Innovation and Space: The Concept of Regional Knowledge Production Functions

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Abstract

In the early stages location theory mainly concentrated on the spatial pattern of industrial activities. Although the focal point of theoretical considerations and empirical analysis has shifted towards the service sector in the meantime, the location of knowledge-based activities has not yet been explained in a satisfying way. Especially the spatial dimension of innovation processes needs further examination. Thus, the article will deal with spatial patterns of patent applications trying to reveal the key location factors of inventive activities. Based on macroeconomic production theory a regional knowledge production function will be developed and empirically tested by statistical data for the Austrian regions.

In this approach regional patent densities are not only explained by "classical" production factors such as human and real capital but also by the accessibility and the availability of relevant knowledge. On the one hand, recent studies have shown that due to the crucial role of „tacit knowledge" proximity still matters even in activities, which were commonly considered to be "footloose". On the other hand, since spatial proximity to competent persons does not guarantee knowledge-spillovers, the institutional conditions in a region, which determine the transaction costs for acquiring knowledge, also have to be regarded. These soft location factors, which are often referred to as "institutional thickness" or "embeddeness" in literature, will therefore play an important role in the regional knowledge production function to be developed.

Key words: invention, innovation, regional knowledge production function, institutional conditions, transaction costs, location factors

1. The concept of Regional Knowledge Production Functions

Regional production functions are specific forms of macroeconomic production functions, which refer to single regions displaying the relation between input factors and the economic output at a given state of technology. Since the early 1980ies a lot of theoretical and empirical work has been done to develop and estimate regional production functions in various spatial contexts. Based on the classical macroeconomic input factors capital, labour and land most approaches in that field try to explain regional Gross Domestic Product (GDP) by a variety of relevant regional production factors: Rietveld (1989) amends labour and capital by "infrastructure" as an additional production factor, which covers relevant public capital (e.g. transport, communication, energy and water supply, education and health services). Contrary to this approach Blum (1982) ignores all mobile factors and considers only immobile "input-potentials" (including agglomeration, traffic capacities, supply of industrial sites, recreation and information potential, natural environment and central place position) in his function. In a similar way Biehl (1991) neglects labour and capital arguing that mobile factors cannot determine regional conditions and defines the "regional development potential" as a function of infrastructure, location, agglomeration, settlement and economic structure. Duffy-Deno (1991) uses a production function in order to estimate the application of labour and capital in the production sector. He shows that private capital can more easily be substituted by public capital than labour concluding that employment effects of public investment are comparably low in industry. Wegener and Boekemann (1998) integrate "regional accessibility" as an additional production factor into the function in order to assess the economic impacts of transport infrastructure investment. Although all these applications are theoretically based on the macroeconomic concept of production functions, most of them obviously differ from the original approach. In most empirical studies production factors are not interpreted literally but roughly indicated by "proxies" describing relevant regional conditions.

This concept has been specified in so-called "Knowledge Production Functions", which do not cover all economic activities but only the production of knowledge and innovation. Griliches (1979) was the first to develop and assess a function which links R&D-investment with innovation output. In a similar way Jaffe (1989) uses a Cobb-Douglas-function to explain patent applications by university research expenditures and industrial investment in R&D. Feldman (1994) enhances this approach by using actual product innovation data instead of patent applications and by applying the presence of related industry and specialised business services as additional explaining variables. Oerlemans et al. (2001) estimate a

microeconomic function explaining innovative output of single firms not only by the existence of relevant resources but by their actual use in the innovation process. Fritsch (2002) estimates the efficiency of R&D-efforts in different spatial contexts in order to reveal relevant conditions for innovation.

Contrary to these approaches the Regional Knowledge Production Function used in this paper refers directly to the basic principles of the general macroeconomic production function. It considers the "classical" production factors labour and capital amending it by information and knowledge as the third relevant factor for knowledge-based activities and especially for invention and innovation. The next chapter will reveal specific characteristics of this additional production factor and explain why it has to be treated in a different way compared to other factors.

2. Introducing knowledge into location theory

In classical economic theory the role of "knowledge" and "information" was largely neglected, since they were considered to be freely available and accessible for all economic subjects. As a consequence classical location theory based on the works of VonThünen (1826), Weber (1909), Christaller (1933), Lösch (1940) or Alonso (1960) did not make use of these categories when explaining locational decisions or spatial patterns. These approaches concentrated their interest on the spatial allocation of commerce and industry, which was explained by immobile factors and transport costs, but they totally ignored service or even knowledge-based activities.

In order to describe the location factors of inventive activities, it is necessary to regard knowledge as an economic good resulting from entrepreneurial efforts on the one hand and as a relevant production factor on the other. In this context two characteristics of knowledge have to be taken into account (see Kramar 2005, p.27):

- Intangibility
- Attributes of a public good

On the one hand knowledge is an intangible good, which makes transport subject to particular principles: While tangible goods have to be transported physically, knowledge transfer can either happen by material carriers (e.g. persons, books or data storage media) or by telecommunication. In this context the discrepancies between „tacit knowledge", which can only be exchanged by face-to-face-contacts, and „codified information", which can also be

transferred by telecommunication[1], have been broadly discussed in geographic and economic literature in recent years (see Cowan, David, Foray 2000, Nightingale 2001, Breschi, Lissoni 2001). Assuming that a great part of relevant and specific knowledge is still bound to persons and their locations, the spatial accessibility of these people, which determines transport costs for acquiring knowledge has to be considered in the production function.

On the other hand knowledge is widely considered to be a public good, because it basically shows some relevant characteristics: it can well be consumed without reducing the benefit for other users ("non-rivalry") and it is difficult to exclude single subjects from its benefits ("non-excludability"). In a knowledge-based economy, however, legal regulations and institutional arrangements define property rights determining exclusive rights of use and disposal. These regulations make knowledge a scarce production factor and a competitive good, which is produced and traded by private firms. This insight implies that the role of knowledge as a production factor can only be assessed properly, when legal conditions are taken in to account. For that reason the main ideas of the theory of „property rights"[2] and the closely related concept of „transaction costs"[3] are applied to indicate the role of knowledge in the production process. These approaches are based on the assumption that transaction costs are determined by the distribution of property rights on the market participants (see Schüller 1982, p.IX) which is closely connected to the institutional conditions established by the organisations involved[4]. Consequently, a contemporary economic approach must not be confined to the spatial accessibility of knowledge, but also has to account for the actual availability of knowledge for potential users, which means that regional production functions need to consider transaction costs for acquiring knowledge.

While accessibility and transport costs of production factors play a dominant role in classical location theory, the actual availability and the resulting transaction costs remain largely unconsidered when explaining spatial patterns of production. Thus, regional innovation

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[1] This classification of knowledge goes back to Polanyi's work "The Tacit Dimension"(1966)

[2] The theory of property rights which deals with the institutional conditions of market transactions basically goes back to Coase (1937, 1960), who was the first to treat institutions in economic terms.

[3] Transaction costs cover all costs incurred by the transfer of property rights and include all expenses necessary to exchange goods on a market (see Pejovic 1997, p.84)

[4] In institutional economics the term "institutions" stands for formal and informal regulations and restrictions ("rules of the game") while groups of individuals are referred to as "organisations" ("players of the game")

disparities are mainly attributed to the spatial concentration of innovative firms in respective literature. Many approaches of the late 1980ies and early 1990ies tried to identify the agglomeration factors of innovation poles, which were referred to as “Innovative Milieus” (Camagni 1991), “Industrial Districts” (Becattini 1990) or ”Clusters” (Porter 1990). Based on the assumption that tacit knowledge can only be exchanged in face-to-face contacts these approaches implicitly treated knowledge as a “local public good” which is equally available to everybody who resides in such a location. Recent research, however, argues that spatial proximity is no guarantee for the exchange of information and the appearance of “knowledge-spillovers” (see Audretsch 1998, Oerlemans et al. 2001, Breschi, Lissoni 2001).

In this context the key conditions that incite the innovative actors to make use of spatial proximity have to be examined (see Fritsch 2003, p.80). An important contribution to that problem has been given by various network approaches which draw their attention to the relations between the firms. While some authors tackle the problem by analysing the composition of firms in such innovative milieus (see Audretsch 2003, p.20), others try to identify hierarchies and dependencies between the innovators (e.g. Storper, Harrison 1991). The concept of “embeddedness”, which goes back to Granovetter (1985), regards the integration and the involvement of the actors in the local milieu as the main basis for collective learning and informal conventions and rules. In a similar way Amin and Thrift (1994) consider the “institutional thickness” in a certain location, which includes social, economic and political relations among the local actors. Although trust and confidence are not explicitly emphasised in these approaches, these categories are implicitly regarded as basic requirements for knowledge-spillovers and as integral parts of innovative spirit.

3. Amending the Regional Production Function with knowledge-related factors

As shown in the previous chapter, the specific characteristics of knowledge demand to consider two different dimensions when integrating it in a Regional Production Function:

- Accessibility of knowledge
- Availability of knowledge

On the one hand accessibility of tacit knowledge, which is influenced by the distance to knowledge carriers, their mobility and the quality of the transport system, is an important location factor for innovative activities. Since these conditions strongly deviate on different locations, it is a spatially differentiated location factor, which has to be considered in the

function. Therefore the “accessibility of knowledge” will be indicated by the local transport costs necessary for acquiring relevant knowledge (see chapter 4).

On the other hand, as argued in the previous chapter, the mere accessibility of knowledge does not imply that it is actually available for potential users. Thus, the availability of knowledge, which is reflected in transaction costs for its acquisition, has to be regarded as an additional location factor of innovative activities. In this context the crucial question is, whether institutional conditions, which determine the availability of knowledge, differ in space: It can be assumed that basic legal regulations, which could be called to account for innovation disparities, hardly show any differences within countries. It is, however, the character of informal rules (e.g. code of conduct, tradition, customs) as constituted by regional actors which accounts for locally unequal conditions for knowledge-based activities. These specific forms of institutional conditions, which are central elements of “institutional thickness” and “embeddeness”, help to overcome and protect existing property barriers and therefore determine the transaction costs for obtaining relevant knowledge in a certain region. Since informal rules are very hard to quantify directly, the „availability of knowledge“ will be indicated by the organisations exerting a significant influence on in the relevant social processes and can therefore be called to account for the local level of transaction costs (see chapter 4).

In addition to these two knowledge-based factors the Regional Knowledge Production Function also includes the “classical” production factors labour and capital, which are simplistically measured by the relevant endowment within the region at a certain point of time. Of course it would also be possible to reflect their accessibility and availability, but due to their limited short-time mobility and the less important role of institutional conditions in their acquisition, it seemed to be justified to refrain from such a differentiation.

Under the assumption that the production factors are complementary and can only be substituted to a certain degree the function is specified in an exponential form with constant elasticity of substitution. Thereby each of the factors is considered to have certain relevance for the emergence of inventions, which cannot be taken over by the other factors. Fulfilling all these considerations, the Regional Knowledge Production Function can be defined as follows:

$$I_i = L_i^{\beta_1} \times C_i^{\beta_2} \times A_i^{\beta_3} \times V_i^{\beta_4}$$

I …..... Inventions
i …… Region i
L ..... Regional endowment with the factor „labour“

C ..... Regional endowment with the factor „capital“
A ..... Regional accessibility of the factor „knowledge“
V ..... Regional availability of the factor „knowledge“
ß …..... Elasticities

4. Calibrating a Regional Knowledge Production Function

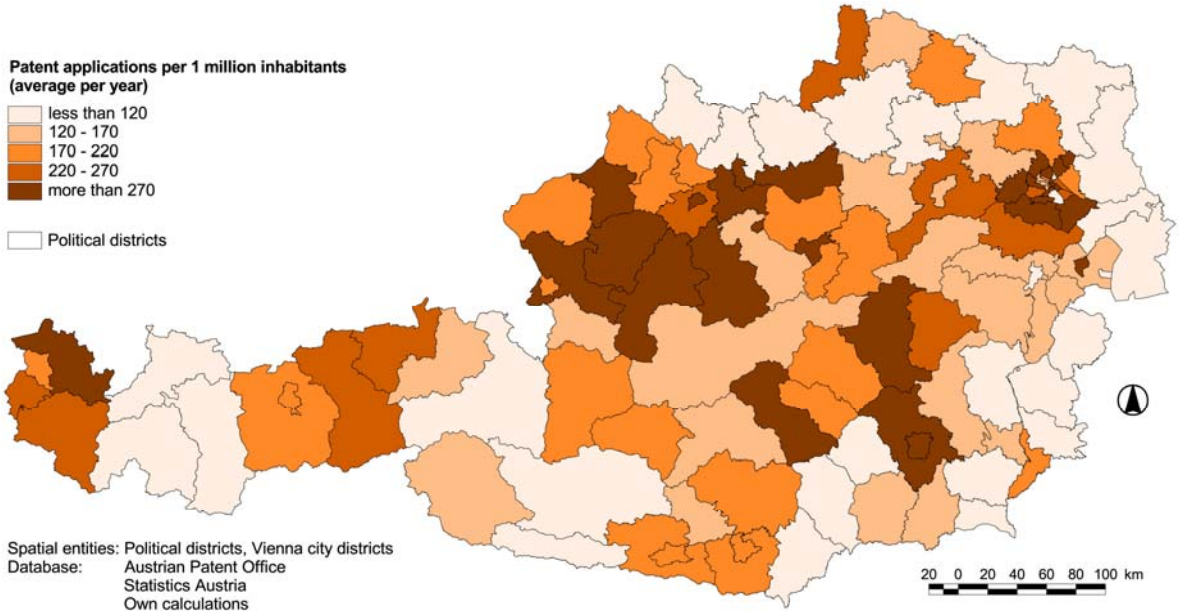
Generally speaking, a Regional Knowledge Production Function aims at explaining the production of new knowledge as a function of the relevant regional conditions. Since it is not possible to cover all knowledge generated, the target value always has to be confined to certain aspects of knowledge. Due to poor availability of proper data patent applications are commonly used as the dependent variable of the function. Assuming economically rational behaviour this indicator comprises all inventions, which have the potential to induce innovation, since only patent registration assures exclusive rights of use and allows profitable industrial application. In that way this indicator reflects on a relevant selection of scientific inventions which is definitely worth to be examined. In spite of that it has to be considered that patent registrations are strongly related to natural and technical sciences neglecting large parts of arts and humanities and totally ignoring creative and artistic achievements.

In spite of these restrictions the number of patent applications is used as the dependent variable of the Regional Knowledge Production Function. The dataset covers 15.267 patent applications registered by the Austrian Patent Office submitted by firms or persons with a registered office or residence in Austria between January 1996 and September 2003. It gives information on the year of submission, the applicants' location (address and postal code) and the kind of invention[5] for each of these applications. Since the data allowed to assign the patents to municipalities, it was possible to identify the number of patent applications on the district level (98 political districts and 23 urban districts of Vienna), which was related to the number of inhabitants in order to get comparable results. The spatial distribution of this indicator ("patent application density") shows the heavy concentration of patent application in the urban and industrial agglomerations of Austria (see figure 1): The Vienna Region, the industrial region in northern Styria, the central region of Upper Austria, the Inn-valley in the Tyrol and most parts of Vorarlberg show the highest number of patent applications per capita.

[5] The patented inventions are differentiated by the 8 sectors of the International Patent Classification (IPC). This analysis, however, only considers the total number of patent applications.

Surprisingly in these regions many of the suburban areas show higher values than the cities themselves. Invention densities are lowest in the peripheral and rural areas in the Alps and along the former external border of the EU.

Figure 1: Patent application density (District level)



These empirical findings, which illustrate the spatial concentration of inventive activities, indicate that locations of applicable inventions are strongly influenced by particular regional conditions. According to the regional knowledge production function specified above there are four factors determining the inventive power a region, which are represented by the following regional indicators:

- „duration of education (DE)“ (number of years that an average employee has spent in vocational education beyond primary school) for „regional endowment with labour“
- „equity investment in research and development (EI)“ (annual investment in real estate and factory equipment in the field of research and development per employee) for „regional endowment with capital“
- „knowledge accessibility potential (KP)“ (accessibility of knowledge-intensive locations calculated by a gravity-based potential model) for „regional accessibility of knowledge“
- „organisation density (OD)“ (employees in firms and organisations aiming at reducing transaction costs per capita) for „regional availability of knowledge“

In order to give a rough evidence on the importance of these four factors for inventive activities, these indicators are implemented by statistical data on the district level for the year 2001 and examined regarding their correlation with regional patent density. Eliminating 4 of 121 districts with extraordinary or zero values the coefficients of correlation range between +0,269 and +0,500 (see table 1).

Table 1: Correlation between production factors and regional patent density

Indicator	DE	EI	KP	OD
R	0.500**	0.269**	0.391**	0.475**
Sign. (2-tailed)	0.000	0.003	0.000	0.000

** Correlation is significant at the 0.01 level (2-tailed).

Although the bivariate correlation analysis reveals statistically significant positive correlations between these four indicators and regional patent density, none of the single indicators is able to explain regional patent disparities to a satisfying degree. Furthermore this kind of monocausal analysis does not consider mutual dependencies of the factors. Using a regional knowledge production function as specified in section 2 it is possible to regard regional patent densities as a function of all four production factors. In that manner the single impacts of the factors considering their complementarities can be quantified. Describing the four production factors by the chosen regional indictors the regional knowledge production function is estimated by means of a multivariate regression on the empirical basis of 120 districts in Austria[6]. To avoid an iterative calibration the non-linear function is transformed into a logarithmic-linear form:

$$\ln(ID_i) = \beta_1 \times \ln(DE_i) + \beta_2 \times \ln(EI_i) + \beta_3 \times \ln(KP_i) + \beta_4 \times \ln(OD_i) + \beta_5$$

ID …..... invention density (representing „invention“)
ln ……. natural logarithm
i …..…. district
DE ..... duration of education (representing „regional endowment with labour“)
IE ..... equity investment in R&D (representing „regional endowment with capital“)
KP ..... knowledge accessibility potential (representing „regional accessibility of knowledge“)
OD ..... organisation density (representing „regional availability of knowledge“)
ß …..... elasticities

[6] Only one of the 121 districts (98 political districts and 23 urban districts in Vienna), which did not have any registered patent application, had to be excluded from the calibration for statistical reasons (the logarithm of zero is not defined).

The calibration of the regression model provides a coefficient of determination (r^2) of 0,519. The F-Test reveals that the explanatory variables contribute to the explanation of the dependent variable in a statistically significant way with a probability of error of less than 1 percent.

The estimated coefficients of the explaining variables are clearly positive and statistically significant: the 95%-confidence intervals of the estimates are confirmed by the results of the T-Test, which shows that all coefficients are significantly different from 0 with a probability of error of less than 1,6% (see table 2). The standardised coefficients (Beta) reveal a higher influence of the factors „endowment with capital" and „availability of knowledge" on regional patent density than „endowment with labour" and „accessibility of knowledge". Considering the fact that the capital indicator showed the lowest correlation with patent density in the monovariate correlation analysis this result might be a bit surprising at first view. The multivariate regression analysis, however, demonstrates that capital endowment explains a relevant part of regional disparities, which is not covered by the other factors. Multicollinearity resulting from high correlation of the explanatory variables, which may spoil the stability and significance of a regression model, is screened out by a collinearity analysis. The relatively high tolerances of the estimates[7] prove that each of the four factors has additional explanatory power for the model which cannot be replaced by the others.

Table 2: Estimation results of the coefficients

	Unstandardised Coefficients		Standard. Coeff.			95% Confidence Interval for B		Collinear. Statistics
	B	Std. Err.	Beta	t	Sign.	Lower Bound	Upper Bound	Tolerance
Constant	-8.206	2.572		-3.191	0.002	-13.300	-3.112	
DE	0.565	0.082	0.479	6.925	0.000	0.403	0.726	0.876
EI	1.414	0.576	0.231	2.454	0.016	0.273	2.555	0.472
KP	0.883	0.240	0.259	3.671	0.000	0.406	1.359	0.843
OD	0.287	0.078	0.374	3.697	0.000	0.133	0.441	0.410

The model predicts logarithmised annual patent densities between 4,28 and 5,65 with a mean value of 5,22 (see table 3). The residuals, which give the deviation between the estimated and the observed values, range between -1,26 and +1,34. Regarding the standardised distribution

[7] The tolerances of the estimates give the share of variance that cannot be explained by a linear combination of the other variables.

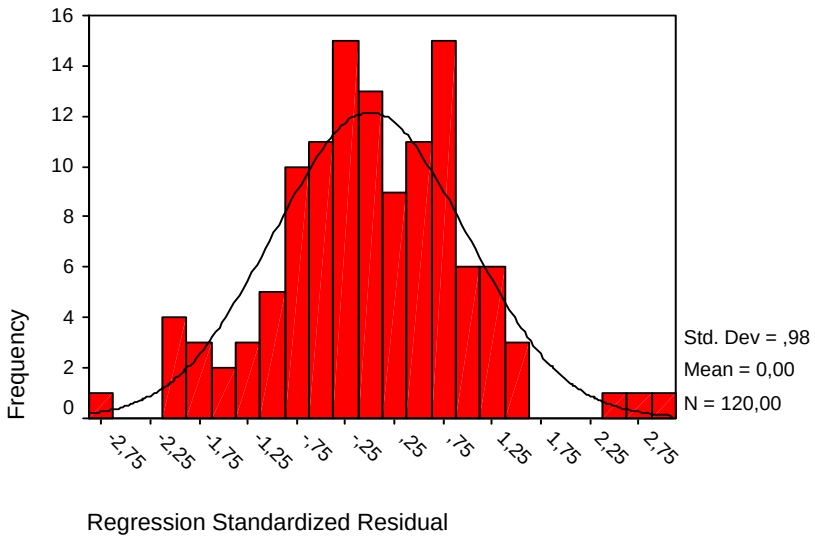
of values[8] it turns out that the maximum positive estimates and residuals are higher than the respective negative values. These results can be attributed to the extraordinary values of the three outliers. In these regions patent densities can not fully be explained by the chosen variables and are therefore clearly under-estimated by the model.

Table 3: Residuals statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4,277	6,561	5,229	,470	120
Residual	-1,264	1,341	-2,1E-16	,453	120
Std. Predicted Value	-2,024	2,831	,000	1,000	120
Std. Residual	-2,743	2,911	,000	,983	120

In spite of these three outliers the frequency distribution of the model residuals resembles a normal distribution to a large extent (see figure 5). These extraordinary regions, which can be seen on the right side of the diagram, do not seriously disturb the symmetry of the distribution.

Figure 2: Frequency distribution of residuals



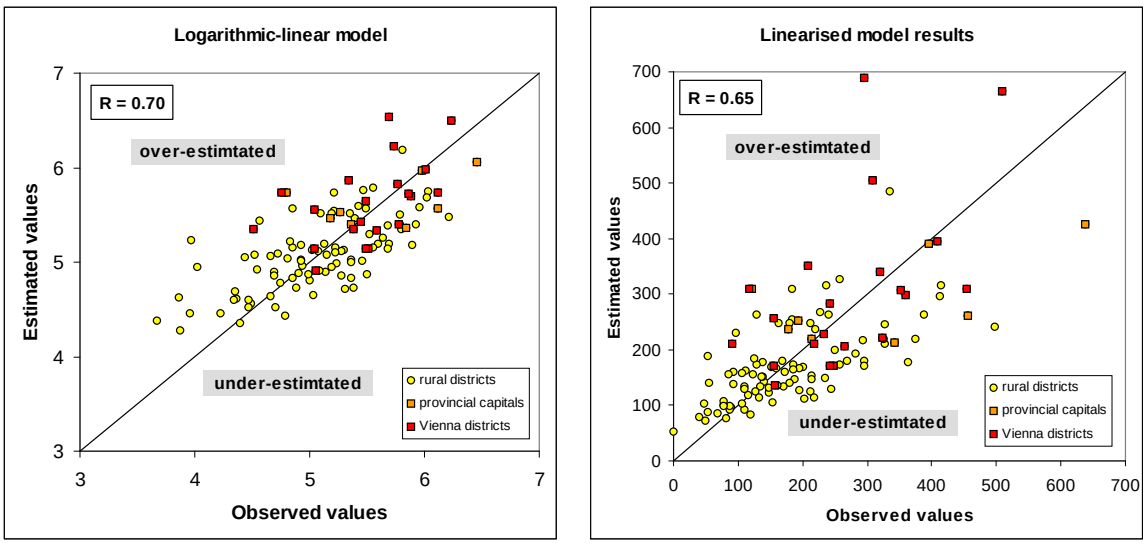
Another important condition for the statistical robustness of a regression model is the absence of autocorrelation of the residuals, which often appears in regression analysis dealing with time series („serial correlation“) or spatial data (“spatial correlation“). In that case the standard deviations of the regression coefficients are distorted, which might cause incorrect

[8] A distribution is standardised by converting it to a distribution with a mean of 0 and a standard deviation of 1.

results in the significance tests. Autocorrelation of residuals are examined by the Durbin-Watson-Test. For the given distribution with 120 values and 4 explaining variables and a significance level of 0,01 the Durbin-Watson statistic of 2,106 clearly resides between the critical values of 1,66 and 2,34, which means that autocorrelation can be excluded with a probability of error of less than 1%.

In order to examine the model residuals in more detail, they are illustrated in scatter-plots which contrast observed and estimated patent densities. The left diagram in figure 3 shows the results of the model in its logarithmic-linear form and therefore gives logarithmic values of the observed and estimated regional patent densities. The dots[9] above the diagonal represent over-estimated districts, in which the estimated results are higher than the observed values, the dots below the line represent under-estimated districts. In order to examine whether the model is able to reproduce not only the logarithmised, but also the absolute patent densities, the estimated values are translated into linear values and compared with the respective observed values (see right diagram in figure 6).

Figure 3: Logarithmic and linearised model results (observed / estimated values)



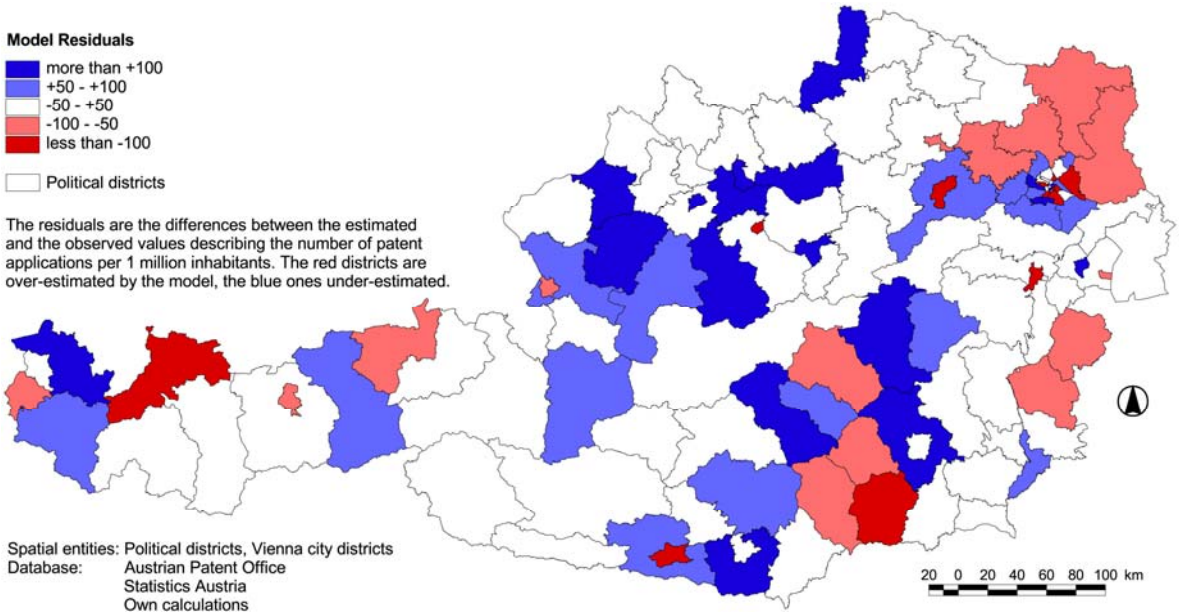
The most evident difference between these two scatter-plots is that the residuals of the absolute values tend to rise with size. This result can easily be explained by the fact that the model was calibrated on the base of logarithmised values, which means that not the differences, but the ratios between observed and estimated values were minimised. Due to the

[9] Since different kinds of districts show different levels of patent densities, Vienna districts, provincial capitals and rural districts are displayed bay different symbols.

relatively high residuals of some districts with high patent densities the correlation coefficient between observed and estimated values is slightly lower when considering the absolute results than in the original logarithmic model. Surprisingly, the correlation analysis in both cases is not very sensitive to the inclusion or exclusion of the three districts with extraordinary patent densities.

Finally, the model residuals are analysed with regard to their spatial distribution. Remarkable spatial concentration of high positive or negative residuals can provide an indication of missing explaining variables or structural weaknesses of the model. Comparing the spatial patterns of estimated and the observed values, however, it becomes obvious that the model is able to reproduce the patent densities of Austrian political and Vienna city districts in a satisfying way: The model assigns the highest values to the big urban centres and their surroundings as well as to the main industrial regions (especially Northern Styria, the Rhine Valley and the central region of Upper Austria). While the urban agglomerations get high values due to their high education and accessibility levels, the industrial regions mainly profit from their good endowment with capital. Although this rough spatial pattern does not deviate significantly from the actual pattern of observed patent densities, the spatial distribution of model residuals (see figure 7) shows considerable differences in some regions.

Figure 4: Model residuals



Under-estimated districts (indicated in blue) are to be found all over the country: not only rural, alpine and remote regions, but also some urban centres belong to this category. Especially the surroundings of the big urban centres (Linz, Salzburg, Graz, St. Pölten

Klagenfurt, Villach) have higher patent densities than the regional values of the four explaining factors would suggest. Contrary to that, the northern and eastern surroundings of Vienna are over-estimated: In these suburban areas the locational advantages caused by the close relation and small distance to the Austrian capital seem to support inventive activities less than expected. Patent densities are also over-estimated in rural areas in the South and West of Austria: In these cases the model failed in considering their locational disadvantages, mainly caused by their remoteness, sufficiently.

On the whole, however, the spatial distribution of residuals does not disclose a clear pattern that could be a sign of basic structural weaknesses of the model or of improper choice of explanatory variables. The vast majority of residuals can therefore be attributed to regional peculiarities, which can not be explained by general location factors. On the whole the analysis of the regression residuals does not point out any lack of statistical significance or of robustness of the model.

5. Conclusions

Based on the methodological principles of the general macroeconomic production function the paper specifies a Regional Knowledge Production Function, which introduces knowledge as an additional relevant factor complementing the “classical” production factors labour and capital. Dealing with the specific characteristics of knowledge (intangibility, attributes of a public good) it turns out that both accessibility and availability of knowledge have to be considered in the production function. On the one hand it is argued that an important part of relevant knowledge is “tacit”, which makes transport costs still necessary. On the other hand, since the mere accessibility of knowledge does not imply that it is actually available, the transaction costs for its acquisition also have to be regarded.

The calibration of a Regional Knowledge Production Function for the Austrian districts clearly shows that regional patent densities depend on both dimensions of knowledge. These results corroborate the hypothesis that both accessibility and availability of knowledge are spatially differentiated location factors for research activities: Contrary to the assumption of several approaches, which say that knowledge has become a ubiquitary factor, the costs for physical transport of tacit knowledge still seem to be important for innovative firms. Beyond that, informal relations, networks, conventions and rules in a certain location, which are represented in categories like “embeddedness” or “institutional thickness”, are crucial requirements for effective research. Finally, the results indicate that the qualification of labour

and the quality of research-related capital also play important roles for inventive activities in a region.

On the one hand these findings confirm the relevance of classical instruments of regional policy like improving occupational skills, promoting investment in private capital and public infrastructure and improving accessibility in a region. On the other hand, however, they suggest political strategies, which go far beyond these approaches by focussing on the reduction of transaction costs incurred by knowledge transfer. These strategies do not primarily aim at increasing the amount and quality of knowledge within a region, but at facilitating its availability and usability for innovative firms. Since legal regulations are largely constituted on the national level, regional policy is confined to guaranteeing the efficiency of relevant law and to improving the institutional and organisational structures within a region. Thus, all measures, which contribute to the reduction of transaction costs by either increasing the predictability of legal decisions or by promoting knowledge transfer between innovative firms, foster the generation of new ideas and innovative activities in a region.

Although the formalisation of the Regional Knowledge Production Function is based on theoretical considerations and the statistical assessment of the function provides satisfying and plausible results, a lot of theoretical, methodological and empirical questions still wait for further research. The following list gives some hints on weaknesses and inaccuracies of the approach specified in this paper and tries to suggest potential improvements:

- As the name already indicates, a Knowledge Production Function tries to display the emergence of new knowledge. Patent applications, however, only give a very fragmentary description of all creative processes, in which applicable knowledge is created. Therefore efforts should be made to define indicators, which cover scientific, creative and artistic achievements in a more comprehensive way.
- A very pragmatic problem referring to patent application data consists in the fact that the location of the application does not necessarily coincide with the location of the creative process. Due to organisational reasons patents are often applied for by legal departments and not by research sections of firms, which can evidently be located elsewhere. This data problem, however, can hardly be solved as long as using patent data relating to the applicant.

- Additionally, patents are of totally different economic and social importance, which makes it difficult to evaluate their actual impact. A patent can either mean a significant innovation with relevant social and economic consequences or a diminutive or even negligible detail. Thus, the total number of patents does not necessarily reflect the inventive achievement. The accurate examination of the data shows that the results are significantly determined by single firms with extraordinary high numbers of patents. In this context the marginal benefit of patents should be reflected conscientiously.
- The availability of data representing the regional capital stock is still rather poor. It would be desirable to define indictors which describe all kinds of real capital relevant for creative processes in a more comprehensive way.
- Evidently, there is little information on the mutual dependencies between the production factors. Especially the question, to which degree the factors can be substituted by the others, has not yet been answered in a satisfying way. Since the combination of factors in the function significantly influences the model results, the ideal form of the function needs additional research.
- The theoretical argumentation and the empirical results emphasize the economic importance of legal regulations and institutional arrangements in a knowledge-based society. The empirical implementation of these categories, however, has turned out to be a big challenge, which has not been met successfully yet. The regional "availability of knowledge", which should reflect formal and informal institutional conditions in a region, is indicated in a very simple way. Future research should therefore tackle the problem of defining more sophisticated indicators assessing regional characteristics like "embeddedness" or "institutional thickness" in a proper way.

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