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Contents

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 (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 and for adjacent regions. 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. Differences in the effect on innovative output can be found according to academic disciplines and type of university.

JEL-classification: O31, O18, R12

Keywords: Knowledge, innovation, spillovers, patents, regional analysis.

Zusammenfassung

„Die Rolle regionaler Wissensquellen für Innovation –Eine empirische Analyse“

Wir untersuchen die Bedeutung verschiedener Inputs, insbesondere verschiedener Wissensquellen, für den regionalen Output an Erfindungen (Patente) mithilfe einer Wissensproduktionsfunktion. Als Wissensquellen werden die FuE-Beschäftigte im Privatsektor, die Größe der Universitäten und Fachhochschulen sowie das Volumen der von ihnen aus verschiedenen Quellen eingeworbenen Drittmittel berücksichtigt. Die Bedeutung dieser Wissensquellen wurde systematisch auf der Ebene der westdeutschen Kreise getestet, wobei Informationen sowohl über den jeweiligen Kreis als auch über die Nachbarkreise einbezogen wurden. Es stellt sich heraus, dass von der Qualität der in den Universitäten und Fachhochschulen betriebenen Forschung ein signifikanter Einfluss auf die regionale Innovationstätigkeit ausgeht. Die reine Größe der Universitäten und Fachhochschulen in der Region hat hingegen keinen Einfluss. Darüber hinaus ermitteln wir Unterschiede nach Herkunft von Drittmitteln sowie Unterschiede in der Bedeutung verschiedener Fachdisziplinen für regionale Innovationsaktivitäten. Wissensspillover sind im Wesentlichen auf die angrenzenden Kreise begrenzt.

JEL-Klassifikation: O31, O18, R12

Schlagworte: Wissen, Innovation, Spillover, Patente, regionale Analyse.

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. An important 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 analyzes the relevance of different types and sources of regional knowledge for 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. Based on the discussion of some estimation issues (section 4), the results of the multivariate analysis are presented in section 5. Concluding, we discuss the results of the analysis and derive policy implication (section 6).

2. Regional knowledge and innovation

There is a general agreement among many economists and particularly economic geographers that innovation activity is shaped by space and concentrated in certain areas (Feldman, 1994). In the European Union, North Rhine-Westphalia, Bavaria, Baden-Wurttemberg, Ile de France, and East Anglia have been responsible for about half of the total number of patents in the 1977-1995 period (Bottazzi & Peri, 2003). The Silicon Valley, Route 128 (Saxenian, 1994), or the Cambridge (UK) technology region (Athreye, 2004) are prominent examples of regions with high concentration of Research & Development (R&D) and surpassing levels of innovative output. However, still little is known about the forces that are responsible for such an uneven distribution of innovative activity and 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; namely university research and R&D in the private sector (Nelson & Phelps, 1966; Nelson, 1993). Both knowledge sources are of a distinct nature. Universities are considered to enhance the knowledge base in the economy by accomplishing many different functions such as performing R&D, teaching and training of scientists and skilled workforce as well as providing services for private agents. University research is supposed to primarily generate basic knowledge. Thus, only a part of the universities' output can be commercialized directly. In contrast to university research, industrial R&D is mainly directed towards 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. However, 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 (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. Using innovation count data from the US Small Business Administration, Acs, Audretsch & Feldman (1991) find considerably stronger evidence for the impact of university research activities on innovation at the US State level than Jaffe (1989). In both studies, the impact of private sector R&D on innovative output is much stronger than that of university R&D (see table A1 for a summary of results of previous studies). Both studies also report that the effects of public and private R&D on innovative output are considerably less pronounced if the US Metropolitan Statistical Areas (MSA) are taken as units of analysis. This indicates the importance of the size of spatial units under analysis.

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 (Polanyi, 1967) entails not only simple facts but involves skills and experiences that cannot 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 tacitness may result from the specific character of the respective knowledge and from the efficiency of the available transfer media. If transfer of tacit knowledge requires face-to-face contact, the transfer cost will increase with the geographical distance. Therefore, spatial proximity may be rather conducive to a transfer of tacit knowledge (Audretsch, 1998; Krugman, 1998). Much 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 the 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 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 the 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 made it still a rather special case. 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. Firstly, 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. Secondly, 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 lag 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 amount of universities' regular funds (*URF*) in thousands of Euros. We are able to identify two types of universities and a number of academic subject areas. While the German Universities of Applied Sciences (*Fachhochschulen*) provide undergraduate education in engineering and in management, the Universities (*Universitäten*) supply a broader range of academic grades and disciplines. While the Universities tend to conduct a relatively pronounced level of mainly basic research, the level of research at the Universities of Applied Sciences is predominantly for practical purposes. Data are available for a number of academic subject areas separately, such as natural science, engineering, human medicine, linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural science, forestry, nutritional science, and arts.

- The amount of external research funds that the universities gained from private sector firms (ERF_{IND}), from the German Science Foundation (DFG, ERF_{DFG}), from government departments[1] (ERF_{PUB}), and from other institutions[2] (ERF_{OTHER}), respectively (in thousands of Euros). The total amount of such external research funds is given by ERF_{TOTAL}. The amount of external funds that is attracted can be regarded as an indicator of the quality of research. The main reason is that university's funding from external sources occurs predominantly by means of some competitive procedure. Thus, universities which attract more external funds can be regarded to have more research of a relatively high quality. Moreover, funds from private firms indicate university-industry collaboration that may 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 & Schwirten, 1999). Information on external research funds is also available by type of university and by academic disciplines as described above.

- 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

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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.

inventor has his main residence. If a patent has more than one inventor, the count is divided by the number of the inventors involved and each inventor is registered with the respective share of that patent. Therefore, in event of the inventors being located in the different regions, the number of patents per district may, therefore, not always be whole-numbered. To adjust the information on the number of patents to the assumptions of the negative binomial estimation model that we apply in section 5, these numbers have been rounded up.

All these data are available on a yearly basis at the level of districts. To test for spatial spillovers, the respective variables are summed up over all adjacent 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 of the other districts that have their geographic center in a 50 to 75 km distance. To account for the higher propensity to patent in the manufacturing sector as compared to the service sector, we include a manufacturing specialization index (*SMI*) that indicates a share of district's own manufacturing employment compared to the national average.[3]

The impact of localized externalities, particularly knowledge spillovers, on regional innovation activities has been widely discussed in the economic literature (e.g. Glaeser et al., 1992; Feldman & Audretsch, 1999). It is a common assumption that regional specialization on certain industries may be conducive to innovation processes due to the creation of pools of specific skills, pecuniary externalities, and knowledge spillover. Externalities that emerge from the local concentration of certain industries are said to be from the Marshall-Arrow-Romer[4] type (MAR). If externalities result from industrial diversity as suggested by Jacobs (1969), they may be labeled as the Jacobs' type. In order to account for such impulses of

[3] In a first step, the specialization in manufacturing of each region (*SM*) was computed as the quotient from the share of the region's own manufacturing employment and the share of manufacturing employment in the whole economy. If the share of the region's own manufacturing employment is the same as in the economy as a whole, then the *SM* becomes the value of unity. For regions with an above average share of manufacturing employment, the *SM* becomes larger than unity and vice versa. To transform the values into a normal distribution, the index (*SMI*) was calculated, as shown by Laursen (1998), as [*SM*-1]/[*SM*+1]. Thus, the *SMI* ranges in [-1;1].

[4] For detailed information see Marshall (1920), Arrow (1962), and Romer (1986).

specialization or diversity, we calculated the inverse value of the Herfindahl index based on the number of employees in the different industries as measure of industrial variety. Because the Herfindahl index can assume values between 1/*j* and 1 with *j* denoting the number of industries in the data, our measure of industrial variety ranges between 1 and *j*.

Table 1: Descriptive statistics (pooled yearly values)

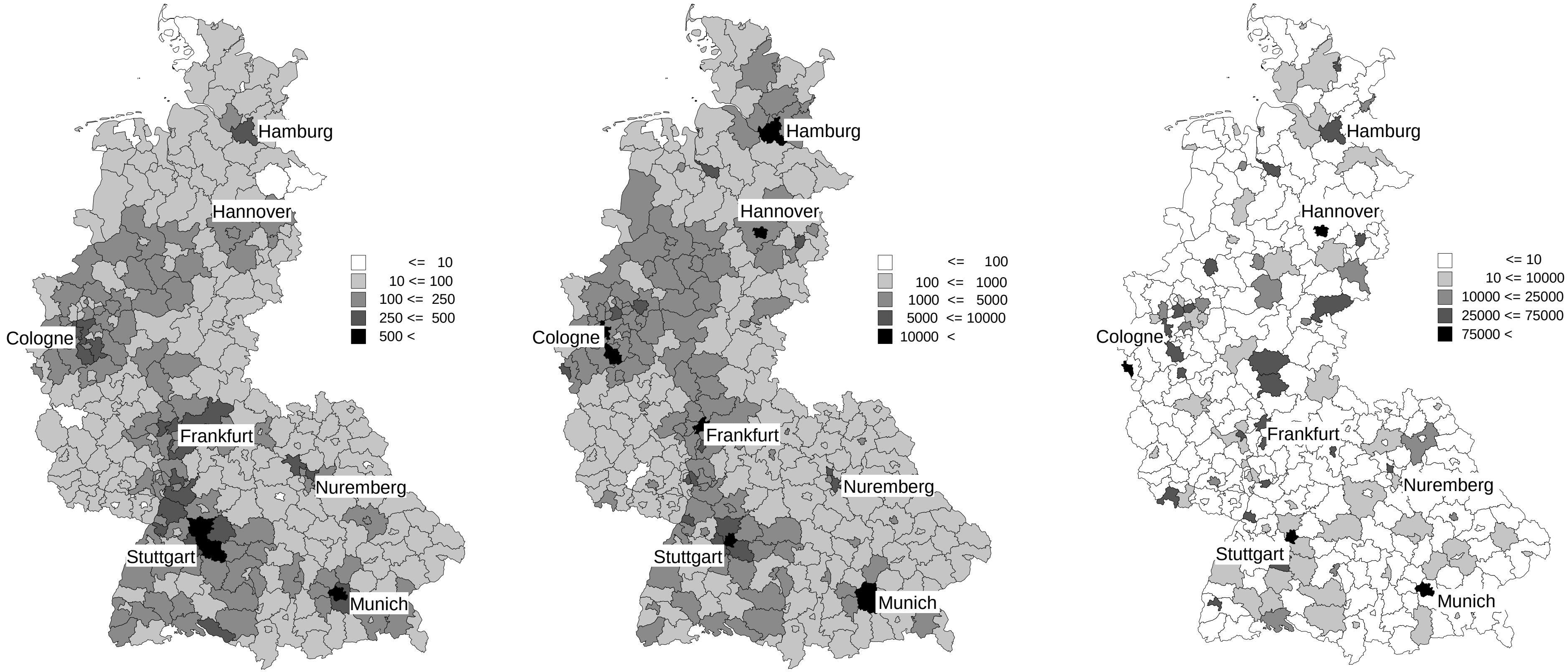
Variable	Mean	Std. Dev.	Min	Max	Median
No. of patents	96.13	116.14	2	1,470	61
No. of private sector R&D employees	1,745.28	3,267.21	60	35,254	659
Universities' regular funds	33,017.59	97,571.27	0	1,201,834	0
External research funds (total)	5,289.83	17,182.66	0	221,675.7	0
External funds from DFG	1,685.16	5,447.77	0	60,028.22	0
External funds from private firms	1,421.04	5,695.51	0	91,537.61	0
External funds from government departments	1,382.38	4,818.39	0	60,606.5	0
External funds from other Sources	605.21	2,028.04	0	24,550.19	0
Manufacturing specialization index	0.056	0.159	-0.439	0.433	0.07
Industrial diversity index	17.33	3.95	1.99	26.00	17.85

There is high dispersion of the different indicators among the regions (table 1). The large differences between the median and the mean values point to a rather skewed distribution of the respective variable. The yearly number of patents varies between two and 1,470 across the West German districts. Every region has at least one patent application. Not surprisingly, the number of patents tends to be relatively high in densely populated regions like the Rhine-Ruhr area and large cities such as Cologne, Frankfurt, Hamburg, Munich, and Stuttgart (figure 1). However, there is a concentration in the Southwest and in the Munich region with the cities of Munich and Stuttgart taking an unequivocal stand with 1,163 (3.7 percent of all German patents) and 554 (1.77 percent) average yearly patents in the 1995-2000 period.[5] As a

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

comparison, the number of patent applications in Spain in 1999 was 2,404 (cf. Gumbau-Albert, 2005).

Comparing the spatial distribution of the number of patents with the number of private sector R&D employees shows a considerable degree of correspondence, i.e. regions with a high number of R&D employees also tend to have a relatively high number of patents. Compared to R&D employment and patents, the external research funds of the universities are much more concentrated. This higher spatial concentration may have at least two reasons. First, universities are placed in less than half of the districts (155 out of the 327 in the year 2000, i.e. about 47 percent), while R&D employment can be found in each district. And second, most external R&D funds are allocated by a competitive procedure. External R&D funds indicate excellence and are, therefore, concentrated at those universities which have the highest quality of research. A number of regions with a high number of patents (e.g. the two extreme cases Munich and Stuttgart) are also characterized by a high level of private R&D input as well as large, high quality universities that attract great volumes of external research funds. However, there are also regions that attain a relatively high number of patents without having a university and with a 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. The picture is quite manifold. There is at least some innovation activity everywhere, and there is hardly any location that does not have a university within a 100 km distance.



Number of Patents

Number of private sector R&D employees

External research funds (in 1,000 Euro)

Figure 1: Spatial distribution of innovation input and output (average yearly values)

4. 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 targeted 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 efforts would lead to a doubling of innovative output. An elasticity value lower than one indicates a less than proportionate rise of innovative output with respect to the particular innovation input. Taking the natural logarithms of both sides and adding an index *t* for time (year) we get

(3) $ln\ (R\&D\ output)_{t} = ln\ a + b\ (ln\ R\&D\ input)_{t}.$

The coefficients of 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. Different estimated values of output elasticity *b* for the innovation inputs imply differences in the impact of the respective knowledge sources 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 the presence of knowledge spillovers between the regions.

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 & 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, the Poisson-regression analysis may be applied. However, we used the negative-binomial (negbin) regression because it is based on somewhat more general assumptions than the Poisson regression.[6] Due to the characteristics of the data set, panel estimation techniques may be applied to control for unobserved region-specific effects. Fixed effects estimates do not appear appropriate because the impact of those of the variables which exhibit only slight changes over time, may be wrongfully included in the fixed effects. Therefore, we focus our discussion on the random effects estimates but present fixed effects estimates in the Appendix. To prevent a priori exclusion of districts without universities, which causes a non-defined logarithm of zero, we add 10,000 Euros to all values of the variables for university related funds.

5. Results

Exploring the contribution of different broad categories of knowledge, we find the strongest impact on patenting of all knowledge sources for private sector R&D employment (table 2). The production elasticity of private sector R&D employment in the same region has an average value of about 0.4 while it is around 0.24 for private R&D resources in the adjacent

[6] The 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.

regions with an average distance up to 50 km, and 0.08 for the districts with an average distance between 50 and 75 km. Private sector R&D activity in more remote areas is not statistically significant or does not lead to plausible estimates. Hence, we conclude that the relevant private sector spillover sources are all located within a radius of about 75 km. Adding up the estimated coefficients for private R&D employment in and around a region, we arrive at an overall effect on patenting of about 0.74. This size of the effect is at the upper limit of results of previous research for other countries (table A1). Also, the spatial pattern of spillovers corresponds quite well to the findings for other countries (Anselin, Varga & Acs, 1997; Anselin, Varga & Acs, 2000). The highly significant positive coefficients for the manufacturing specialization index confirm the expected higher propensity to patent in manufacturing as compared to the service sector (table 2). The positive sign for the industrial diversity index and the negative sign for its squared value indicate a nonlinear relationship with regional patenting that has the shape of an inverse 'u'. This pattern suggests that a certain degree of specialization may be conducive to innovation activity. If, however, this industry concentration exceeds or falls below a certain level the effect of externalities becomes smaller. Obviously both extremes, broad diversity as well as narrow specialization, are relatively unfavorable for the performance of regional innovation systems. The estimation results suggest that a value of about 15.7 for the inverse Herfindahl index (0.06 of the 'regular' Herfindahl index) is most beneficial for innovation.[7]

It is rather remarkable that the size of the regular budget of universities has no significant effect on the regional number of patents. Obviously, the mere size of a university is not important for innovative output of a region. The same result can be attained if the number of scientific and teaching personnel at universities or the number of students or of graduates is taken as a measure of the size of academic research and education. Because there is a close statistical correlation between these indicators and the universities' regular budget, we do not include these alternative indicators in the regression at the same time in order to avoid multicollinearity problems (cf. table A2 in the Appendix). A positive impact on a regions'

[7] The values of the inverse Herfindahl index for the most innovative West German districts are Hamburg (18.06), Hanover (15.95), Frankfurt (14.26), Cologne (17.39), Stuttgart (16.45), Nuremberg (16.04), Munich (16.33). For details on the distribution of the inverse Herfindahl index see table 2.

innovative output can, however, be found for the amount of external funds that the universities 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 size. We also find a statistically significant impact of external research funds of universities in adjacent districts of an average distance of up to 50 km. External funds of more remote universities are not statistically significant.

Table 2: Determinants of the regional number of patents – results of multiple negbin regressions (panel, random effects) [+]

	(1)	(2)	(3)	(4)	(5)	(6)
R&D employment	0.388**	0.415**	0.414**	0.409**	0.382**	0.410*
	(13.58)	(15.32)	(14.21)	(14.50)	(14.40)	(15.87)
R&D employment 0-50km	0.181**	0.287**	0.216**	0.296**	0.214**	0.275**
	(4.92)	(8.29)	(5.80)	(8.28)	(7.26)	(9.50)
R&D employment 50-75km	0.084**	-0.014	0.076*	-0.019	0.083**	-0.010
	(2.63)	(0.46)	(2.42)	(0.63)	(2.65)	(0.34)
Manufacturing specialization index	1.046**	0.392*	1.031**	0.399*	1.026**	0.415**
	(5.75)	(2.44)	(5.62)	(2.46)	(5.80)	(2.59)
Industrial diversity index (Herfindahl	0.093**	0.020	0.104**	0.017	0.088**	0.030
inverse)	(3.58)	(0.81)	(4.05)	(0.72)	(3.43)	(1.27)
Industrial diversity index squared	-0.003**	-0.000	-0.003**	-0.000	-0.002**	-0.000
	(3.13)	(0.15)	(3.63)	(0.01)	(2.97)	(0.61)
All universities						
Regular funds (total)	-0.005	-0.006				
	(0.63)	(0.88)				
External funds (total)	0.027**	0.016				
	(2.65)	(1.88)				
External funds in surrounding districts 0-50km (total)	0.066**	0.025*				
	(5.27)	(2.45)				
Universities only						
Regular funds (total)			-0.024*	-0.009		
			(2.19)	(0.97)		
External funds (total)			0.030*	0.026*		
			(2.08)	(2.13)		
External funds in surrounding districts 0-50km (total)			0.034**	0.018		
			(3.08)	(1.84)		
Universities of Applied Sciences only						
Regular funds (total)					-0.002	-0.001
					(0.21)	(0.16)
External funds (total)					0.038**	0.026**
					(3.64)	(2.82)
External funds in surrounding districts 0-50km (total)					0.070**	0.044**
					(10.82)	(7.72)
Residual from surrounding districts 0-75km		0.967**		0.962**		0.967**
		(27.02)		(28.54)		(24.05)
Constant	-2.813**	-1.968**	-3.083**	-1.892**	-2.760**	-1.904**
	(7.40)	(5.39)	(8.09)	(5.04)	(7.51)	(5.33)
Observations	1962	1962	1962	1962	1962	1962
Number of district	327	327	327	327	327	327

[+] Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

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 in a distance of up to 75 km ($RESID_{75}$). The highly significant positive values of the respective coefficients indicate that neighboring regions have some influences in common, which are not included in the model.

Introducing the different sources of external funds into the model (table 3), we find some interesting results. For the Universities, the strongest effect is due to the external funds from the DFG. Funding of Universities from other external sources has no significant effect on a regions' innovative output (model 3 and 4 in table 3). Funds that the Universities of Applied Sciences attract from the DFG are also not significant while here the resources from private firms and from other sources (e.g. municipalities, foundations, international organizations, German Federal Labor Office) have a positive effect. These results point to different roles of the two types of universities in the innovation system. While the Universities focus on basic research, the main contribution of the Universities of Applied Sciences is the transformation of research results into commercial products. Models that do not distinguish between the two types of universities (model 1 and 2 in table 3) obviously show a mixture of these two patterns with an only slightly positive effect for external funds from private firms and from other sources. This indicates that it may be important to distinguish between the two types of universities.

Since the university data are available for different subject areas, we analyzed the importance of these subject areas for regional innovation output (table 4). Again, the amount of the regular funds allocated to the different subject areas is never statistically significant. A significant impact can mainly be found for the external funds in engineering and in human medicine. Surprisingly, a slight positive impact of external funds in linguistics, cultural science, law, economics etc. can be found in some of the models while external funds in natural science never had any impact.

Fixed effects estimates that are given in the Appendix confirm the results of the random effects estimates. A main differences is that variables with only relatively small changes over time (e.g. manufacturing specialization index or private sector R&D employment) have a lower impact here because parts of their effect is obviously included in the fixed effects.

Table 3: Research quality and regional innovativeness – results of multiple negbin regressions (panel, random effects) [+]

	(1)	(2)	(3)	(4)	(5)	(6)
R&D employment	0.391**	0.414**	0.425**	0.417**	0.397**	0.418**
	(13.81)	(15.31)	(14.79)	(15.01)	(15.15)	(16.29)
R&D employment 0-50km	0.185**	0.286**	0.218**	0.294**	0.215**	0.272**
	(5.04)	(8.30)	(5.86)	(8.27)	(7.35)	(9.48)
R&D employment 50-75km	0.075*	-0.016	0.069*	-0.020	0.082**	-0.006
	(2.35)	(0.52)	(2.18)	(0.67)	(2.62)	(0.19)
Manufacturing specialization index	1.081**	0.431**	0.980**	0.408*	1.028**	0.452**
	(5.94)	(2.68)	(5.36)	(2.51)	(5.86)	(2.83)
Industrial diversity index (Herfindahl inverse)	0.098**	0.021	0.107**	0.021	0.095**	0.037
	(3.78)	(0.86)	(4.16)	(0.89)	(3.73)	(1.52)
Industrial diversity index squared	-0.003**	-0.000	-0.003**	-0.000	-0.003**	-0.001
	(3.35)	(0.18)	(3.72)	(0.18)	(3.20)	(0.83)
All universities						
Regular funds (total)	-0.001	-0.003				
	(0.09)	(0.55)				
External funds from DFG	0.012	0.012				
	(1.21)	(1.48)				
External funds from private firms	0.016	0.002				
	(1.74)	(0.30)				
External funds from government departments	-0.022*	0.002				
	(2.54)	(0.27)				
External funds from other sources	0.027**	0.004				
	(2.79)	(0.52)				
External funds in surrounding districts 0-50km (total)	0.065**	0.025*				
	(5.21)	(2.39)				
Universities only						
Regular funds (total)			-0.012	-0.001		
			(1.30)	(0.07)		
External funds from DFG			0.068**	0.030*		
			(4.31)	(2.30)		
External funds from private firms			-0.011	0.005		
			(0.83)	(0.48)		
External funds from government departments			-0.050**	-0.013		
			(3.50)	(1.05)		
External funds from other sources			0.000	-0.014		
			(0.03)	(1.28)		
External funds in surrounding districts 0-50km (total)			0.032**	0.016		
			(2.94)	(1.64)		
Universities of Applied Sciences only						
Regular funds (total)					-0.005	-0.003
					(0.75)	(0.44)
External funds from DFG					0.014	-0.001
					(1.24)	(0.14)
External funds from private firms					0.043**	0.022**
					(5.03)	(2.87)
External funds from government departments					0.012	0.014*
					(1.43)	(1.98)
External funds from other sources					0.018*	0.013
					(2.15)	(1.78)
External funds in surrounding districts 0-50km (total)					0.067**	0.044**
					(10.46)	(7.70)
Residual from surrounding districts 0-75km		0.979**		0.969**		0.962**
		(26.61)		(28.13)		(22.95)
Constant	-2.803**	-1.937**	-3.094**	-1.926**	-2.884**	-1.997**
	(7.36)	(5.31)	(8.13)	(5.15)	(7.85)	(5.61)
Observations	1962	1962	1962	1962	1962	1962
Number of district	327	327	327	327	327	327

[+] Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

Table 4: Research subjects and regional innovativeness – results of multiple negbin regressions (panel, random effects) [+]

	(1)	(2)	(3)	(4)
R&D employment	0.373**	0.412**	0.385**	0.418**
	(12.00)	(14.26)	(12.53)	(14.59)
R&D employment 0-50km	0.141**	0.256**	0.179**	0.287**
	(3.61)	(7.05)	(4.89)	(8.33)
R&D employment 50-75km	0.089**	-0.005	0.083**	-0.012
	(2.75)	(0.18)	(2.60)	(0.41)
Manufacturing specialization index	1.132**	0.422*	1.106**	0.418*
	(6.08)	(2.58)	(5.94)	(2.56)
Industrial diversity index (Herfindahl inverse)	0.098**	0.030	0.095**	0.023
	(3.76)	(1.27)	(3.67)	(0.95)
Industrial diversity index squared	-0.003**	-0.000	-0.003**	-0.000
	(3.31)	(0.54)	(3.18)	(0.24)
Universities' regular funds				
Natural science	-0.006	-0.007	-0.004	-0.007
	(0.47)	(0.70)	(0.33)	(0.65)
Engineering	-0.011	-0.007	-0.012	-0.007
	(1.14)	(0.77)	(1.19)	(0.78)
Human medicine	-0.000	-0.002	0.000	-0.001
	(0.06)	(0.45)	(0.02)	(0.29)
Linguistics, Cultural science, Sports, Law, Economics, Social science, Veterinary medicine, Agricultural and Nutritional science, Forestry, Arts	0.001	-0.008	0.002	-0.008
	(0.15)	(1.04)	(0.25)	(1.03)
Universities' external funds				
Natural science	0.006	0.013	0.000	0.015
	(0.55)	(1.49)	(0.02)	(1.69)
Engineering	0.030*	0.017	0.029*	0.015
	(2.52)	(1.65)	(2.39)	(1.50)
Human medicine	0.019	0.011	0.021*	0.003
	(1.80)	(1.25)	(2.08)	(0.34)
Linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural and nutritional science, forestry, arts	0.017	0.018*	0.015	0.015
	(1.63)	(2.06)	(1.48)	(1.66)
Universities' external funds 0-50km				
Total			0.067**	0.024*
			(5.27)	(2.34)
Natural science	-0.011	0.003		
	(1.35)	(0.49)		
Engineering	0.026**	0.013		
	(2.82)	(1.61)		
Human medicine	0.026**	0.007		
	(4.52)	(1.38)		
Linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural and nutritional science, forestry, arts	0.044**	0.015		
	(3.68)	(1.51)		
Residual from surrounding districts 0-75km		0.982**		0.973**
		(26.77)		(27.19)
Constant	-2.320**	-1.800**	-2.806**	-2.008**
	(5.68)	(4.64)	(7.31)	(5.48)
Observations	1962	1962	1962	1962
Number of district	327	327	327	327

[+] Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

6. Summary and conclusions

Our analysis of the effect of different knowledge sources on innovative output showed that regional knowledge has a dominant impact. The highest share of innovative output as measured by the number of patents is explained by private sector R&D employment in the same region. Knowledge of private sector R&D employees in adjacent regions is much less important and its effect becomes weaker with increasing distance. Compared to private sector R&D, the contribution of the universities is rather small: it is smaller than what was found in most of the comparable studies for the US (table A1). Our analysis shows that 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 as a measure for the quality of the research. A policy that aims at improving the regional knowledge base should, therefore, focus on excellence of research, not on the number of students or other indicators of size. Comparing the different types of external funds, there are pronounced differences between the Universities and the Universities of Applied Sciences that reflect their role in the regional innovation system. While for the Universities the resources from the DFG play an important role, we find that the strongest effect for the Universities of Applied Sciences stems from funds of private firms. The most important subject areas for regional innovation output are engineering and human medicine.

Accounting for industrial concentration in a region, we found indications that an optimal level of diversity exists. Therefore, both the Marshall-Arrow-Romer as well as Jacobs-externalities may play some role. Compared to studies for the USA, the importance of university knowledge for innovative output seems to be relatively low in West Germany as the estimated coefficients are at the lower range of comparative values. This raises the question concerning the reasons for the relatively weak impact of German universities that has to be answered by future research.

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Appendix

Table A1: 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	0.74	0.1

* significant at 5%; ** significant at 1%.

Table A2: Correlation between main variables

	Ln of …	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	No. of Patents	1.00																										
2	R&D$_{PRIV}$	0.73	1.00																									
3	R&D$_{PRIV}$ 0-50km	0.57	0.41	1.00																								
4	R&D$_{PRIV}$ 50-75km	0.28	0.25	0.44	1.00																							
5	MSI	0.19	-0.02	0.06	0.12	1.00																						
6	HERF$_{INV}$ *	0.16	-0.08	0.03	0.09	0.17	1.00																					
7	HERF$_{INV}^{2}$ *	0.19	-0.06	0.03	0.10	0.27	0.98	1.00																				
8	Clinic dummy *	0.24	0.44	0.05	0.05	-0.30	-0.22	-0.24	1.00																			
9	URF$_{TOTAL}$	0.27	0.55	0.06	0.11	-0.26	-0.12	-0.13	0.55	1.00																		
10	ERF$_{TOTAL}$	0.26	0.58	0.04	0.06	-0.32	-0.16	-0.18	0.64	0.90	1.00																	
11	ERF$_{DFG}$	0.29	0.56	0.06	0.05	-0.32	-0.16	-0.18	0.69	0.78	0.91	1.000																
12	ERF$_{IND}$	0.27	0.58	0.03	0.07	-0.33	-0.19	-0.22	0.67	0.83	0.93	0.92	1.00															
13	ERF$_{PUB}$	0.28	0.56	0.07	0.05	-0.32	-0.15	-0.17	0.67	0.81	0.93	0.95	0.92	1.00														
14	ERF$_{OTHER}$	0.26	0.55	0.05	0.08	-0.32	-0.14	-0.16	0.63	0.85	0.94	0.92	0.90	0.93	1.00													
15	URF$_{NATURAL\ SCIENCE}$	0.29	0.57	0.06	0.08	-0.28	-0.13	-0.15	0.59	0.86	0.92	0.90	0.87	0.89	0.91	1.00												
16	URF$_{ENGINEERING}$	0.26	0.57	0.04	0.10	-0.25	-0.10	-0.11	0.45	0.85	0.83	0.73	0.81	0.76	0.77	0.80	1.00											
17	URF$_{MEDICINE}$	0.22	0.40	-0.00	0.02	-0.28	-0.20	-0.21	0.86	0.51	0.60	0.65	0.63	0.63	0.58	0.57	0.44	1.00										
28	URF$_{OTHER}$	0.27	0.55	0.06	0.12	-0.27	-0.11	-0.13	0.51	0.97	0.89	0.78	0.83	0.80	0.85	0.86	0.80	0.49	1.00									
19	ERF$_{NATURAL\ SCIENCE}$	0.27	0.56	0.06	0.05	-0.32	-0.18	-0.20	0.68	0.78	0.90	0.95	0.91	0.92	0.90	0.92	0.73	0.63	0.78	1.00								
20	ERF$_{ENGINEERING}$	0.25	0.54	0.07	0.06	-0.25	-0.12	-0.13	0.39	0.68	0.78	0.76	0.78	0.78	0.75	0.74	0.81	0.35	0.65	0.77	1.00							
21	ERF$_{MEDICINE}$	0.25	0.44	0.05	0.06	-0.33	-0.21	-0.23	0.93	0.54	0.64	0.69	0.68	0.68	0.64	0.61	0.46	0.89	0.52	0.68	0.40	1.00						
22	ERF$_{OTHER}$	0.28	0.57	0.06	0.04	-0.34	-0.16	-0.18	0.63	0.82	0.93	0.90	0.89	0.90	0.91	0.87	0.73	0.60	0.84	0.90	0.72	0.64	1.00					
23	ERF$_{TOTAL}$ 0-50km	0.31	0.16	0.74	0.17	0.07	0.04	0.02	-0.11	-0.16	-0.18	-0.12	-0.17	-0.12	-0.15	-0.15	-0.17	-0.17	-0.16	-0.12	-0.09	-0.13	-0.11	1.00				
24	ERF$_{NAT.\ SCIENCE}$ 0-50km	0.32	0.17	0.73	0.16	0.08	0.05	0.03	-0.10	-0.12	-0.14	-0.10	-0.12	-0.10	-0.12	-0.11	-0.13	-0.17	-0.12	-0.09	-0.07	-0.13	-0.07	0.90	1.00			
25	ERF$_{ENGINEERING}$ 0-50km	0.30	0.20	0.78	0.21	0.04	-0.04	-0.05	-0.06	-0.08	-0.12	-0.10	-0.12	-0.10	-0.10	-0.11	-0.13	-0.10	-0.08	-0.10	-0.09	-0.08	-0.08	0.78	0.77	1.00		
26	ERF$_{MEDICINE}$ 0-50km	0.39	0.22	0.70	0.21	0.05	0.08	0.07	-0.07	-0.07	-0.10	-0.09	-0.11	-0.09	-0.08	-0.08	-0.07	-0.13	-0.07	-0.09	-0.06	-0.08	-0.05	0.67	0.68	0.53	1.00	
27	ERF$_{OTHER}$ 0-50km	0.31	0.19	0.71	0.16	0.06	0.06	0.04	-0.05	-0.10	-0.11	-0.08	-0.11	-0.06	-0.10	-0.09	-0.11	-0.12	-0.10	-0.07	-0.04	-0.08	-0.05	0.91	0.89	0.74	0.62	1.00

* not logarithmized.

Table A3: Determinants of the regional number of patents – results of multiple negbin regressions (panel, fixed effects) [+]

	(1)	(2)	(3)	(4)	(5)	(6)
R&D employment	0.196**	0.168**	0.227**	0.150**	0.174**	0.148**
	(4.95)	(3.98)	(5.31)	(3.40)	(4.59)	(3.45)
R&D employment 0-50km	0.140*	0.397**	0.117	0.334**	0.239**	0.386**
	(2.32)	(5.47)	(1.88)	(4.33)	(4.34)	(5.56)
R&D employment 50-75km	0.299**	0.180*	0.308**	0.131	0.329**	0.166*
	(4.85)	(2.32)	(5.03)	(1.61)	(5.32)	(2.13)
Manufacturing specialization index	0.365	-0.143	0.507	-0.080	0.377	-0.120
	(1.20)	(0.55)	(1.66)	(0.31)	(1.24)	(0.45)
Industrial diversity index (Herfindahl inverse)	0.087**	0.003	0.109**	0.003	0.078*	0.013
	(2.64)	(0.08)	(3.24)	(0.08)	(2.35)	(0.39)
Industrial diversity index squared	-0.003**	-0.000	-0.004**	-0.000	-0.003**	-0.000
	(2.92)	(0.15)	(3.55)	(0.08)	(2.74)	(0.48)
All universities						
Regular funds (total)	0.000	-0.002				
	(0.05)	(0.25)				
External funds (total)	0.030**	0.020*				
	(2.63)	(2.06)				
External funds in surrounding districts 0-50km (total)	0.125**	0.050**				
	(7.52)	(3.69)				
Universities only						
Regular funds (total)			-0.026*	-0.010		
			(2.08)	(0.87)		
External funds (total)			0.029	0.039*		
			(1.61)	(2.53)		
External funds in surrounding districts 0-50km (total)			0.100**	0.053**		
			(6.32)	(3.81)		
Universities of Applied Sciences only						
Regular funds (total)					0.005	0.006
					(0.68)	(0.86)
External funds (total)					0.041**	0.024*
					(3.73)	(2.45)
External funds in surrounding districts 0-50km (total)					0.076**	0.051**
					(11.50)	(8.45)
Residual from surrounding districts 0-75km		0.982**		0.987**		0.978**
		(23.71)		(25.48)		(21.97)
Constant	-3.250**	-2.776**	-3.263**	-1.602	-3.542**	-2.261**
	(4.74)	(3.54)	(4.78)	(1.91)	(5.19)	(2.87)
Observations	1962	1962	1962	1962	1962	1962
Number of district	327	327	327	327	327	327

[+] Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

Table A4: Research quality and regional innovativeness – results of multiple negbin regressions (panel, fixed effects) [+]

	(1)	(2)	(3)	(4)	(5)	(6)
R&D employment	0.204**	0.164**	0.243**	0.163**	0.202**	0.161**
	(5.15)	(3.85)	(5.80)	(3.70)	(5.26)	(3.74)
R&D employment 0-50km	0.142*	0.377**	0.110	0.308**	0.241**	0.374**
	(2.36)	(5.23)	(1.78)	(4.03)	(4.33)	(5.40)
R&D employment 50-75km	0.284**	0.175*	0.293**	0.131	0.341**	0.188*
	(4.58)	(2.25)	(4.76)	(1.61)	(5.45)	(2.42)
Manufacturing specialization index	0.431	-0.057	0.437	-0.047	0.393	-0.062
	(1.43)	(0.22)	(1.44)	(0.18)	(1.32)	(0.23)
Industrial diversity index (Herfindahl inverse)	0.093**	0.002	0.117**	0.008	0.089**	0.020
	(2.82)	(0.07)	(3.51)	(0.23)	(2.70)	(0.62)
Industrial diversity index squared	-0.003**	-0.000	-0.004**	-0.000	-0.003**	-0.001
	(3.12)	(0.12)	(3.76)	(0.24)	(3.01)	(0.69)
All universities						
Regular funds (total)	0.006	0.002				
	(0.84)	(0.36)				
External funds from DFG	0.011	0.011				
	(1.03)	(1.31)				
External funds from private firms	0.016	0.001				
	(1.73)	(0.17)				
External funds from government departments	-0.018*	0.005				
	(2.05)	(0.68)				
External funds from other sources	0.024*	0.001				
	(2.40)	(0.11)				
External funds in surrounding districts 0-50km (total)	0.124**	0.051**				
	(7.49)	(3.72)				
Universities only						
Regular funds (total)			-0.020	-0.007		
			(1.64)	(0.60)		
External funds from DFG			0.063**	0.033*		
			(3.73)	(2.37)		
External funds from private firms			-0.012	-0.000		
			(0.85)	(0.03)		
External funds from government departments			-0.045**	-0.009		
			(2.93)	(0.70)		
External funds from other sources			0.000	-0.014		
			(0.01)	(1.20)		
External funds in surrounding districts 0-50km (total)			0.098**	0.050**		
			(6.24)	(3.59)		
Universities of Applied Sciences only						
Regular funds (total)					0.004	0.006
					(0.55)	(0.91)
External funds from DFG					0.011	-0.002
					(0.95)	(0.20)
External funds from private firms					0.041**	0.019*
					(4.72)	(2.37)
External funds from government departments					0.010	0.011
					(1.24)	(1.53)
External funds from other sources					0.017*	0.011
					(2.03)	(1.36)
External funds in surrounding districts 0-50km (total)					0.073**	0.051**
					(11.13)	(8.41)
Residual from surrounding districts 0-75km		1.002**		0.999**		0.977**
		(23.32)		(25.28)		(20.91)
Constant	-3.220**	-2.536**	-3.214**	-1.436	-3.925**	-2.487**
	(4.67)	(3.24)	(4.68)	(1.73)	(5.66)	(3.15)
Observations	1962	1962	1962	1962	1962	1962
Number of district	327	327	327	327	327	327

[+] Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

Table A5: Research subjects and regional innovativeness – results of multiple negbin regressions (panel, fixed effects) +

	(1)	(2)	(3)	(4)
R&D employment	0.149**	0.148**	0.179**	0.174**
	(3.48)	(3.32)	(4.24)	(3.98)
R&D employment 0-50km	0.112	0.324**	0.141*	0.393**
	(1.83)	(4.40)	(2.33)	(5.39)
R&D employment 50-75km	0.314**	0.136	0.312**	0.187*
	(5.01)	(1.74)	(5.01)	(2.40)
Manufacturing specialization index	0.552	-0.064	0.465	-0.116
	(1.84)	(0.25)	(1.52)	(0.44)
Industrial diversity index (Herfindahl inverse)	0.085*	0.025	0.087**	0.008
	(2.56)	(0.79)	(2.62)	(0.26)
Industrial diversity index squared	-0.003**	-0.001	-0.003**	-0.000
	(2.93)	(0.80)	(2.92)	(0.31)
Universities' regular funds				
Natural science	0.009	-0.002	0.010	-0.001
	(0.64)	(0.13)	(0.77)	(0.12)
Engineering	0.001	0.003	-0.000	0.002
	(0.10)	(0.32)	(0.01)	(0.23)
Human medicine	-0.003	-0.005	-0.003	-0.005
	(0.58)	(1.00)	(0.46)	(0.90)
Linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural and nutritional science, forestry, arts	-0.001	-0.006	-0.002	-0.007
	(0.06)	(0.75)	(0.21)	(0.87)
Universities' external funds				
Natural science	0.015	0.021	0.008	0.018
	(1.23)	(1.95)	(0.63)	(1.69)
Engineering	0.029*	0.012	0.032*	0.011
	(2.31)	(1.05)	(2.49)	(0.98)
Human medicine	0.009	0.003	0.014	-0.005
	(0.72)	(0.29)	(1.20)	(0.47)
Linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural and nutritional science, forestry, arts	0.021*	0.023*	0.015	0.016
	(1.98)	(2.52)	(1.41)	(1.73)
Universities' external funds 0-50km				
Total			0.128**	0.050**
			(7.74)	(3.69)
Natural science	-0.006	0.008		
	(0.73)	(1.10)		
Engineering	0.050**	0.032**		
	(4.77)	(3.37)		
Human medicine	0.026**	0.009		
	(4.22)	(1.70)		
Linguistics, cultural science, sports, law, economics, social science, veterinary medicine, agricultural and nutritional science, forestry, arts	0.068**	0.029*		
	(5.09)	(2.56)		
Residual from surrounding districts 0-75km		1.003**		0.992**
		(23.13)		(23.38)
Constant	-2.535**	-1.718*	-3.296**	-2.864**
	(3.51)	(2.08)	(4.75)	(3.63)
Observations	1962	1962	1962	1962
Number of district	327	327	327	327

+ Absolute value of z-statistics in parentheses. * significant at 5%; ** significant at 1%.

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