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Universities and Innovation in Space

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ABSTRACT We investigate the role of universities as a knowledge source for regional innovation processes. The contribution of universities is tested on the level of German NUTS-3 regions (*Kreise*) by using a variety of indicators. We find that the intensity and quality of the research conducted by the universities have a significant effect on regional innovative output while pure size is unimportant. Therefore, a policy that wants to promote regional innovation processes by building up universities should place substantial emphasis on the intensity and quality of the research conducted there. We also find the effects of universities to be concentrated in space. Obviously, the geographical proximity to particular knowledge sources is important for regional innovative activities.

KEY WORDS: Universities, innovation, knowledge, spillovers, patents, regional analysis

1. Introduction

Academic institutions for education and research are assumed to be a key element of regional innovation systems. There are many different ways in which they may have an effect on economic activities. However, the main element of these mechanisms seems to always be the same: academic institutions contribute to the performance of the innovation system by generating and diffusing knowledge. Policy has frequently adopted this view and has used the establishment of academic institutions as a means to promote regional innovation processes and stimulate economic growth. However, our knowledge about the role of academic institutions in innovation systems is still quite fragmentary and can only provide insufficient guidance for policy.

In this paper, we analyze the effect of universities on regional innovative output in West Germany. We are able to build on a rich dataset which provides a variety of indicators for

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the size of universities[1] as well as for the intensity and quality of their research and development (R&D) activities. Based on a review of possible contributions of universities to innovation processes (Section 2), we investigate their spatial distribution and their relationship with private sector R&D (Section 3). Section 4 discusses the measurement issue based on the framework of a knowledge production function. The contribution of universities is then analyzed in Section 5. Concluding, the results are summarized in the final section (Section 6).

2. The Role of Academic Institutions in the (Regional) Innovation System

It can hardly be disputed that scientific knowledge can play an essential role for innovation and economic development. Two main sources of such knowledge may be distinguished, namely, university R&D and R&D conducted by private sector firms (Nelson, 1993; Edquist, 1997). Both knowledge sources are, however, of a quite distinct nature.

Universities are assumed to accomplish a number of different functions in a regional innovation system. By conducting R&D activities, they generate and accumulate knowledge.[2] However, because of the predominantly generic nature of this knowledge and the non-profit orientation of universities, they may not be able or even interested in commercializing the results of their R&D directly. Despite its basic character, the academic knowledge may be an important input for private sector innovative activity and may induce further private R&D activities (Jaffe, 1989). One can, therefore, expect that the effect of university R&D on economic development is more indirect in nature than industrial R&D, which is mainly directed towards commercial ends, striving to apply knowledge, and transforming it into marketable products or production technologies. Due to such indirect effects of universities on the output of the innovation system, an assessment of their relative importance is a rather difficult task. Taking, for example, the share of patents held by academic institutions may severely underestimate their contribution to the innovative output of the whole innovation system.[3]

One important channel for the transfer of academic knowledge into the private sector is the teaching and training of students, which increases the qualification of the labor force. This may also strengthen the absorptive capacity of the private sector and lead to improved innovative performance.[4] Academic knowledge can also disseminate through R&D cooperation with private sector firms or by providing innovation-related services

[1] Universities here also include the German *Fachhochschulen* (Universities of Applied Sciences) which provide undergraduate education mainly in engineering and in management. The level of research at the *Fachhochschulen* is relatively low and predominantly for practical purposes.

[2] See Mansfield (1995), Beise and Stahl (1999), Blind and Grupp (1999) and Hall *et al.* (2003). Knowledge flows between universities and private sector firms may be in both directions: from the universities to the private sector and vice versa (Kline and Rosenberg, 1986). Hence, private sector R&D can constitute an important input for university R&D (Blind and Grupp, 1999; Nedeva *et al.*, 1999; Schartinger *et al.*, 2001).

[3] According to Greif and Schmiedl (2002), only about 4 percent of the West German patent applications between 1995 and 2000 can be directly traced to academic institutions. This figure, however, underestimates the number of patents generated in academic institutions due to the fact that until 2002 inventors working in German universities were entitled to freely control the rights of their inventions. Hence, the greater majority of patents from academic research were officially attributed to private individuals.

[4] See Nelson and Phelps (1966), Cohen and Levinthal (1990) and Siegel *et al.* (2004).

(Mansfield and Lee, 1996). Moreover, universities may serve as an "incubator" for knowledge intensive spin-offs.[5] Scientific publications, seminars, workshops and informal relationships can also be important ways of transfer of academic knowledge to the private sector.

The strength of a university's impact on innovative performance of private sector firms may differ considerably according to the quality of their research and to the intensity in which they interact with other actors in the regional and national innovation system (e.g. Mansfield and Lee, 1996; Feldman and Desrochers, 2003). Therefore, the mere presence of a university seems to be in no way a guarantee for a significant contribution to the performance of an innovation system. Thus far, our knowledge about the factors that determine the impact of universities in innovation systems and the different functions they may accomplish is rather incomplete.

In order to capture the effects of academic institutions on innovative output, Griliches (1979) introduced the concept of a knowledge production function (see Section 4 for details). Based on this concept, Jaffe (1989) found a significantly positive contribution of university R&D to private sector innovative output as indicated by corporate patents at the US-state level. Based on innovation count data from the US Small Business Administration, Acs *et al.* (1991) and Feldman (1994) identified an even stronger impact of university research on regional innovative output. A number of empirical studies that analyzed the impact of universities on regional innovative output in European countries are in line with the results for the USA.[6] Licht and Zoz (1998) and Becker (2003) confirmed the importance of academic knowledge for private sector innovative activities in Germany. However, since the unit of investigation in these two studies was the firm, activities of multi-plant firms cannot be unambiguously assigned to certain regions; thus, the spatial dimension of university R&D is not adequately accounted for. Blind and Grupp (1999) found a strong impact of universities' R&D as indicated by the number of universities' patents on private sector patenting activities in different industries with the example of two West German NUTS-1 regions (*Länder*). In general, the empirical evidence shows that the contribution of universities to private sector R&D is largely limited to the university's vicinity indicating the significant importance of space.

Obviously, academic knowledge tends to be spatially bounded so that knowledge spillovers between actors which are located in different regions may be seriously constrained. The obvious reason for such constraints of transferring academic knowledge is that part of this knowledge is tacit in nature (Polanyi, 1967). Transmission of such tacit knowledge requires particular channels and media—often frequent face-to-face contact—and becomes increasingly costly with geographical distance (von Hippel, 1994). Therefore, spatial proximity can be rather conducive to communicating of academic knowledge (Audretsch, 1998; Krugman, 1998). Another reason for the spatial limitations to communication of certain types of academic knowledge may be caused by the fact that scientists and graduates who are leaving the universities tend to work in places which are

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[5] See Audretsch and Stephan (1996, 1999), Meyer-Krahmer and Schmoch (1998), Zucker and Brewer (1998), Feldman (2001) and Markman *et al.* (2004).

[6] See, for example, Andersson and Ejermo (2004) for Sweden; Fischer and Varga (2003) for Austria; Piergiovanni and Santarelli (2001), Ronde and Hussler (2005) as well as Autand-Bernard (2001) for France; Barrio-Castro and Garcia-Quevedo (2005) for Spain; and Piergiovanni *et al.* (1997) for Italy.

located in close proximity to their academic origin (Jaffe, 1989). Analyzing location decisions of newly founded innovative firms in Germany, Bade and Nerlinger (2000), Audretsch *et al.* (2004) and Audretsch and Lehmann (2005) found that spatial proximity to universities obviously plays a significant role. This suggests that these firms try to capture localized knowledge spillovers through the choice of their location.

With regard to the spatial scope of knowledge spillovers from academic institutions, Anselin *et al.* (1997, 2000) and Acs *et al.* (2002) found that in the USA the significant effects of university R&D on innovation output of private sector firms are limited to a distance of about 75 miles. Autant-Bernard (2001) analyzed the geographical dimension of knowledge spillovers from public research in France at the level of NUTS-3 regions by using the number of scientific publications. According to this study, sources located outside the region have only a relatively weak effect on regional innovation output. Based on about 2,300 responses to a postal questionnaire, Beise and Stahl (1999) found the impact of public research institutions in Germany on corporate innovations to be concentrated in spatial proximity to the respective source. More than half of the firms that had introduced university-based innovations were located at a distance of up to 100 km from the particular knowledge source. According to an innovation survey in selected European regions, most of the private sector cooperation partners of universities are located at relatively close distance (Fritsch, 2003, 2005). Assuming that a cooperative relationship between universities and private sector firms serves as a vehicle for spillovers, this finding also supports the limited spatial scope of academic knowledge.[7]

As a tentative conclusion from the theory and the available empirical evidence, we can state that the amount of local R&D input as well as spatially bounded knowledge spillovers may cause pronounced differences in regional innovative performance. As a result, innovative activities can be expected to be unevenly distributed over space and concentrated in locations with a relatively rich knowledge base.

3. Spatial Distribution of Academic Institutions, Private Sector R&D and Regional Patent Output

Our measure for innovative output is based on the number of regional patent applications in the years 1995–2000 which is taken from the database of the German Patent Office (*Deutsches Patent- und Markenamt*) as published in Greif and Schmiedl (2002). A number of limitations of the number of patents as a measure of the regional innovative output should be mentioned. First, patents reflect an invention which is not necessarily transformed into an innovation (new product or new production technology) that is introduced in the market. Second, since there are other possibilities to appropriate the benefits of an invention (cf. Cohen *et al.*, 2000), the number of patents may underestimate the innovative output. Third, since universities are focused on basic research that produces results which cannot be patented, the number of patents may capture the university's impact on innovative output rather incompletely. Furthermore, the patent applications in our data are assigned to the

[7] Peri (2005) analyzed the geographical dimension of knowledge flows by using patent citations across regions in Europe and North America. He found that on the average only about 20 percent of the newly generated knowledge spills over to locations outside the region of origin and only 9 percent cross the country's border. This study was, however, not limited to academic knowledge.

residence of inventors. If the inventor's place of employment and the place of residence are not located in the same district, the spatial distribution of innovative output may be distorted to a certain degree (Deyle and Grupp, 2005). Since R&D facilities tend to be located in the center, the innovative output of large cities may be underestimated if R&D employees reside in a surrounding district. Accordingly, the level of innovation output of these surrounding districts, as provided by the number of patents, may be somewhat overrated.

The distribution of innovative output across West German NUTS-3 regions[8] (Table 1 and Figure 1) clearly shows an uneven spread. The large difference between the median and the mean values results in a rather skewed distribution. The yearly number of patents varies between two in rural regions located southeast of Hamburg and 1,470 in the city of Munich. Not surprisingly, the number of patents tends to be relatively high in agglomeration areas such as Cologne, Frankfurt, Hamburg, Munich and Stuttgart (Figure 1). However, there is a remarkable concentration in southwestern Germany and in the Munich region.[9]

As an indicator of private sector R&D, we use the number of R&D employees in that sector. Employees are assumed to work in R&D if they have a tertiary degree in engineering or in natural sciences. The information on R&D employment is taken from the German Social Insurance Statistics (*Statistik der sozialversicherungspflichtig Beschäftigten*).[10] Comparing the spatial distribution of the number of patents with the number of private sector R&D employees shows a considerable degree of correspondence. At the level of German districts, the Pearson correlation coefficient between the number of patents and the number of private sector R&D employees is 0.73, indicating that regions with a high number of R&D employees also tend to have a relatively large number of patents.

The university-related indicators used here are the universities' regular funds (*URF*) and the universities' research funds gained from external sources (*ERF*). The data on universities were taken from the German University Statistics available at the German Federal Statistical Office. Universities' regular funds are resources for teaching and training but also for various kinds of equipment which indicate their mere size. Since the allocation of university regular funds in Germany is largely based on the number of students and personnel, these resources are concentrated to about the same degree in space as the number of the universities' scientific and teaching personnel. The amount of external research funds comprises resources attracted from private sector firms, from the German Science Foundation (DFG), from government departments as well as from other institutions such as municipalities, foundations, international organizations, etc. Such external funds are predominantly allocated by means of highly competitive procedures. Hence, they indicate high intensity and quality of research.[11] This is, particularly, true for external funds from the German Science Foundation which are designated to basic research. Funds from private firms signify university–industry linkages that may result in relatively pronounced

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[8] German NUTS-3 regions coincide with districts (*Kreise*).

[9] For a detailed description of the regional distribution of innovative input and output see Greif and Schmiedl (2002) and Fritsch and Slavtchev (2005).

[10] For a detailed description see Fritsch and Brixy (2004).

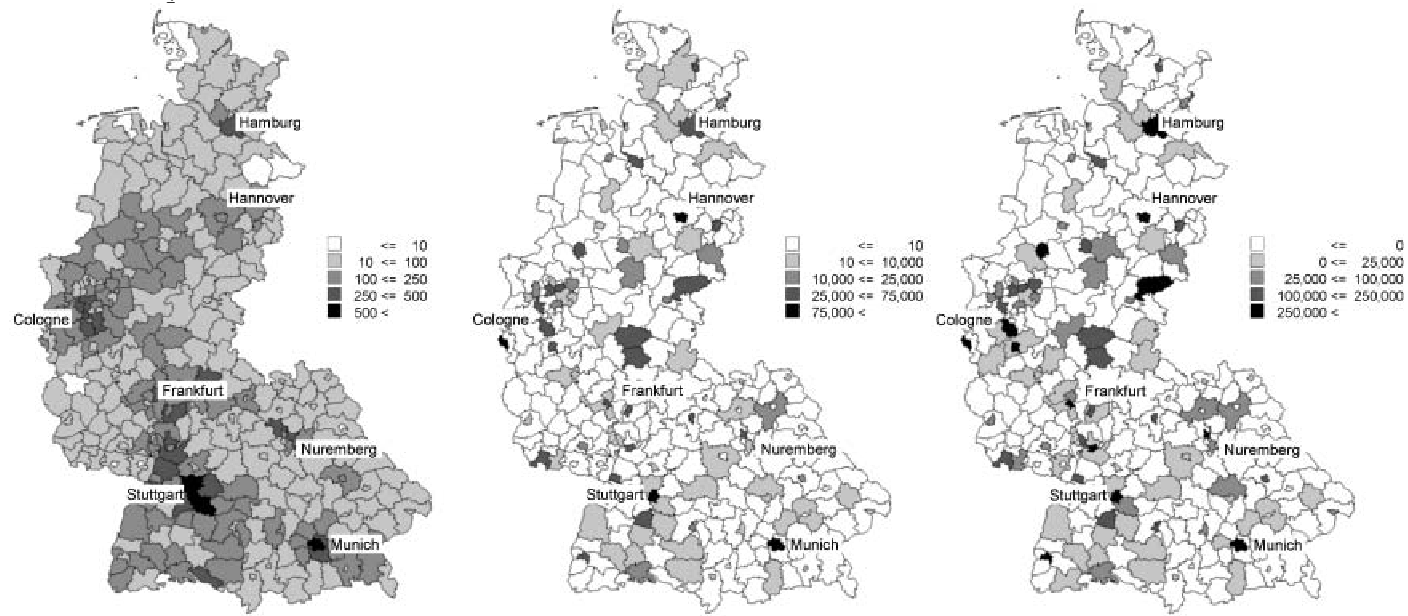
[11] According to Hornbostel (2001), there is a pronounced correspondence between indicators that are based on external research funds and bibliometric indicators for high quality research such as SCI publications.

Table 1. Descriptive statistics (pooled yearly values)

Variable	Mean	Std. dev.	Minimum	Maximum	Median	Gini[a]	*PAT*[b]	RD_{PRIV}[b]	*URF*[b]	*ERF*[b]	*MSI*	*POP*[b]
No. of patents (*PAT*)	96.13	116.14	2	1,470	61	0.50	1.00					
No. of private sector R&D employees (RD_{PRIV})	1,745.28	3,267.21	60	35,254	659	0.63	0.73	1.00				
Universities' regular funds (*URF*)	33,017.59	97,571.27	0	1,201,834	0	0.89	0.27	0.55	1.00			
External research funds (*ERF*)	5,289.83	17,182.66	0	221,675.7	0	0.91	0.26	0.58	0.90	1.00		
Manufacturing specialization index (*MSI*)	0.056	0.159	−0.439	0.433	0.07	–	0.19	−0.02	−0.26	−0.32	1.00	
Population (*POP*)	195,551.3	164,524.8	35,400	1,708,000	145,450	–	0.72	0.75	0.35	0.34	−0.06	1.00
Industrial concentration index (*ICI*)	0.753	0.029	0.694	0.902	0.751	–	−0.16	−0.11	−0.15	−0.13	0.13	−0.30

[a]Donaldson–Weymark relative S-Gini inequality measure. The Gini coefficients for the number of university graduates and for the number of university scientific and teaching personnel are 0.84 and 0.88, respectively.

[b]Pearson's correlation coefficients of the logarithmic values.



Number of patents | University regular funds (in 10,000 Euro) | University external research funds (in 10,000 Euro)

Figure 1. Spatial distribution of innovative input and output (average yearly values)

knowledge spillovers.[12] Thus, external R&D funds indicate high quality of research (see Fritsch and Slavtchev, 2005). Since universities differ with regard to the quality of their research, the geographical concentration of their external R&D funds should be more pronounced than the concentration of their regular funds. The Lorenz curves in Figure 2 as well as the Gini coefficients in Table 1 confirm this expectation.

The Lorenz curves for different measures of innovation activity and the respective Gini coefficients show a relatively high degree of concentration for the variables which are related to universities. One explanation for this high spatial concentration is that more than half of the West German districts (170 out of 327; i.e. about 52 percent) do not have a university located within the region while R&D employment and patent output can be found in every region. Whereas half of the patents and private sector R&D employees are concentrated in 18 and 10 percent of the districts, respectively, nearly half of the universities' regular research funds can be found in less than 6 percent of the regions.

Despite the higher concentration of university-related variables, we find a remarkable degree of correspondence of the spatial distribution of patents and of the universities' external research funds (Figure 1). Obviously, regions with a high number of patents (e.g. the two extreme cases of Munich and Stuttgart) are characterized by high quality universities which attract great volumes of external resources for research. Regions that attain a relatively high number of patents without having a university are rather the exception. However, there is hardly any location which does not also have a university within a 100 km distance. Nevertheless, there may be further factors such as the intensity and quality of interaction of the different elements of the regional innovation system (Fritsch, 2004, 2005; Fritsch and Slavtchev, 2006) that determine the efficiency of that system.

4. Measurement Issues

We use a knowledge production function as introduced by Griliches (1979) for analyzing the contribution of academic institutions to regional innovative output. The knowledge production function describes the relationship between innovative input and innovative output, that is,

$$R\&D\ output = f(R\&D\ input). \tag{1}$$

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

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

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. When relating innovative input to innovative output, a time lag of 3 years is assumed, that is, innovative output for the years 1995–2000 is related to innovative input for the years 1992–1997.[13] This is done for a

[12] External research funds from the German Science Foundation and from private firms comprised about two-thirds of the total amount of external research funds obtained by academic institutions in the period of analysis.

[13] Fischer and Varga (2003) use a 2-year lag between R&D efforts and patent counts in Austria in 1993. Ronde and Hussler (2005) link the number of patent applications submitted between 1997 and 2000 to R&D efforts in 1997. Autant-Bernard (2001) chooses a time lag of 3 years between innovative input and output.

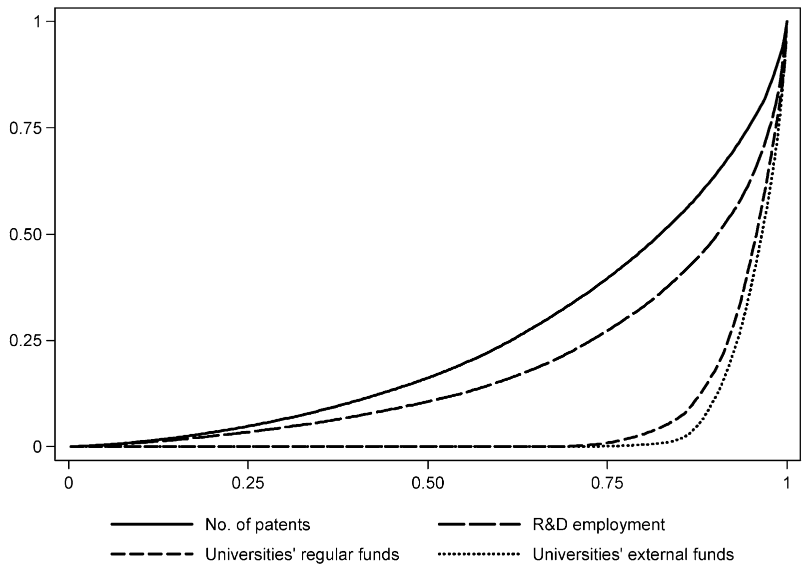


Figure 2. Lorenz curves of spatial inequality of innovative input and output (average yearly values)

number of reasons. First, R&D activity requires time for attaining a patentable result. Second, patent applications are published only about 12–18 months after submission. This is the time necessary to verify whether an application fulfills the basic preconditions for being granted a patent or to complete the patent document (Greif and Schmiedl, 2002). Taking the natural logarithms of both sides and adding a regional index *r* as well as a time index *t* (year) we get

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

The coefficients of this equation can be estimated by applying standard regression techniques. Different estimated values of output elasticity *b* for the innovative inputs imply differences in the impact of the respective knowledge sources on innovative output. The coefficients of output elasticity are dimensionless; thus, the relative importance of the different knowledge sources can be directly assessed by comparing the respective estimates. The constant term *a* captures the impact of inputs which are not represented by the other variables of the empirical model and may signify the random character of innovation processes (Fritsch, 2002; Fritsch and Franke, 2004).

In order to test for knowledge spillovers from neighboring regions, we sum up the values of the different knowledge sources (private sector R&D as well as university R&D) for all the adjacent districts that have their geographic center within a 50 km radius of the district under inspection. These districts form the "first ring". Applying the same procedure, a "second ring" is built for all other districts with centers within a distance of 50 and 75 km. A significantly positive impact of innovative resources located in neighboring districts implies the presence of knowledge spillovers between the regions. Moreover, identifying a first and a second ring enables us to test the hypothesis that the significance of spatial knowledge spillovers decreases with distance, that is, between the first and the second ring.

A large body of empirical literature has shown that economies external to a firm but internal to the spatial units in which it operates may be conducive to its innovative activities. On the one hand, it is argued that the geographical concentration of firms belonging to the same industry may constitute an advantage by creating a large pool of common inputs or by making a high degree of labor division possible. Such effects are labeled Marshall–Arrow–Romer (MAR) externalities (Glaeser *et al.*, 1992). On the other hand, the exchange of complementary knowledge between agents of different industries may also stimulate the generation of new ideas. Thus, a broader variety of economic activities can play an important role for innovative activities (Jacobs externalities according to Jacobs, 1969). To account for the effects of concentration in certain industries, we include the industrial concentration index (ICI_r). Being calculated as the Gini coefficient based on the number of employees in 58 different industries, this index ranges between 0 and 1. The larger this value, the higher the degree of industrial concentration. Thus, an estimated positive sign for the variable suggests a significant impact of concentration on innovative activities and vice versa. In order to control for the effects of the size of the region, which may lead to economies of scale, we include the number of regional population into the model. A positive sign of this variable suggests the existence of such scale economies at the regional level. Furthermore, to account for the higher propensity of patenting in the manufacturing sector as compared to the service sector, we include a manufacturing specialization index (MSI_r) that indicates the share of the district's manufacturing employment as compared to the national average.[14] If innovation activities within manufacturing industries are more closely related to each other than to innovation activities in service industries, the *MSI* may also capture some types of MAR externalities.

Our dependent variable, which is 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 method may be applied. However, we applied the negative-binomial regression because it is based on somewhat more general assumptions than Poisson regression.[15] Due to the characteristics of the dataset, panel estimation techniques should be applied in order to control for unobserved region-specific effects. Such fixed effects estimates may, however, not be appropriate because the impact of those variables which exhibit only slight changes over time may be wrongfully included in the fixed effects.

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[14] The specialization in the manufacturing sector for each region (SM_r) was calculated as the regional employment share of manufacturing relative to the national average. Employment data are taken from the German Social Science Insurance Statistics. If the share of the region's manufacturing employment is the same as in the economy as a whole, then the SM_r assumes the value of unity. For regions with an above average share of manufacturing employment, the value of SM_r is above unity and vice versa. According to Paci and Usai (1999), the manufacturing specialization index (MSI_r) was calculated as $[SM_r - 1]/[SM_r+1]$. Thus, *MSI* is symmetrically distributed within the interval between -1 and $+1$.

[15] Negative-binomial regression allows for greater variance of observations than the Poisson regression. For a more detailed description of these estimation methods see Greene (2003: 740–745). We find at least one patent per year for each district in our data; hence, the problem of having "too many zero values" does not apply. To adjust the information of the number of patents to the assumptions of the negative-binomial estimation approach, the number of regional patents has been rounded up.

Table 2. Determinants of the regional number of patents—results of multiple negative-binomial panel regressions[a]

	(1)	(2)	(3)	(4)
	Random effects		Fixed effects	
R&D employment (ln)	0.224** (6.27)	0.168** (5.44)	0.238** (4.40)	0.140** (2.65)
R&D employment 0–50 km (ln)	0.170** (4.85)	0.261** (8.89)	0.124* (2.06)	0.358** (4.93)
R&D employment 50–75 km (ln)	0.072* (2.42)	−0.025 (0.99)	0.296** (4.82)	0.170* (2.21)
Manufacturing specialization index (*MSI*)	1.139** (6.83)	0.670** (5.04)	0.310 (1.05)	−0.032 (0.12)
Industrial concentration index (*ICI*)	−3.322** (3.34)	0.034 (0.04)	−10.091** (5.14)	−8.098** (3.24)
Population (ln)	0.436** (6.56)	0.770** (13.83)	−0.145 (1.04)	0.115 (0.80)
Regular funds (ln)	−0.006 (0.82)	−0.007 (1.19)	−0.001 (0.08)	−0.002 (0.35)
External funds (ln)	0.029** (3.01)	0.017* (2.11)	0.035** (3.18)	0.024* (2.47)
External funds in surrounding districts 0–50 km (ln)	0.057** (4.67)	0.005 (0.56)	0.134** (8.32)	0.054** (4.05)
Residual from surrounding districts 0–75 km	–	0.985** (30.17)	–	0.956** (23.52)
Intercept	−3.374** (2.85)	−8.809 (8.78)	6.513** (2.69)	2.567 (0.89)
Number of observations	1,962	1,962	1,962	1,962
Number of NUTS-3 regions	327	327	327	327
Log likelihood	−8,327.24	−7,962.97	−6,093.58	−5,847.61

[a]Absolute value of *z*-statistics in parentheses.
*Significant at the 5 percent level; **significant at the 1 percent level.

Accordingly, we focus our interpretation on the random effects estimates (Table 2) but also provide information about the fixed effects estimates.[16]

5. Contribution of Universities to Regional Innovative Output

The results of multiple negative-binomial panel regressions for the determinants of the number of regional patents are reported in Table 2. We find the strongest impact on patenting for private sector R&D employment.

According to the random effects estimates (models 1 and 2), the production elasticity of a region's private sector R&D employment has a value of about 0.22 and 0.17, respectively. The estimated elasticity of private R&D resources in the adjacent regions with an average distance up to 50 km (first ring) is about 0.17–0.26 and the elasticity of private sector R&D in the districts which form the second ring amounts to 0.07. Private sector R&D activity in more remote areas has no statistically significant effect.

[16] In the regression analysis both, the universities' regular funds and the external research funds are expressed in 10,000 Euro. To prevent a priori exclusion of districts without universities, which causes a non-defined logarithm of zero, we add a unity to all values of the variables for university-related funds (10,000 euro). Thus, the logarithmic values of districts without external research funds are zero.

The highly significant positive coefficients for the manufacturing specialization index (models 1 and 2) confirm the expected higher propensity to patent in manufacturing as compared to the service sector. This result is particularly consistent with Blind and Grupp (1999) who found no significant impact of the share of employment in services on regional patent output for selected German regions. The negative sign for the industrial concentration index suggests that diversity may be favorable for the performance of regional innovation systems. This finding is consistent with Greunz (2004) who tested the impact of industrial structure on innovation in European regions by means of Gini coefficients as well as with Paci and Usai (1999) who used the Herfindahl index as a measure of industrial diversity. Furthermore, there are positive scale effects as indicated by the number of population (models 1 and 2).

It is rather remarkable that the size of the universities' regular budget has no significant effect on the regional number of patents. Obviously, the mere size of a university is not important for the innovative output of a region. The same result is obtained if the number of scientific and teaching personnel at the universities or the number of students or the number of university graduates is taken as a measure of the volume of academic research and education, respectively. Since there is a close statistical correlation between these indicators and the universities' regular budget, we do not include these alternative indicators in the regression in order to avoid multicollinearity problems. A positive impact on a region's innovative output can, however, be found for the amount of external funds that the academic institutions attract. This indicates that it is the amount and quality of the research at the universities that is important for their contribution to the innovation system and not their size. We also find a statistically significant impact of external research funds of universities located within the first ring, that is, in districts within an average distance of up to 50 km. External funds of more remote academic institutions have no statistically significant impact on the number of regional inventions as indicated by patent applications. This pattern is highly consistent with Beise and Stahl (1999).

In order to account for spatial autocorrelation, we included the average mean residual of the adjacent regions in a distance of up to 75 km. The highly significant positive values of the respective coefficients indicate that neighboring regions share some common influences which are not measured by the other variables included in the model. If a control for spatial autocorrelation is included (models 2 and 4 in Table 2), the effect of private as well as university R&D is smaller than without such a control. Particularly, the coefficient for external research funds of universities in adjacent regions decreases considerably but still remains statistically significant. Moreover, when controlling for unobserved spatial dependencies the industrial concentration index (*ICI*) becomes insignificant (model 2). All models have been run for all districts as well as only for those districts which include a university. We find a somewhat stronger effect of universities in this sub-sample because districts with a considerable number of patents but no university are excluded. However, in qualitative terms the results are the same as those in the models reported here.[17]

[17] For a detailed analysis according to the type of university as well as according to the type of department see Fritsch and Slavtchev (2005).

Our estimates of the production elasticity of universities' R&D are considerably smaller than what has been found in many studies for other countries, particularly in studies for the USA (Table 3). This indicates that the innovative output or the technology transfer from German universities into the private sector is comparatively weak.[18] However, the value of the coefficient for the contribution of university knowledge becomes nearly twice as large if we restrict the estimates to those districts in which a university is located.

There are a number of reasons for assuming that the importance of universities for education and research is underestimated by the type of analysis that has been conducted here. A main cause of such an underestimation could be that many of the effects of universities are long term in nature. For example, innovative activity of spin-off firms from academic institutions is, in our analysis, completely assigned to the private sector; thus, disregarding the fact that the respective academic incubator may have made a considerable contribution. Moreover, the presence of universities and the access to academically trained labor may attract innovative private firms into a region that would otherwise not have been established there. Therefore, one may assume that our estimates signify a kind of lower boundary for the impact of academic institutions. A more comprehensive assessment of the diverse direct and indirect effects certainly requires a considerably broader approach than the one being conducted here.

6. Summary and Conclusion

Our analysis of the effect of universities and private sector R&D on regional innovative output shows 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. Private sector R&D activities in adjacent regions are much less important and their effect becomes weaker with increasing distance. Our analysis clearly indicates that the mere size of the universities in terms of the number of employees, number of students and university graduates as well as the volume of 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 of the intensity and quality of the research. This clearly indicates that it is not the pure existence or the size of universities but rather the amount and quality of the research conducted there which are relevant. Therefore, a policy that wants to promote regional innovation processes by building up universities should place substantial emphasis on the amount and quality of the research conducted there. However, compared to private sector R&D, the contribution of the universities is rather small. It is also smaller than that which is found in most of the studies for the USA and for other European countries.

Accounting for industrial concentration in a region, we find that diversity is conductive for innovative activities. Therefore, Jacobs externalities obviously play some role. We also find clear evidence for a positive impact of specialization in manufacturing industries as compared to the service sector as well as significant scale effects of regional population.

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[18] A detailed discussion of the technology transfer from German universities is provided in Abramson *et al.* (1997: 272–302).

Table 3. Estimated production 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	Description
Jaffe (1989)/USA	0.60**–0.89**	Not significant–0.33**	Regression method: OLS pooled. Dependent: number of corporate patents. Independent: industry as well as university R&D expenditures. Sector level: all/four technological areas. Spatial level: US states.
Acs *et al.* (1991)/USA	Not significant–0.65*	0.33*–0.52**	Regression method: OLS. Dependent: innovation counts. Independent: industry as well as university R&D expenditures. Sector level: all/two technological areas. Spatial level: US states.
Anselin *et al.* (1997)/USA	0.51** (US states) 0.54** (MSAs)	0.57** (US states) 0.11** (MSAs)	Regression method: OLS pooled (reported here), spatial ML. Dependent: innovation counts. Independent: industry as well as university R&D expenditures. Sector level: high-tech sector (two-digit ISIC). Spatial level: US states, Metropolitan Statistical Areas (MSAs).
Fischer and Varga (2003)/Austria	0.10**–0.40**	0.13**–0.21**	Regression method: OLS, spatial error ML. Dependent: number of patents. Independent: industry as well as university R&D budget. Sector level: high-tech sector (two-digit ISIC). Spatial level: political districts (LAU-1).
Ronde and Hussler (2005)/France	0.46**–0.10**	−0.77**–not significant	Regression method: logit, OLS, negative-binomial. Dependent: number of patents. Independent: number of researchers in the private and in the public sector per 10,000 inhabitants. Sector level: 14 manufacturing industries. Spatial level: NUTS-3.
Blind and Grupp (1999)/Germany	Not significant	0.51**–0.71**	Regression method: OLS. Dependent: number of corporate patents. Independent: industry R&D personnel, university patents. Sector level: 18 technological areas (based on IPC). Spatial level: two NUTS-1 regions.

Table 3. Continued

Study/country	Estimated output elasticity for private sector R&D	Estimated output elasticity for university R&D	Description
Andersson and Ejermo (2004)/ Sweden	0.07*	Not significant	Regression method: OLS. Dependent: number of patents (EPO). Independent: industry as well as university R&D man-years. Sector level: 19 industries (two-digit SNI92). Spatial level: Swedish labor market regions.
Piergiovanni and Santarelli (2001)/ France	0.08**	0.66**	Regression method: log-linear. Dependent: number of corporate patents per employee. Independent: salaries for R&D personnel in the private sector as well as at universities. Sector level: manufacturing industries. Spatial level: NUTS-2.
Autant-Bernard (2001)/France	0.34**–0.48**	Not significant–0.20*	Regression method: OLS, 3SLS. Dependent: number of patents (3 years average). Independent: private R&D expenditures, public R&D publications. Sector level: all. Spatial level: NUTS-3.
Piergiovanni *et al.* (1997)/Italy	0.15** (all firms) 0.01** (small firms only)	0.03 (all firms) 0.02** (small firms only)	Regression method: OLS pooled. Dependent: number of corporate patents per capita. Independent: private and university R&D expenditures per capita. Sector level: all. Spatial level: NUTS-2.
Barrio-Castro and Garcia-Quevedo (2005)/Spain	0.08–0.37* (fixed effects) 0.29–0.47** (random effects)	0.35–0.77** (fixed effects) 0.47–0.76** (random effects)	Regression method: negative-binomial (panel). Dependent: number of private patents. Independent: private as well as university R&D expenditures. Sector level: all. Spatial level: NUTS-2.

*Significant at the 5 percent level; **significant at the 1 percent level.

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