32)				(1.60)
ERF_{IND}				0.010**			0.006
				(2.11)			(1.28)
ERF_{PUB}					0.008*		
					(1.95)		
ERF_{OTHER}						0.009***	
						(2.67)	
ERF_{TOTAL} 0-50km	-0.002	-0.001	-0.002	-0.002	-0.002	-0.003	-0.002
	(0.25)	(0.15)	(0.29)	(0.22)	(0.29)	(0.41)	(0.23)
URF	-0.001	-0.002	0.002	0.002	0.002	0.001	0.001
	(0.11)	(0.51)	(0.56)	(0.38)	(0.42)	(0.36)	(0.20)
SIZE	-1.553***	-1.551***	-1.552***	-1.557***	-1.555***	-1.540***	-1.556***
	(22.28)	(22.24)	(22.31)	(22.37)	(22.35)	(22.06)	(22.37)
IND_{DEGREE}	0.533***	0.556***	0.553***	0.556***	0.538***	0.532***	0.569***
	(5.16)	(5.37)	(5.34)	(5.37)	(5.21)	(5.17)	(5.48)
GRAD		0.011**					
		(2.11)					
$RESID_{MEAN}$	0.795***	0.793***	0.795***	0.791***	0.802***	0.794***	0.791***
	(15.71)	(15.68)	(15.69)	(15.58)	(15.90)	(15.78)	(15.56)
Constant	0.624**	0.641**	0.624**	0.613**	0.623**	0.598**	0.620*
	(2.12)	(2.18)	(2.13)	(2.09)	(2.12)	(2.04)	(2.11)
No. of observations	1962	1962	1962	1962	1962	1962	1962
No. of districts	327	327	327	327	327	327	327

+ Absolute value of z-statistics in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%. a) z-statistics >=1.61 means significant at 10 percent.

Table 4: Estimated output elasticities for private sector R&D and university R&D

Study / country	*Estimated output elasticity for private sector R&D*	*Estimated output elasticity for university R&D*
Jaffe (1989) / USA	0.71**	0.084**
Feldman (1994) / USA	0.67**	0.24**
Anselin, Varga & Acs (1997) / USA	0.54**	0.11**
Fischer & Varga (2003)	0.402***(basic model) 0.100***(ext. model) 0.130***(ext. spatial model)	0.128***(basic model) 0.211***(ext. model) 0.213***(ext. spatial model)
Ronde & Hussler (2005) / France	0.713**	n.s.
This study / West-Germany	0.67	0.017

External research funds of universities in the adjacent regions of the first ring are not statistically significant. The negative impact that we find for average establishment size in the region indicates that smaller firms apply for more patents per unit of R&D input than larger ones and confirms the results of earlier research (Acs & Audretsch, 1990; Cohen & Klepper, 1996). Concentration of the manufacturing sector is also highly significant with a positive sign indicating a relatively high propensity of patenting in these industries. Because a *Moran's I*-test indicates significant spatial autocorrelation with regard to the error terms, we also include the average mean residual of the adjacent regions ($RESID_{MEAN}$). The positive values of the respective coefficients indicate that neighbouring regions have some influences in common, which are not included in the model. The number of graduates from the regional universities also has a significantly positive impact on regional innovation activity (model 2 in table 3). Because there is a pronounced correlation between this variable and a number of other variables (table A1), it is not included in the further models in order to avoid multicollinearity problems.

Introducing the different sources of external funds separately into the model (model 3 to 6 in table 3), we find a positive sign for all of them. However, the coefficient for external funds from government departments is only statistically significant at the ten percent level. It is quite remarkable that, according to these estimates, the funds from private firms (model 4) appear to be about as important for explaining regional patenting as those from the German Science Foundation (DFG; model 3). However, due to considerable correlation between the variables for the different sources of external funds (table A1 in the Appendix) these estimates must be regarded as not very reliable. If one includes all of these variables into one model none of them are statistically significant at the five percent level. This also holds for including the external funds from private firms and from German Science Foundation only (model 7). The results do, however, indicate that the resources of the German Science Foundation have a somewhat higher impact.

Since the university data are available for different subject areas such as natural sciences, social sciences, engineering, sports, etc., we tested if some of these subject areas have a higher impact than others on regional patenting but did not find any clear pattern. Running the models only for those 76 districts where there is a university located leads to a one and a half time higher coefficients of the university related variables.

7. Summary and Conclusions

Our analysis of the knowledge sources of innovative output showed that innovation activity is highly concentrated in space. The highest share of innovative output measured by the number of patents is explained by private sector R&D employment. Compared to private R&D, the contribution of the universities is rather small, considerably smaller than what was found in comparable studies for the US (table 4). The mere size of the universities in terms of the number of employees or the regular budget has no statistically significant impact on innovative output. Such an effect is, however, found for the external funds attracted by the universities, which can be regarded an indicator for the quality of the research. Comparing the different types of external funds, the resources from government departments appear to have a relatively weak impact. The yearly number of graduates from universities also makes a significant contribution to a region’s innovation output.

We found pronounced knowledge spillovers from private sector R&D in adjacent regions that have their geographic center within a 50 km radius around the district under inspection. For university related measures and for more remote regions no such geographic spillovers could be detected. We also could not find differences in the importance of the different universities subject areas for the level of regional output

The relatively low impact of university R&D as compared to what was found in studies for the US raises the question how these differences could be explained and how the impact could be increased. The result suggests that the transfer of university R&D in the US is more effective than in Germany. Because the differences between the university systems in the two countries are manifold, the question regarding what part of these differences is responsible for the comparative ineffectiveness of the German system arises.

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Appendix

Table A1: Correlation between main variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 *Patents*	1.00													
2 $R\&D_{PRIV}$	0.75*	1.00												
3 $R\&D_{PRIV}$ *0-50km*	0.38*	0.22*	1.00											
4 $R\&D_{PRIV}$ *50-75km*	0.10*	0.06*	0.27*	1.00										
5 ERF_{TOTAL}	0.48*	0.70*	0.03	0.03	1.00									
6 ERF_{DFG}	0.43*	0.61*	0.04	0.04	0.96*	1.00								
7 ERF_{IND}	0.52*	0.70*	0.00	0.01	0.94*	0.88*	1.00							
8 ERF_{PUB}	0.48*	0.71*	0.04	0.02	0.94*	0.90*	0.88*	1.00						
9 ERF_{OTHER}	0.22*	0.41*	0.05*	0.03	0.63*	0.48*	0.42*	0.47*	1.00					
10 ERF_{TOTAL} *0-50km*	0.31*	0.11*	0.86*	0.23*	-0.11*	-0.11*	-0.12*	-0.10*	-0.06*	1.00				
11 *URF*	0.50*	0.74*	0.05*	0.03	0.93*	0.90*	0.87*	0.89*	0.55*	-0.10*	1.00			
12 *SIZE*	0.15*	0.38*	0.07*	0.12*	0.23*	0.20*	0.22*	0.21*	0.17*	-0.01	0.24*	1.00		
13 *GRAD*	0.47*	0.73*	0.07*	0.06*	0.86*	0.84*	0.79*	0.81*	0.55*	-0.07*	0.95*	0.26*	1.00	
14 IND_{DEGREE}	-0.02	-0.23*	-0.09*	0.08*	-0.34*	-0.34*	-0.29*	-0.32*	-0.27*	-0.05*	-0.38*	0.20*	-0.40*	1.00

Table A2: Determinants of the regional number of patents – results of single regressions

	Negbin, panel, random effects	Negbin, pooled Huber-White	Negbin, cluster, Huber-White	GLS, panel, random effects	OLS, pooled, Huber-White	OLS, cluster, Huber-White
$R\&D_{PRIV}$	0.494***	0.625***	0.625***	0.709***	0.673***	0.673***
	(20.85)	(42.31)	(18.17)	(24.85)	(50.21)	(21.70)
$R\&D_{PRIV}$ 0-50km	0.493***	0.510***	0.510***	0.622***	0.514***	0.514***
	(17.08)	(28.43)	(12.08)	(16.29)	(32.62)	(13.95)
$R\&D_{PRIV}$ 50-75km	0.387***	0.250***	0.250***	0.485***	0.299***	0.299***
	(10.34)	(10.37)	(4.31)	(9.50)	(14.19)	(6.00)
ERF_{TOTAL}	0.044***	0.061***	0.061***	0.050***	0.066***	0.066***
	(7.17)	(9.16)	(3.89)	(7.07)	(12.40)	(5.27)
ERF_{DFG}	0.038***	0.075***	0.075***	0.050***	0.090***	0.090***
	(6.40)	(9.78)	(4.19)	(6.98)	(15.34)	(6.60)
ERF_{IND}	0.034***	0.072***	0.072***	0.044***	0.081***	0.081***
	(6.01)	(9.21)	(3.93)	(6.46)	(12.85)	(5.53)
ERF_{PUB}	0.026***	0.078***	0.078***	0.038***	0.087***	0.087***
	(5.07)	(9.98)	(4.26)	(6.03)	(14.13)	(6.10)
ERF_{OTHER}	0.033***	0.077***	0.077***	0.035***	0.080***	0.080***
	(6.61)	(8.96)	(4.08)	(5.82)	(11.54)	(5.03)
ERF_{TOTAL} 0-50km	0.117***	0.070***	0.070***	0.097***	0.093***	0.093***
	(11.80)	(8.12)	(3.41)	(10.85)	(12.60)	(5.32)
URF	0.026***	0.053***	0.053***	0.032***	0.055***	0.055***
	(5.38)	(10.13)	(4.25)	(5.62)	(12.78)	(5.41)
$R\&D_{UNIV}$	0.061***	0.092***	0.092***	0.091***	0.104***	0.104***
	(6.12)	(10.40)	(4.36)	(7.30)	(14.21)	(5.99)
GRAD	0.048***	0.084***	0.084***	0.057***	0.093***	0.093***
	(6.96)	(10.79)	(4.53)	(6.87)	(14.15)	(5.99)
SIZE	-1.556***	0.919***	0.919***	-1.445***	0.763***	0.763***
	(14.65)	(9.76)	(4.11)	(12.58)	(8.81)	(3.76)
IND_{DEGREE}	0.306*	-0.115	-0.115	0.581***	0.321***	0.321
	(1.77)	(0.87)	(0.36)	(3.06)	(2.79)	(1.17)
Observations	1962	1962	1962	1962	1962	1962
No. of districts	327			327		

Table A3: Determinants of the regional number of patents – results of multiple GLS regressions (panel, random effects)

	(1)	(2)	(3)	(4)	(6)	(6)	(7)	(8)
$R\&D_{PRIV}$	0.769***	0.764***	0.758***	0.764***	0.763***	0.769***	0.756***	0.752***
	(28.96)	(28.22)	(28.41)	(28.91)	(29.06)	(29.15)	(28.25)	(27.60)
$R\&D_{PRIV}$ 0-50km	0.249***	0.248***	0.254***	0.250***	0.249***	0.250***	0.254***	0.253***
	(8.59)	(8.56)	(8.76)	(8.65)	(8.62)	(8.62)	(8.74)	(8.71)
$R\&D_{PRIV}$ 50-75km	0.004	0.003	0.004	0.003	0.005	0.003	0.004	0.003
	(0.14)	(0.10)	(0.13)	(0.13)	(0.21)	(0.13)	(0.14)	(0.11)
ERF_{TOTAL}	0.005	0.004						
	(0.75)	(0.54)						
ERF_{DFG}			0.015***				0.012*	0.012*
			(2.62)				(1.88)	(1.78)
ERF_{IND}				0.012**			0.007	0.006
				(2.09)			(1.02)	(0.96)
ERF_{PUB}					0.015***			
					(2.76)			
ERF_{OTHER}						0.007		
						(1.30)		
ERF_{TOTAL} 0-50km	-0.006	-0.005	-0.006	-0.005	-0.006	-0.006	-0.006	-0.005
	(0.77)	(0.69)	(0.87)	(0.69)	(0.76)	(0.80)	(0.79)	(0.73)
URF	-0.000	-0.002	-0.001	-0.001	-0.003	0.000	-0.002	-0.004
	(0.02)	(0.28)	(0.17)	(0.30)	(0.67)	(0.06)	(0.50)	(0.77)
SIZE	-1.561***	-1.563***	-1.557***	-1.562***	-1.554***	-1.558***	-1.560***	-1.561***
	(18.67)	(18.70)	(18.64)	(18.71)	(18.62)	(18.63)	(18.66)	(18.68)
IND_{DEGREE}	0.679***	0.693***	0.722***	0.709***	0.700***	0.684***	0.733***	0.743***
	(6.25)	(6.35)	(6.62)	(6.51)	(6.47)	(6.31)	(6.69)	(6.75)
GRAD		0.008						0.006
		(1.25)						(0.94)
$RESID_{MEAN}$	0.788***	0.788***	0.784***	0.784***	0.790***	0.787***	0.782***	0.782***
	(14.12)	(14.13)	(13.99)	(14.00)	(14.21)	(14.14)	(13.92)	(13.94)
Constant	-0.144	-0.119	-0.164	-0.158	-0.165	-0.152	-0.166	-0.147
	(0.48)	(0.40)	(0.55)	(0.53)	(0.55)	(0.51)	(0.55)	(0.49)
No. of observations	1962	1962	1962	1962	1962	1962	1962	1962
No. of districts	327	327	327	327	327	327	327	327

Z-statistics in parentheses. *** significant at 1 percent level; ** significant at five percent level; * significant at ten percent level.