The Geography of Innovation in Small and Medium-Sized Firms in West Germany

Oliver Pfirrmann

ABSTRACT. Since the 1980s a more micro-economic oriented view has settled the dispute between macro-economic theories over the causes of regional development. Differentiated studies revealed an unequal spatial distribution of R&D laboratories and innovating firms, and furthermore it was discovered that the innovation behaviour of firms differs between types of regions. However, these studies still left several questions unanswered.

This study attempts to explain some of the regional innovation disparities in the former West Germany and to describe the factors that significantly influence the use of resources in a firm's innovation activities. Based on two samples of innovating small and medium-sized firms, the analysis confirms other studies which maintain that regional innovation disparities are more pronounced if input indicators relating to the innovation process are employed, rather than throughput or output indicators. The results also indicate that internal factors are more important for the innovation efforts of a firm than its regional environment.

1. Introduction

Many different theories have been discussed regarding the causes and determinants of regional development. But the macro-economic dispute between the neoclassical growth theory and unorthodox theories and approaches (growth pole, cumulative causation and development phases theories, multisectoral development planning models and export base theory) has given way to a more micro-economic oriented view (Thomas, 1985). In the 1980s a number of differentiated analyses provided new insights into the regional structure of establishments, their organisation, mode of production (product life cycle), and intra-regional interconnections.[1] These studies also argue that regional differences exist in firms' R&D and innovation efforts, which must consequently lead to differences in regional development.

Regional policies have tried to stimulate R&D and innovation in less favoured regions, especially in small and medium-sized firms: they were to be the vehicle of regional growth (Rothwell, 1982) The fact that regional differences exists in the spread of industrial and public R&D is largely undisputed (Malecki, 1980; Malecki and Variaya, 1986). In the former West Germany there was an extensive debate about a south-north divide in regional development and one of the causes was seen in the location of public and industrial R&D activities. In this context it was argued, on the basis of various indicators, that R&D in the southern regions of Germany is more intensive and more successful than in the northern regions of Germany (Bonkowski and Legler, 1985). The higher concentration of universities and publicly financed R&D laboratories in the south of Germany and their collaboration with firms appeared prima facie as one important reason for this phenomenon. Even on the US state level Jaffe (1989) and Acs et al. (1992) found evidence for geographically produced R&D spillovers from university research to innovating firms. But there is still no agreement on a firm's ability to innovate and the relevance of its regional environment, which includes a great number of factors such as the region's firm size and sectoral structure, the regional labour market, agglomeration (dis-)economies and the technological infrastructure (universities, R&D laboratories).[2]

Final version accepted on October 19, 1992

VDI/VDE Technologiezentrum Informationstechnik GmbH
Potsdamer Str. 12
D-14513 Teltow
Germany

Small Business Economics **6**: 41—54, 1994.

More recent studies in particular draw the conclusion that not only the regional environment of the firm but also internal factors such as the firm's market performance, its range of products and the qualification structure of its staff are responsible for innovative efforts within the firm (Ewers and Fritsch, 1987; Meyer-Krahmer, 1985; Thwaites, 1982; Tödtling, 1990). Tödtling (1990) provides a typical explanation of the on-going debate when he argues that in the medium and long term a connection exists between the regional environment and the size, sectoral and internal structure of a firm, and, therefore its ability to innovate.

Studies on the former West Germany analyzed regional innovation activities from the company angle. Ewers (1984) and Ewers and Fritsch (1987) did this in respect of the regional spread of different computer-based machinery and office communication technologies. But this is only one possibility. Meyer-Krahmer (1985) analyzed the development of new products and processes in a firm as well as the firm's R&D resources. He used input and output indicators relating to the innovation process and compared them on a regional level. The various individual analytical approaches point to innovation disparities of differing magnitude. This begs the question whether regional innovation disparities correspond to a center-periphery-divide, a thesis which is often used since the major work undertaken by Hägerstrand (1967). The connection between firms' R&D activities and the region in which they are being carried out also needs to be explored.

The following analysis attempts to measure regional innovation disparities on and an estimation of factors that significantly influence the use of resources for R&D and R&D employment productivity. In the following section the data which was used for the purpose of this study is described in detail, the sample of firms having been taken from a government programme for R&D staff in small and medium-sized firms. In the third section the geographic spread of innovation activities in the former West Germany is described using the same sample of innovating small and medium-sized firms and the R&D- and innovation indicators of these firms. The variance analysis is studied in the fourth section to estimate the influence of regional and structural factors on a firm's R&D process. Finally, a summary and conclusion are provided in the last section.

2. The data base

This analysis is based on information from a total of 18,020 innovating small and medium-sized firms. Only firms were eligible for funds, whereas other types of establishments were not. Between 1979 and 1985 each of these companies participated once in a programme called PKZ (Personalkostenzuschuß). The programme provided financial subsidies for R&D personnel in small and medium-sized firms. In the case of all these firms information about research and development and firm data are available.[3] It has to be added that this sample is not a random sample, but due to the widespread use of PKZ one can assume that this sample includes the vast majority of all innovating small and medium-sized firms in the former West Germany.[4]

Until 1981 only those firms from the industrial sectors and the agri-business, whose sales in the year preceding their application was less than 150 million DM or which employed fewer than 1,000 people, were eligible for funds. At the beginning of 1982 an important change was introduced in the guidelines: from then on only firms with less than 50 million DM sales and fewer than 500 employees were eligible for funds.[5]

For the purpose of this paper two main conclusions can be drawn from the (changes in) guidelines. First, the vast majority of company data is based on information given in the application, i.e. this information is valid for the year preceding the application and not for the year of the application or sponsorship. Second, the tightening of eligibility criteria concerning the firm's size led to the firm sample being divided into two parts. Instead of examining the entire period of 1978 to 1984, the periods 1978 to 1980 and 1981 to 1984 are examined separately.

The use of two periods seems to be a possible approach and interesting from two standpoints. For the first period Meyer-Krahmer (1985) has provided a large number of notable insights into the extent and explanations for regional innovation disparities in the former West Germany. Taking account of a second time period allows us to compare between small and medium-sized firms of up to 500 employees and to analyze if regional innovation disparities have changed.

Starting from the respective base year (1978 or 1981) those firms were taken into account that joined the programme in the year following the corresponding time period. For the period 1978 to 1980 information from 8,000 firms is available, for the period 1981 to 1984 we have information for 14,069 firms.[6] The data thus obtained are inevitably subject to provisos, in as far as firm data only enter our calculations for one year at a time. The alternative would have been to choose only those firms for which information is available for all the years within one period. However, the method employed here was preferred for the reason that a number of firms discontinued their participation in the PKZ programme, i.e. they participated more than once, but with at least one interruption. In this context it has also to be added that the number of firms for which continuous information was available or would have been available through interpolation was considerably lower than the actual number of innovating small and medium-sized firms that were registered under the PKZ programme. The corresponding numbers would have been 3,700 for the period from 1978 to 1980, and 3,200 for the period 1981 to 1984.

To solve the methodology problem of firm entries or exits over the years, those firms that were founded within the respective time periods were taken out of the sample. Hence the firms in the subsample are at least one year old or older.

For the purpose of this study the information from the firms' applications was supplemented with data from two surveys from 1980 and 1983 among the firms which were sponsored during the previous year. The representative survey samples are based on information from 708 (promoted in 1979) and 757 (promoted in 1982) firms, respectively.[7]

The analysis is based on data from the area that formerly constituted West Germany, including West Berlin. The regional division follows the system of planning regions (Raumordnungsregionen), which is operated by the BfLR. The system consists of 88 regions. Based on this subdivision, each region is classified according to its population density as an agglomeration, moderately congested region, or a rural region.

Agglomerations are regions with the highest population density, which include regions like the Ruhr area or large cities like Berlin. Moderately congested regions are regions with a lower population density than agglomerations but with a higher population density than rural areas, such as the Alp region.

3. Regional differences in innovation: Empirical findings

3.1. *The spread and structure of innovating small and medium-sized firms*

Analyzing the distribution of innovating small and medium-sized firms across the observed regions is a first step to determining regional differences in innovation. As the distribution in Table 1 clearly indicates for both periods, the number of innovating small and medium-sized firms was considerably higher in agglomerations than in moderately congested areas, and far higher than in rural areas.

In order to ascertain how many firms of the total number of firms in a region carry out R&D and innovation and to see whether the distribution across regional types reflects the actual structure, all innovating small and medium-sized firms were compared to all establishments per regional type. However, the following proviso applies: The legal entity on which the sample is based is firms. To ascertain precisely the degree of innovation, i.e. the share of all firms in a regional type accounted for by innovating small and medium-sized firms, would require a set of regional company statistics. This, however, does not exist. Regional statistics (on the basis of districts) are only available for establishments and this is used for lack of anything more accurate. Still, surveys of small and medium-sized firms have shown that more than 80% of all PKZ firms consist of the headquarters only. Thus the distortions caused by the different reference frames should not be too serious.

A second proviso concerns the minimum size limit for all establishments and the maximum limit for the sample. In general, the regional statistics in the industrial periodicals published by the Federal Statistical Office only cover firms with more than

TABLE I
The firm structure and innovation density according to regional type

	innovating small and medium-sized firms (1)		all establishments in manufacturing industry (2)		innovation density in per cent (1):(2)	
	1978–1980	1981–1984	1978–1980**	1981–1984**	1978–1980	1981–1984
agglomerations	4374 (3637)*	7750 (5704)*	24116	22793	18.1 (15.1)	34.0 (25.0)
moderately congested regions	2416 (2056)*	4204 (3274)*	15753	15147	15.3 (13.1)	27.8 (21.6)
rural regions	1210 (1032)*	2115 (1658)*	9439	9122	12.8 (10.9)	23.2 (18.2)
total	8000 (6725)*	14069 (10636)*	49308	47062	16.2 (13.6)	29.9 (22.6)

* firms with 20 and more employees.
** arithmetic mean.
Source: AIF, FhG-ISI, BfLR, own calculations.

20 employees. In certain sectors, however, the size limit for registration has been lowered to 10 or more employees.[8] For this reason the regional distribution and degree of innovation were calculated additionally for the PKZ sample of innovating small and medium-sized firms with 20 and more employees. The relatively strict size limit in the PKZ sample survey concerning firms with more than 500 employees in the period 1981 to 1984 has also to be taken into account. Owing to a lack of information on the regional size distribution of establishments the data could not be prepared in this case.

Based on the assumption that possible distortions will occur in equally strong or equally weak measures in all analyzed regions, the results from Table I allow the following conclusions: not only in absolute numbers, but also as a share of all establishments, the highest share of innovating small and medium-sized firms in West Germany can be found in agglomerated areas, followed by moderately congested areas, and, at a distance, rural regions.

3.2. *Distribution of size classes*

As Table II shows, for both periods the differentiation according to size class reflects no major deviation across the regional types.

For the first period, only minor differences exist in the size classes with up to 499 employees in the respective regions. For the second period, from 1981 to 1984, however, the deviations between small firms in agglomerated regions and other regions have increased compared to the first period. The same applies for bigger firms (more than 200 employees) in rural areas.

For the first period the ratio of small to medium-sized firms is 1:2. For the second period the ratio changes in favour of small firms to 1:1.[9] Those firms with more than 1,000 employees, which are defined as large, are only represented for the years 1978 to 1980. These are exclusively firms who over a three-year-average have fewer than 1,000 employees and thus for this study qualify as medium-sized firms.

For the period 1981 to 1984 and also for the period 1978 to 1980 the distribution of firms was determined by the PKZ programme guidelines, or rather by the change in these guidelines. Thus, the increased share of small firms during the second period can partly be explained by restrictions on the firms' size (up to 500 employees) and sales (50 million DM per year or over a three-year-average).

It should be noted that a deviation in employment size classes does not vary strongly across regional types. In this sample the rural .areas

TABLE II
Size distribution of innovating small and medium-sized firms according to regional type

	1978–1980						1981–1984					
	agglomerations		moderately congested regions		rural regions		agglomerations		moderately congested regions		rural regions	
Employee/Size of firm	number	%	number	%	number	%	number	%	number	%	number	%
1–19	737	16.8	360	14.9	178	14.7	2047	26.4	932	22.2	457	21.6
20–49	872	19.9	437	18.1	229	18.9	2142	27.6	1128	26.8	556	26.2
50–99	813	18.6	434	18.0	227	18.8	1608	20.7	876	20.8	441	20.8
100–199	767	17.5	486	20.1	218	18.0	1133	14.1	752	17.9	361	17.1
200–499	781	17.8	479	19.8	239	19.8	774	10.0	483	11.5	280	13.2
500–999	291	6.7	170	7.0	88	7.3	46	0.6	34	0.8	20	0.9
1000 and more	113	2.6	50	2.1	31	2.6	–	–	–	–	–	–
total	4374	100.0	2416	100.0	1210	100.0	7750	100.0	4204	100.0	2115	100.0

Source: AIF, FhG-ISI, own calculations.

are predominantly represented by medium-sized firms. A predominance of small firms in rural areas could not be detected. It is relevant for the following analysis that across all regional types the number of small firms (up to 49 employees) increased considerably for the second period, compared to the first.

3.3. *Distribution of R&D-intensive economic sectors*

The analysis of R&D intensive sectors was carried out on the basis of R&D employment intensity, using the system employed by the German manufacturing industry (four-digit SYPRO numbers).[10] The results confirm those of the German Stifterverband (Echterhoff-Severitt, 1976) and the studies based on it (Kamp and May, 1981; Tabbert, 1974). They reflect the dominance of those economic sectors that according to the German Stifterverband have always had the highest R&D spending of German industry and moreover they do not seem to show distortions in terms of size. With regard to R&D employment intensity, the most R&D intensive sectors are office equipment and electronic data processing machinery, electrical equipment, chemicals, mechanical engineering, precision engineering, optics, watches and synthetic materials. The aerospace industry was not taken into account because of the limited member of cases.

As Table III indicates, there does not appear to be a strong difference in the distribution of R&D intensive small and medium-sized firms across regions. For the period 1978 to 1980 the share of all innovating small and medium-sized firms accounted for by firms from the R&D intensive sectors is about 60% for all regional types. For the period 1981 to 1984 the corresponding figure is nearly 60%. Yet the tendency for agglomerated regions to have the highest ratings, followed by moderately congested areas and rural regions, persists.

3.4. *R&D and innovation indicators*

Analyses of different phases of the innovation process have shown repeatedly that a high number or a high intensity of input factors, such as R&D staff and R&D spending, are a necessary but no sufficient condition for successful technological innovation (Kamien and Schwartz, 1975; Freeman, 1982).

An output-oriented approach to innovation processes shows that the results of innovation processes can be interpreted differently. On the most basic level a differentiation is made between product innovation and process innovation. In addition, product innovations can be classified according to their "age". The innovation might take place within the company, which has not produced a certain product before (firm innovation), or the

TABLE III
Distribution of R&D intensive sectors according to regional type

	1978–1980						1981–1984					
	agglomerations		moderately congested regions		rural regions		agglomerations		moderately congested regions		rural regions	
	number	%	number	%	number	%	number	%	number	%	number	%
mechanical engineering	1264	44.1	789	54.0	324	46.3	2082	44.3	1257	53.2	528	44.8
electronics	803	28.0	305	20.9	195	27.9	1325	28.2	494	20.9	325	27.6
precision engineering, optics, watches	168	5.9	101	6.9	54	7.7	262	5.6	140	5.9	93	7.9
chemical industry	350	12.2	113	7.7	48	6.9	442	9.4	175	7.4	60	5.1
electronic computing equipment, office machines	72	2.5	9	0.6	17	2.4	141	3.0	34	1.4	34	2.9
manufacturing of synthetic materials	211	7.4	144	9.9	62	8.9	446	3.5	265	11.2	139	11.8
total	2868	100.0	1461	100.0	700	100.0	4698	100.0	2365	100.0	1179	100.0

Source: AIF, FhG-ISI, own calculations

innovation could occur at market level. For example, a certain product had not been manufactured at all before (market innovation, Meyer-Krahmer et al. 1984). Measured in terms of the absolute number of R&D staff, scientists in R&D and R&D spending, firms from agglomerated regions clearly dominate in both time periods (Table IV). According to our results to date moderately congested and rural regions lag behind at a clear distance.

The absolute differences between regional types roughly correspond to the distribution of small and medium-sized firms across regional types.[11] Those figures, however, are qualified if we include a reference frame for the absolute values. For the first time period there are less marked differences between regional types if we base the analysis on R&D employment intensity, the ratio of scientists in R&D (for firms that employ scientists in R&D) or the rate of R&D spending. The differentiation between types of R&D spending reveals another qualifying factor. The absolute value of R&D spending in agglomerated regions is mainly accounted for by staff expenditure. In rural areas, on the other hand, followed by moderately congested regions, more is invested in R&D equipment. Since some possibly relevant factors, such as wage differences and availability of R&D know-how, are not accounted for, any conclusion concerning the quality of R&D processes in different regional types is highly speculative.

If the results of the innovation process are used as indicators by way of comparison, the picture changes slightly in favour of rural areas for the period 1981 to 1984 (Table V).

With the exception of a few sporadic deviations (R&D employment density), there is, in a similar way to the spatial hierarchy, a tendency for agglomerated regions to come out on top, followed by moderately congested and rural areas. For the period 1981 to 1984 the relatively high values for R&D throughput indicators (patents registered and patents granted) and the innovation output indicators (product and process innovations) allow us to draw conclusions concerning the innovative potential of rural areas. These indicators which estimate regional R&D potential show that, with regard to innovation processes, rural regions are not backward, but on the contrary, partly achieve above-average results (patents registered or granted, new processes, one or more introduced over the last five years).

This result is all the more important as the

TABLE IV
R&D staff and R&D outlays according to regional type

	1978—1980			1981—1984		
	agglomerations	moderately congested regions	rural regions	agglomerations	moderately congested regions	rural regions
(1) R&D staff (full-time equivalents)	40,662	21,970	10,754	43,117	24,637	12,240
(2) R&D employment intensity (in per cent)	7.1	5.9	6.0	9.4	8.5	8.3
(3) scientists in R&D (full-time equivalents)	7,287	3,436	1,740	10,517	4,960	2,297
(4) share of scientists in R&D (in per cent)	0.6	0.5	0.5	0.4	0.3	0.3
(5) R&D outlays in 1000	1,886,060	940,598	451,574	2,251,981	1,189,391	507,776
(6) R&D outlay intensity in 1000	46.4	42.8	42.0	52.2	48.8	41.5

(2) R&D employees as share of all employees of innovating small and medium-sized firms.
(4) share of R&D employees accounted for by scientists per innovating small or medium-sized firm (for the first period the unavailable data for 1978 was estimated on the basis of the 1980 survey and size class and sector aspects).
(6) R&D outlays per R&D employee.
Source: AIF, FhG-ISI, own calculations.

TABLE V
Innovation indicators according to regional type (in percent)

	1978—1980			1981—1984		
	agglomerations	moderately congested regions	rural regions	agglomerations	moderately congested regions	rural regions
(1) patents (registered)	39.3	41.6	37.4	19.7	19.7	20.4
(2) patents (granted)	28.7	30.0	25.2	9.8	11.2	11.17
(3) new product within last five years (firm innovation)	94.0	93.3	90.8	81.5	74.9	81.3
(4) new product within last five years (market innovation)	64.2	65.9	57.7	55.7	49.4	51.4
(5) new processes	69.8	75.0	73.5	61.1	59.0	63.2

(1/2) This indicator only existed up to 1983.
(3/4/5) For the period 1978 to 1980 the results are based on the 1980 survey (N = 703). For 1981—1984 the results are based on the weighed arithmetic mean of the 1983 survey (N = 757) and the year of application 1985 (N = 2250).
Source: AIF, FhG-ISI, own calculations.

number of very small firms increased considerably over the second period. Harris (1988) confirms that the share of process innovations in rural/peripheral areas is above average. He attributes this to the product life cycle hypothesis, which states that the share of process innovations is particularly high in regions that find themselves in a late phase of the product life cycle.

The results of this frequency distribution thus require further analysis, which takes into account regional and structural factors and which evaluates the significance of these factors.

4. The influence of regional and structural factors on R&D employment intensity and R&D employment productivity – results of the variance analysis

4.1. *Method and indicators*

The dependent variables in this analysis are the number of R&D employees (in full-time equivalents) relative to the total number of employees per firm, as well as the number of patents granted per R&D employee (R&D employees in full-time equivalents).

The first indicator guarantees a large number of cases, since the relevant data are available for almost all firms and the comparability with other studies is ensured (Tödtling, 1990). The second indicator, despite the small number of cases, is an effort to link differences in the productivity of R&D processes in small and medium-sized firms to different regional and structural influences.

A survey of other studies shows that for an evaluation of R&D input/output relations different approaches with varying degrees of complexity can be taken. Brockhoff (1983), utilising a Cobb-Douglas production function with time lag variables, estimates the impact of R&D employment and R&D spending on the turnover of industrial firms. Bound et al. (1984) and Scherer (1983), with the help of different functional types, analyze the correlation between R&D spending and patented inventions for different size groups among firms. Acs and Audretsch (1991) used R&D spending as an input indicator, and product, process or service innovations as output indicators. Contrary to the aforementioned studies, this study does not focus on a production function approach, but on questions which have relevance to external company factors on R&D. Despite possible drawbacks, the analysis was carried out using patents as an indicator.

For assumed regional influences the regional type variable is employed; for assumed intrafirm effects we use the employment size class variable, and for sector-specific influences the aggregated sectors using the two-digit SYPRO system.

In addition, a company's age was integrated into the explanatory variable of R&D employment intensity in a dichotomised form: newly-established firms, i.e. five years and younger (group 1), and established firms, i.e. older than five years (group 2). In the case of the employment productivity dependent variable the ratio of scientists per firm was used as a dichotomous variable, defined as the above-average (group 1) and below-average (group 2). Since for the first period, 1978 to 1980, the scientist ratio variable was strongly influenced by estimations for the year 1978, the age of firms was used as an alternative. The classification of the regional type, number of employees, and sector variables largely corresponds to the classification used in the tables above. The employment size classes and certain sectors measured in SYPRO two-digits had to be condensed into four or eight groups, respectively, because of the extremely dissimilar cell frequencies, which result from a combination of independent variables.[12]

4.2. *Determinants of R&D employment intensity*

For both periods the model is highly significant at the 0.1% level (Table VI). Comparable studies, such as Tödtling's analysis of Austrian regions, (1990: 114 f), arrive at a considerably lower explained variance. With one exception, he was able to explain 12% of the variance for the same dependent variable and comparable independent variables. Among other things the different results can be traced back to the fact that, on top of the variables employed here, other factors, such as the product life cycle phase or competition strategy, influence the R&D employment intensity of Austrian establishments.

The slight differences in the explanatory power between the time periods (R^2 1978—1980: 0.55; and R^2 1981—1984: 0.49) indicate that with a growing number of cases the intensity of stochastic influences also increases. The analysis of the first time period is based on data from 5,000 firms, while for the second period data from more than 12,000 firms were available.

The interaction effects, i.e. the interaction of two (2-way interaction), three (3-way interaction) and four (4-way interaction) variables are, as far as they were calculated, negligible. The interactions that occur with the combination of two variables are highly significant at the 0.1% level, yet irrelevant measured against the explained variance.

The high significance of the interaction of two variables results from a combination of structural and regional influences, depending on the time period. The respective interactions between firm size and age, and between regional type and sector were constantly significant over both time periods. The interactions between other structural factors are only temporarily significant: the combination firm size and sector is only significant for the period from 1978 to 1980, while that of age and sector is only significant for the period from 1981 to 1984. However, the share of variance explained through interaction (especially 3- and 4-way interaction) is so minimal, that even their exclusion from the calculation would only slightly increase the share of residual variance.

The variable sector, in varying combinations with other structural factors, turns out to be highly significant across both time periods. This result, however, has no influence on higher interaction effects. Taking the results of all interaction effects it turns out that their influence on the dependent variable is negligibly small and for the most part insignificant.

Two other questions have to be investigated: how strong are the effects of the independent variables (Beta), and what differences in degree are there among the effects of different groups of variables.

The strongest influence for both periods stems from the firm size, followed, at a distance, by the sector variable and the age of the firm. This confirms the results of Tödtling (1990, p. 116). All the main effects of the individual variables are highly significant across both time periods (significance level of $F < 0.001$). Regional influence, on the other hand, is only weak, or totally absent, for the period 1981 to 1984. Compared to other factors, too, the regional influence is almost insignificant. In comparison to other rural areas, there is a disproportionally high number of firms in the rural regions of the Alp periphery. In order to qualify the significant, but weak, regional influence for the first period, a "south-dummy" was

TABLE VI

Results of the 4-way interaction variance analyses

Dependent variable: R&D employment intensity

independent variable	1978–1980 individual effects: Beta	1978–1980 individual effects: significance of F	1978–1980 model: multiple R (R2)	1978–1980 model: significance of main effects	1978–1980 model: interaction effects Eta2 (significance)	1981–1984 individual effects: Beta	1981–1984 individual effects: significance of F	1981–1984 model: multiple R (R2)	1981–1984 model: significance of main effects	1981–1984 model: interaction effects Eta2 (significance)
regional type	0.03	**			2-way interactions: 0.01 (***)	0.01	not significant			2-way interactions 0.004 (***)
sector	0.22	***	0.74 (0.55)	***	3-way interactions: 0.003 (not significant)	0.18	***	0.70 (0.49)	***	3-way interactions: (not calculated)
size of employment	0.62	***				0.61	***			
age	0.13	***			4-way interactions: 0.002 (not significant)	0.11	***			4-way interactions (not calculated)

* significant at the 5% level.
** significant at the 1% level.
*** significant at the 0.1% level.
Source: AIF, FhG-ISI, own calculations.

constructed to indicate the possible influence of south or north locations on R&D employment intensity.

This regional factor also does not increase the share of explained variance. Neither for all regional types nor for rural areas in particular can a statistically significant "location advantage" be detected in favour of the rural regions in the Alp periphery.

In order to answer the second question, the individual group mean was compared to the grand mean. Looking at the different individual groups, the strongest effects with regard to R&D employment intensity for both periods were to be found in small firms (fewer than 50 employees), firms from the electronics and electronic data processing sector and in newly established firms.

This result is also reflected in Table VII, where the respective group means are compared to the grand mean. Using the R&D employment intensity grand mean of 6.5 for the first period and 9.0 for the second period, the strongest deviations for both periods — both absolutely and relative to the other group means — occurred in the first group (size category: 1—49 and age: newly founded) and in the fourth (sectors: electronics and electronic data processing).

4.3. *Determinants of R&D employment productivity*

As regards the explanatory variables, the model employed to explain the variance of R&D employment productivity hardly differs from the previous one.

The variable explaining the ratio of scientists (of all R&D employees) was additionally added, but only for the period 1981 to 1984, since for 1978 only estimates about scientists in R&D were available. Alternatively, the age variable was used.

As Table VIII shows, the model is significant for both periods. Yet the share of explained variance is much lower than before. The majority of the interaction effects are insignificant and thus were not estimated any longer. For this reason the interaction effects were ignored in this case, too. Thus Table VIII only contains the results of the individual effects. More important are the effects of the individual variables (Beta) and their significance. For the period 1978 to 1980 the strongest effects were to be found in the firm size and the aggregated sectors. Both variables are highly significant (significance level of $F < 0.001$). The regional type and age variables only exert minor, and even insignificant influence. For the period 1981 to 1984 the influence of firm size is again dominant and highly significant; the influence of the type of sector is weaker, but still very significant. The scientist ratio variable exerts a relatively clear influence (significance level of $F < 0.01$) on R&D employment productivity. Furthermore, the share of explained variance for this variable is considerably higher than that of the age variable, which also results in a higher share of explained variance for the entire model.

As regards the differences between groups, small firms again turn out to be dominant. In a direct comparison of size classes the R&D employment productivity decreases, i.e. with growing firm size the R&D employees on average produce fewer patents. Yet these findings are somewhat distorted in favour of smaller firms, since, com-

TABLE VII
Grand mean and group mean of R&D employment intensity (mean values in per cent)

	1978—1980								1981—1984							
Grand mean	6.5								9.0							
group	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
region	7.1	5.9	6.0	—	—	—	—	—	9.4	8.5	8.3	—	—	—	—	—
size class	17.6	6.7	3.5	2.4	—	—	—	—	16.4	6.7	3.7	3.0	—	—	—	—
sector	7.4	4.4	7.5	9.5	5.1	3.7	2.8	3.4	8.7	7.1	10.5	12.4	7.8	6.1	4.0	6.5
age	17.4	5.6	—	—	—	—	—	—	16.4	7.7	—	—	—	—	—	—

Source: AIF, FhG-ISI, own calculations.

TABLE VIII
Results of the 4-way interaction variance analysis: R&D employment productivity
Dependent variable: R&D employment productivity

independent variable	1978–1980 individual effects: Beta	significance of F	model: multiple R (R2)	significance of main effects	significance of interaction effects	1981–1984 individual effects: Beta	significance of F	model: multiple R (R2)	significance of main effects	significance of interaction effects
regional type	0.04	not significant				0.03	not significant			
sector	0.16	***	0.24 (0.06)	***	not calculated	0.24	**	0.42 (0.18)	***	not calculated
size of employment	0.19	***				0.32	***			
share of scientists	—	—				0.15	**			
age	0.02	not significant				—	—			

* significant at the 5% level.
** significant at the 1% level.
*** significant at the 0.1% level.
Source: AIF, FhG-ISI, own calculations.

pared to their percentage of all firms, they hold relatively fewer patents than firms in higher size classes, i.e. the share of firms holding no patents at all is larger among smaller firms than among bigger firms. This result confirms the findings of Bound et al. (1984) and Scherer (1983), who employ similar indicators: patents/P&D spending, also with a bias towards smaller firms who take out patents in R&D spending, also with a bias towards smaller firms who take out patents in R&D. A higher rate of innovation efficiency among the lower size classes is also confirmed by Acs and Audretsch (1989). As regards the types of sectors it partly confirms the results of Wrigley and Brouwer (1985), but their data base is partially different from this sample.

Highly productive firms distinguish themselves through an above-average ratio of scientists compared to all R&D employees. As Table IX shows, a calculation of the group mean partly confirms

TABLE IX
Grand mean and group mean of R&D employment productivity (mean values in patents per R&D employee)

	1978–1980								1981–1984							
Grand mean	0.51								0.22							
group	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
region	0.51	0.53	0.44	—	—	—	—	—	0.23	0.23	0.21	—	—	—	—	—
size class	0.65	0.64	0.51	0.34	—	—	—	—	0.38	0.24	0.18	0.11	—	—	—	—
sector	0.39	0.63	0.58	0.39	0.60	0.50	0.41	0.56	0.26	0.39	0.21	0.19	0.37	0.33	0.36	0.11
age	0.54	0.51	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Source: AIF, FhG-ISI, own calculations

this tendency: firms with a high R&D productivity have fewer than 100 employees (first and second group), and tend to be in the metal, ceramics, glass or synthetics sector (second and first group), and employ an above-average ratio of scientists (second group). Yet on the regional level no clear differences can be detected. The "south dummy" used for this model as well proved to be slightly significant only for the first period ($F < 0.05$).

Owing to the often discussed explanatory power of the patents indicator (Grilliches, 1991; Scherer, 1983), these results have to be interpreted cautiously, since the higher productivity of smaller firms does not allow any conclusions concerning the quality or use of patents.

5. Conclusion

The purpose of this paper was to provide at least some insights into two questions in the extensive debate about the geography of innovation. The first question which had to be explored was whether regional innovation disparities correspond to a center-periphery divide. Especially as regards the former West Germany the hypothesis of a strong south-north divide in industrial R&D was of additional relevance. The second question was which factors significantly influence the use of resources for R&D and R&D employment productivity. Internal firm factors and factors which describe the regional environment of the firm were used.

Based on two samples of innovating small and medium-sized firms, the analysis revealed regional differences of varying magnitude. It has to be noted that the use of several R&D and innovation indicators confirms the results of other studies (Arend and Stuckey, 1984; Meyer-Krahmer, 1985), which state that regional innovation disparities are more pronounced if input indicators of the innovation process are employed, than if throughput or output indicators are used.

In addition, this analysis has shown that measured in absolute terms distinct differences exist between the regional types as regards the number of firms, R&D spending, the number of R&D staff and their respective qualifications. These disparities correspond to a center-periphery divide. But if we take into account the distribution of size classes, of R&D intensive sectors, and corresponding reference frameworks for the absolute values, some of these differences are considerably qualified. Thus, the disparities between regions are less pronounced with regard to intensity (R&D employment intensity, ratio of scientists, level of R&D spending). Certain R&D and innovation indicators (patents registered and granted, as well as firm or market innovations for the period 1981—1984), reveal that firms in rural areas register and hold more patents and also produce more innovations than firms in moderately congested regions, and in some cases also more than firms in agglomerated regions.

Several analyses of variance were carried out in order to determine the relevance of regional and/or structural factors for R&D resources and R&D processes. The results show clearly that, regardless of the time period, regional influences have no, or, in combination with structural variables, very limited, and mainly insignificant relevance. The location of the planning region (south or north) is also statistically insignificant. For this sample it is mainly structural factors, such as the firm size, sector affiliation, and partly also the age of firms, that significantly influence the use of resources (R&D employment intensity) and the R&D employment productivity (patents per R&D employee). In this outcome the individual effects of the variables dominate, while interaction effects are hardly or not at all present. The strong explanatory power of the firm size factor, together with the theoretical findings, suggest that firm size here has to be regarded as a proxi measure for a number of firm-specific factors, underscored by the relatively high relevance of the scientist ratio factor for R&D processes.

From a regional point of view these results, in connection with other empirical studies (Ewers and Fritsch, 1987; O'Farrell and Hitchins, 1988; Tödtling, 1990) indicate that internal factors are more important for the innovation efforts of a firm, rather than the regional environment. As Tödtling pointed out internal factors include various firm characteristics such as marketing, organisation and (innovation) management.

This analysis, like other studies (Scherer, 1983; Bound et al., 1984; Acs and Audretsch, 1991; Rothwell, 1982) also confirms the fact that innovating small and medium-sized firms should not be regarded as a homogenous group. For this sample of small and medium-sized firms it can be stated that the R&D employment intensity decreased with a firm's increasing size. The divergencies in productivity increased over time, i.e. from the first period to the second, with its large number of small firms. Yet there is a bias towards smaller firms which hold patents. The conclusion for this sample is that the productivity of R&D employees, measured by the number of patents, is higher among a minority of small firms (up to 49 employees) than in the next higher size class.

Notes

[1] See the works of Bade (1979, 1983), Watts (1981), Markusen (1985), Grabher (1988).

[2] In my dissertation (Pfirrmann, 1991) I have compared regional studies of industrialized countries which analyze the diffusion and generation of innovation and which address the determining factors. Most of them emphasize internal company factors but only few, for example Ewers and Fritsch (1987), deny the relevance of the firm's regional environment.

[3] The data were provided by the Fraunhofer Institut für Systemtechnik und Innovationsforschung (ISI). Where necessary, the data were supplemented by information from the periodicals of the Bundesforschungsanstalt für Landeskunde und Raumordnung (BfLR) and the Statistical Offices of the Federal States.

[4] In their latest publication "Forschungs-und Technologiepolitischen Gesamtkonzept" (1989) the Federal Ministry for Research and Technology (BMFT) and the Federal Ministry for Trade and Commerce (BMWi) talk of 25,000 innovating small and medium-sized firms. This figure is based on estimates of firms who participated in the programme PKZ, as well as in a number of other indirect-specific promotion initiatives.

[5] Firms whose sales and number of employees over a three year average stabilized within the eligibility criteria could also apply for funds; for an extensive study of the programme guidelines see Becher 1989: 9 ff. The content and impact of the PKZ programme are not being discussed in this paper. They have been evaluated extensively elsewhere (Meyer-Krahmer, Gielow and Kuntze, 1984; Becher, 1989).

[6] The intersection of the two subsets consists of around 4,000 firms, which points to considerable differences in the two subsamples.

[7] For conditions concerning content and methodology of the sample see Pfirrmann (1991) and the literature cited there.

[8] For an overview of these economic sectors see Statistisches Bundesamt, Reihe 4.1.3, *Regionale Verteilung der Betriebe im Bergbau und im Verarbeitenden Gewerbe und deren Beschäftigte*, 1984, p. 4.

[9] The classification of firms as small, medium-sized and large is defined in the guidelines of the PKZ programme and the guidelines generally agreed upon in German literature on the subject. Firms with up to 49 employees are classified as small, firms with up to 999 employees as medium-sized, and firms with 1,000 and more employees are classified as large (see Meyer-Krahmer et al., 1984; Fritsch 1987, p. 175). For the purpose of this analysis the first year of participation in the programme determines a firm's allocation to a particular employment size class.

[10] In this context the work of Hughes (1988) should be mentioned. She discovered that if an intra-industrial approach is taken, R&D intensity often deviates more strongly than with an inter-industrial approach. An analysis at this level, however, would have been beyond the scope of this study, which is why the possibly heterogenous economic sectors will be treated as homogenous with regard to R&D employment intensity. Furthermore, Tabbert (1974) in his analysis of R&D efforts in German industry points out that the choice of indicator is significant in terms of what counts as R&D employment intensity was chosen, because experience has proved it to show the least distortions.

[11] For both periods, 1978—1980 and 1981 to 1984, the ratio of small and medium-sized firms is 1:2:4, i.e. in agglomerated regions there are four times as many innovating small and medium-sized firms as in rural areas, and twice as many as in moderately congested areas. Size and/or sector effects do not play a role here.

[12] The employment size classes were divided into 1—49 employees, 50—99, 100—499, 500 and more; the sectors were divided into energy and chemicals, metal, mechanical engineering and automotives, electronics and electronic data processing, ceramics, glass and synthetic materials, wood and paper, textiles and garments, food and construction. For more information about the methodology concerning the variance analysis see Pfirrmann (1991).

References

Acs, Z. J. and D. B. Audretsch, 1991, 'R&D, Firm Size, and Innovative Activity', in Z. J. Acs and D. B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 39—59.

Acs, Z. J., D. B. Audretsch, and M. P. Feldman, 1992, 'Real Effects of Academic Research', *American Economic Review* **82**, 363—367.

Arend, M. and B. Stuckey, 1984, 'Zu den Ursachen räumlicher Innovationsdisparitäten in der Schweiz', in E. A. Brugger (ed.), *Regionale Innovationsprozesse und Innovationspolitik*, Diessenhofen: Rüegger, pp. 23—40.

Bade, F. J., 1979, 'Funktionale Aspekte der regionalen Wirtschaftsstruktur', *Raumforschung und Raumordnung* **6**, 253—268.

Becher, G., 1989, *FuE-Personalkostenzuschüsse. Strukturentwicklung, Beschäftigungswirkungen und Konsequenzen für die Innovationspolitik*, Study of the Fraunhofer-Institut für Systemtechnik und Innovationsforschung and the Deutsches Institut für Wirtschaftsforschung, Karlsruhe and Berlin.

Bonkowski, S. and H. Legler, 1985, 'Süd-Nord-Gefälle bei industrieller Forschung und Entwicklung?', *Raumforschung und Raumordnung* **1**, 1—10.

Bound, J., G. Cummins, Z. Griliches, B. Hall and A. Jaffe, 1984, 'Who Does R&D and Who Patents', in Z. Griliches (ed.), *R&D, Patents, and Productivity*, Chicago: University of Chicago Press, pp. 21—54.

Brockhoff, K., 1986, 'Die Produktivität der Forschung und Entwicklung eines Industrieunternehmens', *Zeitschrift für Betriebswirtschaft* **6**, 525—537.

Bundesministerium für Forschung und Technologie/Bundesministerium für Wirtschaft, 1989, *Forschungs-und Technologiepolitisches Gesamtkonzept für kleine und mittlere Unternehmen*, Bonn.

Echterhoff-Severitt, H., 1976, *FuE-Aufwendungen in Unternehmen der Bundesrepublik Deutschland 1971/1973. Eine empirische Analyse unter besonderer Berücksichtigung kleiner und mittlerer Unternehmen*, Essen: Stifterverband für die Deutsche Wissenschaft.

Ewers, H.-J., 1984, 'Räumliche Innovationsdisparitäten und räumliche Diffusion neuer Technologien', in E. A. Brugger (ed.), *Regionale Innovationsprozesse und Innovationspolitik*, Diessenhofen: Rüegger, pp. 97—118.

Ewers, H.-J. and M. Fritsch, 1987, *Die räumliche Verbreitung von computergestützten Techniken in der Bundesrepublik Deutschland*, Technical University of Berlin, Diskussionspapier No. 120, Berlin.

Freeman, C., 1982, *The Economics of Industrial Innovation*, 2nd edition, London: Francis Pinter.

Fritsch, M., 1987, 'Groß und Klein in der Wirtschaft? Was Man Darüber Weiß und Was Man Darüber Wissen Sollte', in M. Fritsch and C. Hull (eds.), *Arbeitsplatzdynamik und Regionalentwicklung, Beiträge zur beschäftigungspolitischen Bedeutung von Klein-und Großunternehmen*, Berlin: Sigma, pp. 175—201.

Grabher, G., 1988, *De-Industrialisierung oder Neo-Industrialisierung? Innovationsprozesse in traditionellen Industrieregionen*, Berlin: Sigma.

Griliches, Z., 1991, 'Patents Statistics as Economic Indicators: A Survey', *Journal of Economic Literature* **28**, 1661—1707.

Hägerstrand, T., 1967, *Innovation Diffusion as a Spatial Process*, Chicago: University of Chicago Press.

Harris, R. I. D., 1988, 'Technological Change and Regional Development in the UK: Evidence from the SPRU Database on Innovations', *Regional Studies* **22**, 361—374.

Hughes, K., 1988, 'The Interpretation and Measurement of R&D-intensity — A Note', *Research Policy* **17**, 301—307.

Jaffe, A. B., 1989, 'Real Effects of Academic Research', *American Economic Review* **79**, 957—970.

Kamien, M. I. and N. L. Schwartz, 1975, 'Market Structure and Innovation: A Survey', *Journal of Economic Literature* **13**, 1—37.

Kamp, E. M. and E. May, 1981, 'Forschung und Entwicklung in kleinen und mittleren Unternehmen', *Zeitschrift für Betriebswirtschaft* **4**, 347—369.

Malecki, E. J., 1980, 'Corporate Organization of R&D and the Location of Technological Activities', *Regional Studies* **14**, 219—234.

Malecki, E. J. and P. Variaya, 1986, 'Innovation and Changes in Regional Structure', in P. Nijkamp (ed.), *Handbook of Regional and Urban Economics* I, Amsterdam: Elsevier, pp. 629—645.

Markusen, A. R., 1985, *Profit Cycles, Oligopoly and Regional Development*, Cambridge, Mass.: Cambridge University Press.

Meyer-Krahmer, F., G. Gielow and U. Kuntze, 1984, *Wirkungsanalyse der Zuschüsse für Personal in Forschung und Entwicklung*, Study of the Fraunhofer-Instituts für Systemtechnik und Innovationsforschung, Karlsruhe.

Meyer-Krahmer, F., 1985, 'Innovation Behaviour and Regional Indegenous Potential', *Regional Studies* **19**, 523—534.

O'Farrell, P. N. and D. Hitchins, 1988, 'The Relative Competitiveness of Small Manufacturing Firms in Scotland and the Mid-West of Ireland: An Analysis of Matched Pairs', *Regional Studies* **22**, 399—416.

Pfirrmann, O., 1991, *Innovation und regionale Entwicklung. Eine empirische Analyse der Forschungs-, Entwicklungs- und Innovationstätigkeit kleiner und mittlerer Unternehmen in den Regionen der Bundesrepublik Deutschland 1978—1984*, München: V. Florentz.

Rothwell, R., 1982, 'The Role of Technology in Industrial Change: Implications for Regional Policy', *Regional Studies* **16**, 361—369.

Scherer, F. M., 1983, 'The Propensity to Patent', *International Journal of Industrial Organisation* **1**, 107—128.

Statistiches Bundesamt (ed.), 1984, *Regionale Verteilung der Betriebe im Bergbau und im Verarbeitenden Gewerbe und deren Beschäftigte 1982*, Reihe 4.1.3, Wiesbaden: Kohlhammer.

Tabbert, J., 1974, *Unternehmensgröße und technischer Forschritt. Eine empirische Untersuchung für die Bundesrepublik Deutschland*, Göttingen: Otto Schwartz & Co.

Thomas, M. D., 1985, 'The Innovation Factor in the Process of Microeconomic Industrial Change — Conceptual Explorations', in G. A. van der Knaap and E. Wever (eds.), *New Technology and Regional Development*, London: Croom Helm, pp. 21—44.

Thwaites, A. T., 1982, 'Evidence of Product Innovation in the Economic Planning Regions of Great Britain', in D. Maillat (ed.), *Technology: A Key Factor for Regional Development*, Saint-Saphorin: Georgi, pp. 97—119.

Tödtling, F., 1990, *Räumliche Differenzierung betrieblicher Innovation. Erklärungsansätze und empirische Befunde für österreichische Regionen*, Berlin: Sigma.

Watts, H., 1981, *The Branch Plant Economy: A Study in External Control*, London: Croom Helm.

Wrigley, N. and F. Brouwer, 1986, 'Qualitative Statistical Models for Regional Economic Analysis', in P. Nijkamp (ed.), *Handbook of Regional and Urban Economics* I, Amsterdam: Elsevier, pp. 444—490.