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► **To cite this version:**

Michael Fritsch, Viktor Slavtchev. Determinants of the efficiency of regional innovation systems. *Regional Studies*, 2008, pp.1. 10.1080/00343400802251494 . hal-00514716

**HAL Id: hal-00514716**

**<https://hal.science/hal-00514716>**

Submitted on 3 Sep 2010

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**Determinants of the efficiency of regional innovation systems**

Journal:	<i>Regional Studies</i>
Manuscript ID:	CRES-2007-0279.R1
Manuscript Type:	Main Section
JEL codes:	O18 - Regional, Urban, and Rural Analyses < O1 - Economic Development < O - Economic Development, Technological Change, and Growth, O31 - Innovation and Invention: Processes and Incentives < O3 - Technological Change Research and Development < O - Economic Development, Technological Change, and Growth, R12 - Size and Spatial Distributions of Regional Economic Activity < R1 - General Regional Economics < R - Urban, Rural, and Regional Economics
Keywords:	Technical efficiency, Innovation, Patents, Knowledge, Spillovers, Regional Innovation System

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Manuscripts

# Determinants of the efficiency of regional innovation systems

Michael Fritsch<sup>‡\*</sup> & Viktor Slavtchev<sup>‡</sup>

First received: September 2007

Accepted: March 2008

## Abstract

This paper analyzes differences in the efficiency of regional innovation systems (RIS). Alternative measures for the efficiency of RIS based on the concept of a knowledge production function are discussed. The empirical findings suggest that spillovers from within the private sector as well as from universities and other public research institutions have a positive effect on the efficiency of private sector R&D. It is particularly the intensity of interactions between private and public sector R&D that increases the efficiency. We find that regions dominated by large establishments tend to be less efficient than regions with a lower average establishment size.

## Zusammenfassung

Wir analysieren Unterschiede in der Effizienz regionaler Innovationssysteme (RIS). Zunächst werden alternative Maße für die Effizienz von RIS diskutiert, die auf dem Konzept der Wissensproduktionsfunktion aufbauen. Die empirischen Ergebnisse deuten darauf hin, dass sowohl Spillover aus dem privaten Sektor als auch von Hochschulen und anderen öffentlichen Forschungseinrichtungen die Effizienz privater F&E-Aktivitäten positiv beeinflussen. Insbesondere die Intensität der Interaktion zwischen öffentlichen Einrichtungen und dem Privatsektor führt zu hoher Effizienz. Regionen, die durch Großbetriebe dominiert sind, weisen tendenziell eine geringere Effizienz der Innovationsaktivitäten auf als Regionen mit einer geringeren durchschnittlichen Betriebsgröße.

JEL-classification: O31, O18, R12

Keywords: Regional innovation system, technical efficiency, patents.

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19 Les déterminants de l'efficacité des systèmes d'innovation régionaux.  
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45 Cet article cherche à analyser les écarts de l'efficacité des systèmes d'innovation  
46 régionaux (SIR). On discute des autres mesures de l'efficacité des SIR fondées sur la  
47 notion d'une fonction de production de la connaissance. Les résultats empiriques  
48 laissent supposer que les retombées provenant de l'intérieur du secteur privé aussi  
49 bien que des universités et des autres établissements publics de recherche ont un effet  
50 positif sur l'efficacité de la R et D du secteur privé. C'est notamment l'intensité de  
51 l'interaction entre la R et D du secteur privé et celle du secteur public qui augmente  
52 l'efficacité. Il s'avère que les régions où prédominent les grands établissements ont  
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7 tendance à être moins efficaces que ne le sont les régions où la taille des  
8 établissements est inférieure à la moyenne.  
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43 Determinantes de la eficiencia de los sistemas de innovación regional  
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46 Michael Fritsch & Viktor Slavtchev  
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53 En este artículo analizamos las diferencias en la eficiencia de los sistemas  
54 regionales de innovación (SRI). Asimismo estudiamos medidas alternativas para la  
55 eficiencia de los SRI en función del concepto de una función de producción del  
56 conocimiento. Los resultados empíricos indican que los desbordamientos desde  
57 dentro del sector privado así como de las universidades y otras instituciones de  
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7 investigación públicas tienen un efecto positivo en la eficiencia de I+D del sector  
8 privado. Es especialmente la intensidad de las interacciones entre la I+D del sector  
9 privado y público la que aumenta la eficiencia. Observamos que las regiones  
10 dominadas por grandes establecimientos tienden a ser menos eficientes que las  
11 regiones con un tamaño medio más bajo de establecimientos.  
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17 Keywords:

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20 Sistema de innovación regional

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## 1. Introduction

Inventions and innovations are not evenly distributed in space but tend to be clustered in certain locations (FELDMAN, 1994; PACI and USAI, 1999, 2000; MORENO, PACI and USAI, 2005). Possible reasons for this phenomenon include regional differences in the availability and the quality of local inputs, as well as geographically bounded knowledge spillovers (GREUNZ, 2003; FRITSCH and SLAVTCHEV, 2007, 2008). Another reason may be that locations differ with regard to the “quality” or the “efficiency” of regional innovation systems (RIS), leading to different levels of innovative output even if the inputs are identical in quantitative as well as in qualitative terms. The available empirical evidence for such differences in RIS efficiency is, however, sparse and not at all convincing. We still know only very little about the conditions that are conducive or unfavorable for innovation activity and how policy could help improve the functioning of RIS. Moreover, it is not clear how to assess the efficiency of regional innovation processes.

This paper elaborates on the determinants of RIS efficiency. We first introduce two different measures for RIS efficiency, both of which are based on the concept of a knowledge production function (Section 2), and describe the spatial distribution of efficiency among German planning regions (Section 3). Section 4 discusses the possible determinants of RIS efficiency. The results of multivariate regression analyses of the impact of different factors

on RIS efficiency are presented in Section 5. Finally, we draw conclusions for further research (Section 6).

## 2. Assessing the efficiency of RIS

Our understanding of RIS<sup>1</sup> efficiency corresponds to the concept of technical efficiency as introduced by FARRELL (1957). Farrell regards an economic unit as being inefficient if it fails to generate the maximum feasible output from a given set of inputs. Reasons for technical inefficiency can be manifold and comprise all sorts of mismanagement, such as inappropriate work organization, improper use of technology, as well as X-inefficiency, as defined in LEIBENSTEIN's (1966) seminal work. Applying this definition to the concept of a regional innovation system means that a region is technically efficient if it is able to produce the possible maximum of innovative output from a given amount of innovative input. Accordingly, a RIS is regarded as technically inefficient if its output falls below the maximum possible value.

In this paper, we use the concept of a knowledge production function (KPF) for analyzing the relationship between input and output of the innovation process, which is essential for assessing the technical efficiency of regional innovation systems. The basic hypothesis behind the KPF is that inventions do not simply occur out of "thin air," but result predominantly from R&D activities. According to GRILICHES (1979) and JAFFE (1989), who



assume a Cobb-Douglas type function for the relation between input and output, the KPF can be expressed as

$$(1) \quad Y_i = A_i X_i^{\beta_i} .$$

$Y_i$  denotes the innovative output of a region  $i$ , and  $X_i$  is a set of inputs.

$A_i = \alpha e^{-u_i}$  is an inefficiency parameter, with  $\alpha$  as a constant term, which is common for all regions, while  $u_i \in [0;1]$  denotes the technical inefficiency of a certain region  $i$ .

Our measure for innovative output is based on the number of disclosed regional patent applications in the years 1995 to 2000. These data were provided by the German Patent Office (*Deutsches Patent- und Markenamt*), as published in GREIF and SCHMIEDL (2002). A patent application indicates that an invention has been made that extends the existing knowledge pool. However, there are several limitations to using the number of patents as a measure of innovative output. First, patents are granted for an invention, but that invention is not necessarily transformed into an innovation, i.e., a new product or production technology. Second, patents are for products, rather than processes (COHEN, NELSON and WALSH 2000). Third, because there are other ways besides patenting to appropriate the returns of successful R&D

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7 activities (cf. COHEN, NELSON and WALSH 2002), the number of patents may  
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9 underestimate actual innovative output.  
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14 The German Patent Office provides information on the number of  
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16 regional patent applications in 31 different technological fields and from three  
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18 distinct sources: private companies, public research, and private persons.  
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20 However, although classification of the patents into different technological  
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22 fields is based on the International Patent Classification (IPC),<sup>2</sup> the level of  
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24 aggregation into technological fields does not allow assigning patent  
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26 applications to R&D activities related to a specific industry or academic  
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28 discipline. As this paper focuses on the efficiency of private R&D, only  
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30 corporate patent applications are analyzed, i.e., patent applications by public  
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32 research institutions or private persons are omitted.<sup>3</sup> The patent applications  
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34 are assigned to the region where the inventor resides.<sup>4</sup>  
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43 As a proxy for input to the innovation process in the private sector, we  
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45 use the number of R&D employees in this sector (*R&D*). This information is  
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47 taken from the establishment file of the German Social Insurance Statistics  
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49 (*Statistik der sozialversicherungspflichtig Beschaeftigten*), as described and  
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51 documented by FRITSCH and BRIXY (2004). Employees are classified as  
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53 working in R&D if they have a tertiary degree in engineering or in the natural  
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55 sciences. Only regional private sector R&D employment is included as an  
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57 explanatory variable in the knowledge production function; other input  
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7 variables are omitted. The reason for this is that the number of private sector  
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9 R&D employees appears to be the only factor that has a direct impact on  
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11 innovative output in that sector. Knowledge spillovers from adjacent regions  
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13 or spillovers from other sources, such as public research institutions, may  
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15 also make a considerable contribution to the innovation process in the private  
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17 sector; however, their impact is rather indirect in nature, mainly through the  
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19 private sector R&D employees.<sup>5</sup>  
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26 When relating knowledge input to innovative output, we have to assume  
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28 that there is a time lag, mostly because a certain amount of time is required  
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30 before R&D activity will result in a patent. Moreover, patent applications are  
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32 published anywhere from 12 to 18 months after submission, which is the  
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34 amount of time the patent office needs to verify whether an application fulfils  
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36 the basic preconditions for being granted a patent and to complete the patent  
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38 documents (GREIF and SCHMIEDL, 2002). Therefore, a time lag between  
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40 innovative inputs and output of at least two years should be assumed.<sup>6</sup>  
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45 However, because reliable data on R&D employment in East Germany are  
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47 available only from 1996 onward, we reduce the time lag between R&D input  
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49 and the patent application to a period of one year. Hence, the R&D output for  
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51 the 1997–2000 period is related to R&D input between 1996 and 1999. This  
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53 appears justified because there are no great fluctuations of either innovation  
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55 input or innovation output during these years and the differences between the  
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57 estimated parameters of a KPF with a time lag of one year and with a time  
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7 lag of two years are negligible.<sup>7</sup> Moreover, reducing the time lag increases  
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9 the number of available observations and degrees of freedom.

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14 The spatial framework used for analysis of RIS efficiency consists of the  
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16 97 German planning regions (*Raumordnungsregionen*). The main advantage  
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18 of using planning regions is that they are functional units that account for  
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20 travel to work areas and they include at least one core city as well as its  
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22 surroundings.<sup>8</sup> This is particularly important because the patents in our  
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24 database are assigned to the inventor's residence; thus, using the planning  
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26 region as the unit of observation makes it more likely that the inventor will  
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28 both work and live in the same region, thus avoiding the problem of having  
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30 R&D input assigned to an area different from where its output occurs (DEYLE  
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32 and GRUPP, 2005). For historical reasons, the cities of Berlin, Hamburg, and  
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34 Bremen are defined as planning regions even though they are not functional  
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36 economic units. To avoid possible distortions, we merged these cities with  
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38 adjacent planning regions (Berlin with the region of Havelland-Flaeming,  
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40 Hamburg with the region of Schleswig-Holstein-South, and Bremen with  
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42 Bremerhaven and Bremen-Umland). Hence, the estimation approach applied  
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44 in this paper is based on observations for 93 regions over four years.  
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54 From the perspective of the KPF, there are two possible reasons why a  
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56 region's innovative output is lower than the highest possible level. The first  
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58 reason is due to a relatively low value of the slope parameter  $\beta_i$ , which can  
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be interpreted as the marginal patent productivity or output elasticity of private sector R&D employees. A second reason could have to do with differences in the level of the function with a given slope. Such differences reflect the various levels of R&D output with a certain input in terms of average productivity and would correspond to different values of the constant term of the function. Based on these two types of differences, we employ two approaches for assessing RIS efficiency (for further discussion, see KALIRAJAN and SHAND, 1999).

The first approach relies on the idea of regional differences in the slope of the knowledge production function. To estimate the specific productivity of each region in terms of the marginal return to R&D input, we include a binary dummy variable for each region,  $D_i$  ( $D_i = 1$  if  $i = i$ , otherwise 0), that is multiplied by the respective number of private sector R&D employees. The constant term  $A$  is assumed to be identical for all regions. Hence, Equation (1) can be rewritten as

$$(2) \quad \ln(\text{Number of patents}_i) = \ln A + \sum_i \beta_i * D_i * \ln(R \& D \text{ priv}_i) + \varepsilon_i,$$

with  $\beta_i$  as a measure of the output elasticity of private sector R&D employment in the  $i^{\text{th}}$  region ( $i = 1, \dots, 93$ ). Based on the estimated values for the output elasticity of private sector R&D, we define the efficiency of a

certain region as the quotient of the observed output of a particular region and the maximum possible value, i.e.,

$$(3) \quad TE_i^{DET} = \exp(\ln(\text{Number of patents}_i) - (\ln A + \beta_{\max} * \ln(R \& D \text{ priv}_i) + \varepsilon_i)),$$

where  $\beta_{\max} = \max_i \{\beta_i\}$  is the maximum estimated output elasticity of R&D input. Accordingly, at least one region is assumed to be fully efficient. We label this approach “deterministic” because it implies that all deviations from the maximum value are due to inefficiency, and therefore ignores the possibility that values could be affected by measurement errors or by random disturbances.<sup>9</sup> The output elasticity of private sector R&D is estimated by means of a negative binomial regression technique (GREENE, 2003, 931–939). Due to the relatively short length of the time series (four years), the data are pooled.

In our second approach, the produced output may fall systematically below the maximum, not because of lower output elasticities of the factors of production, but because of a lower level of the function. In this case  $\beta_i$  is identical for all regions ( $\beta_i = \beta, \forall i$ ). Thus, the knowledge production function can be expressed as

$$(4) \quad \text{Number of patents}_i = \alpha R \& D \text{ priv}_i^\beta e^{-v_i} e^{u_i},$$

where  $v_i$  denotes effects of the region-specific environment on innovative output and  $u_i$  represents the stochastic error term. The technical efficiency of a region can, therefore, be calculated as

$$(5) \quad TE_i^{SFA} = e^{-v_i}.$$

Therefore, a RIS achieves its maximum feasible output if, and only if, it is fully efficient ( $v_i = 0$ ). The value of  $v_i$  provides a measure of the deviation of observed output from the possible maximum. This type of approach is called a stochastic frontier function (SFA) because it allows for stochastic disturbances. This implies that extreme values are not necessarily taken as the benchmark for the measurement of efficiency. The yearly data for the regions are pooled, and the technical efficiency is estimated as the average value per region. To separate the impact of technical inefficiency  $v_i$  from the general stochastic effects  $u_i$ , an a priori assumption about the distribution of technical inefficiency is necessary. The general assumption in this respect is that the distribution of technical efficiency has a negative skewness (SCHMIDT and LIN, 1984), i.e., that most regions are clustered close to the efficiency frontier. Several specifications for the inefficiency term  $v_i$  are possible:  $v_i$  can be assumed to be independently and exponentially distributed with variance  $\sigma_v^2$ , or independently and half-normally  $N^+(0; \sigma_v^2)$  distributed, or independently  $N^+(\mu; \sigma_v^2)$  distributed with a truncation point at 0. Due to the

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7 fact that the choice of the distributional assumption is a priori not clear, we  
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9 estimate the efficiency measure with all three alternatives in order to check  
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11 the robustness of the results. Table A1 in the Appendix provides descriptive  
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13 statistics of private sector R&D input and output used to estimate RIS  
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15 efficiency.  
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### 20 3. The distribution of RIS efficiency

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25 There are considerable differences between the technical efficiency values  
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27 for the German planning regions. The efficiency levels estimated by means of  
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29 both approaches—the deterministic frontier function and the stochastic  
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31 frontier function—show a wide spread, with the least efficient region attaining  
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33 only 6.7 and 9.9 percent of the highest value (Table 1 and Figure 1). As  
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35 compared to the stochastic frontier method, the deterministic approach leads  
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37 to a slightly more differentiated assessment of RIS efficiency. However, the  
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39 spatial distribution of the technical efficiency of RIS according to the different  
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41 approaches is virtually identical. The Pearson correlation coefficients suggest  
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43 almost perfect correlation between the efficiency values estimated by either  
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45 approaches (Table 1).  
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The spatial distribution of the efficiency values (Figure 1) suggests that regions with similar values of technical efficiency tend to be clustered together. Planning regions with the highest values of technical efficiency are located in the south, in the west, and in the center of the country. None of the planning regions in the north or in the east of Germany fall into this category. In particular, the values for the technical efficiency of RIS tend to be relatively high in larger, densely populated areas such as Munich, Stuttgart, Cologne, and Frankfurt. The Berlin region, which is in the middle range of efficiency ranking, is an exception in the East German innovation landscape. Regions with relatively low values for the efficiency of their innovation system are entirely located in the north and in the east. Generally, border region location appears unfavorable. Regions with moderate values of technical efficiency are found predominantly in the center of the country, separating the west from the east as well as the south from the north. This indicates that the German innovation system is spatially divided into different regimes with diverging levels of performance.

-- Insert Figure 1 here --

#### 4. Possible determinants of RIS efficiency

There are many factors that influence RIS efficiency. It is plausible to assume that the ability of private sector R&D employees to produce innovative output may depend on the availability and the quality of knowledge and other innovative inputs in the region. Given that innovation processes are characterized by a pronounced division of labor,<sup>10</sup> one may expect that RIS efficiency depends on how intensely the regional knowledge base is exploited and expanded through the interaction of regional agents. RIS efficiency may, therefore, be strongly influenced by the level and the quality of interaction and exchange between different elements and the respective knowledge flows (spillovers). This interaction may be critically dependent on the availability of potential cooperation partners in the region, such as other private firms working in the same technological field, public research institutes, and suppliers of innovative inputs and services. Therefore, the density and industrial composition of the regional actors, the accessibility of the region, and the technological, industrial, and institutional infrastructure (e.g., the “networks”) all may play an important role.<sup>11</sup> The interaction between the different elements of RIS generates partly self-enforcing systemic effects that may result in specific knowledge as well as specific technologies and methods of problem solving (GERTLER, 2003), which can be

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7 expected to affect the workability of the system (LEYDESDORFF and FRITSCH,  
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14 We assume that the amount of knowledge spillover within the private  
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16 sector is related to the number of R&D employees in this sector. The greater  
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18 the number of R&D employees, the greater the opportunity to find a suitable  
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20 partner for cooperation and knowledge exchange. The indicator for  
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22 knowledge spillovers within the private sector is the share of R&D  
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24 employment in that sector (*R&D*).  
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31 The knowledge generated and accumulated by universities may  
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33 constitute a basic precondition for private sector R&D activity (JAFPE, 1989).  
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35 However, since universities are nonprofit organizations, they can hardly  
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37 market the results of their own R&D in terms of new products or  
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39 technologies. For this reason, their knowledge has to spill over to other  
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41 actors (e.g., private companies) in order to become commercially effective.  
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43 There are various ways such knowledge transfers can occur (see VARGA,  
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45 1998, for an overview). In particular, channels for transfer of academic  
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47 knowledge, such as R&D cooperation with private sector firms or the  
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49 provision of innovation-related services, play a major role in private sector  
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51 innovative activity (MANSFIELD and LEE, 1996; COHEN, NELSON, and WALSH  
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53 2002). However, the impact of universities on private sector firm innovation  
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55 may vary considerably depending on the quality of a university's research  
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7 and the intensity with which the university interacts with the firms (e.g.,  
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9 FELDMAN and DESROCHERS, 2003; MANSFIELD and LEE, 1996; FRITSCH and  
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11 SLAVTCHEV, 2007, 2008). To test the impact of universities on private sector  
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13 performance we introduce the amount of third-party funds the universities  
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15 obtain from private firms (*TPF-PRIV*). In general, third-party funds can be  
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17 regarded as an indicator of the amount and quality of the university's  
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19 research because allocation of third-party funds is usually based on some  
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21 competitive procedure and is, therefore, largely dependent on the quality of  
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23 the research conducted. According to HORNBOSTEL (2001), there is a distinct  
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25 correspondence between indicators that are based on third-party funds and  
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27 bibliometric indicators for high-quality research, such as SCI publications.  
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29 Funds from private sector firms, in particular, can be regarded as  
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31 compensation for academic R&D or other services. Hence, these revenues  
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33 are an appropriate indication of the relevance of academic research to  
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35 commercial applications, as well as of the intensity of university-industry  
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37 linkages, which may lead to pronounced knowledge spillovers (FRITSCH and  
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39 SLAVTCHEV, 2007, 2008).  
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51 Although we have no detailed information about the location of the  
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53 private firms that cooperate with universities, one can assume that, in most  
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55 cases, universities and cooperating private firms are located in the same  
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57 planning region (FRITSCH and SCHWIRTEN, 1999).<sup>12</sup> To avoid possible scale  
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59 effects of large universities, which are likely to attract larger amounts of third-  
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7 party funds from private firms, we use the average amount of third-party  
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9 funds from private sector firms per university professor.  
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14 Nonuniversity public research institutions, such as the Max-Planck-  
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16 Society (*MPG*) and the Fraunhofer-Society (*FhG*), may also have a positive  
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18 effect on the technical efficiency of private sector R&D employees.  
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20 Unfortunately, we do not have information about the third-party funds of  
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22 these institutes; thus, we introduce the regional number of institutes in our  
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24 analysis.  
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31 As far as a technology is unique in the sense that the transfer and the  
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33 application of knowledge pertinent to it requires specific skills or a specific  
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35 common language, the strength of knowledge spillovers depends critically on  
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37 the degree of technological similarity between the parties (JAFPE, 1986;  
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39 NADIRI, 1993). Therefore, we introduce the technological proximity between  
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41 public and private sector R&D as a measure of correspondence and potential  
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43 interplay of the regional actors in the innovation process (*PROXTECH*). The  
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45 technological proximity between public and private sector R&D is measured  
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47 as the degree of congruence between the technological fields of the patent  
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49 output of public research institutions ( $PAT_{ACAD}$ ) and private sector firms  
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51 ( $PAT_{PRIV}$ ):<sup>13</sup>  
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$$(6) \quad PROXTECH_i = \frac{PAT_{ACAD_i} * PAT_{PRIV_i}}{|PAT_{ACAD_i}| * |PAT_{PRIV_i}|}$$

This index can assume values between 0 and 1. The larger the value, the closer the technological proximity between public and private sector R&D, and the greater the possibility for cooperation and knowledge spillovers.

The service sector may provide important support for R&D activity in diverse ways, such as counseling, technical services, provision of venture capital, etc. This is particularly true of knowledge-intensive business services, which in some cases have even been associated with the emergence of high-tech regions such as Silicon Valley and Route 128 (SAXENIAN, 1985; DORFMAN, 1983). According to FELDMAN and FLORIDA (1994), the presence of business services indicates a relatively well-developed infrastructure that may be beneficial for innovation. One could, therefore, expect a positive impact of the share of the regional service sector (*SERVICES*) on RIS efficiency. On the other hand, a high share of the service sector in the region could have a negative effect due to the relatively low propensity of this sector to apply for and be granted patents (GREIF and POTKOWIK, 1990; BODE, 2004).

Population density (number of inhabitants in the region per squared kilometer, *POPDEN*) is a measure not only of the effects of urbanization

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7 economies on RIS performance, but can also be regarded as a catch-all  
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9 variable for diverse types of unobserved region-specific influences. The  
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11 literature suggests that high population density should be conducive to  
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13 innovation activity because it is related to intensive contacts and cooperation  
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15 (for an overview, see FELDMAN, 2000; FRITSCH, 2000). Therefore, one could  
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17 expect a positive sign for this variable. The average number of employees  
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19 per establishment (*SIZE*) is intended to capture the effects of establishment  
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21 size. According to a number of previous empirical studies, the number of  
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23 patents per employee is higher in smaller firms than in large firms (see  
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25 COHEN and KLEPPER, 1996, for a discussion); therefore, a negative sign could  
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27 be expected. Two binary dummy variables are employed to capture  
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29 additional unobserved effects of location in West Germany (*WEST*) and on  
30  
31 the periphery (*PERIPHERY*). We expect a positive sign for location in West  
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33 Germany due to the generally weaker performance of the economy in the  
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35 eastern part of the country, which is obvious from the assessment of RIS  
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37 efficiency shown in Figure 1. Assuming that a location on the periphery  
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39 (border) is unfavorable for innovation activity due to relatively great  
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41 geographical distance from other actors, we expect a negative sign for this  
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43 variable.  
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54 As the propensity to patent the results of R&D may differ between  
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56 industries (e.g., some industries might find more profitable ways to  
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58 appropriate the returns of R&D than patenting), RIS efficiency may be subject  
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7 to industry-specific effects. To control for the impact of regional specialization  
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9 in certain industries having a relatively high level of patenting, we include the  
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11 share of employees in transportation engineering (*TRANSPORT*), in  
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13 electrical engineering (*ELECTRICAL*), in measurement engineering and  
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15 optics (*OPTICS*), and in chemistry (including biochemistry) (*CHEMICALS*)  
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17 into our model. According to GREIF and SCHMIEDL (2002), these are the  
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19 technological fields with the highest share of patent applications in  
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21 Germany.<sup>14</sup> Table 2 provides a summary of the definitions and data sources  
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23 of the variables. Descriptive statistics for the variables are provided in Table  
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28 3. Table A2 in the Appendix sets out the correlations between the variables.  
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To estimate the model, we transform the dependent, as well as the independent, variables into log-values. An important advantage of logging



both sides of the equation is that the estimated coefficients can be regarded as elasticities that can be directly compared with each other. To assess the presence and the importance of interdependences between the geographical units of investigation, we carried out several diagnostic tests (Moran's I, LM-Error, robust LM-Error, LM-Lag and robust LM-Lag) for such spatial dependences. These tests indicate the presence of spatial dependence that takes the form of a spatial autoregressive process in the error term.

Therefore, we apply a spatial error model

$$(7) \quad Y = X\beta + \varepsilon ,$$

where  $\varepsilon = \lambda W\varepsilon + \mu$ ,  $\lambda$  denotes the spatial autoregressive parameter,  $\mu$  denotes a homoscedastic and uncorrelated error term, and  $W$  row-standardized spatial weights matrix based on a first-order contiguity (ANSELIN, 1988; ANSELIN and BERA, 1998). Additionally, a robust variance-covariance estimator is applied (WHITE, 1980).

## 5. Empirical results

The impact of different determinants on RIS efficiency under the deterministic and stochastic frontier approaches are reported in Table 4. With respect to the stochastic frontier approach, there are three different assumptions about the distribution of the inefficiency term: half-normal distribution, normal

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7 distribution with a truncation point at zero, and exponential distribution.

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9 However, since the efficiency measures obtained with all three assumptions  
10 are almost perfectly correlated (see Table 1), we compare the deterministic  
11 frontier approach with only one version of the stochastic frontier approach,  
12 that of the half-normal distribution.<sup>15</sup>  
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21 The share of private sector R&D employment (*R&D*) has a pronounced  
22 positive impact on RIS efficiency. The estimated coefficient provides clear  
23 evidence for the relevance of scale economies, i.e., an increase in the share  
24 of private sector R&D employment at a certain location can lead to higher  
25 efficiency of innovation processes. Obviously, high R&D intensity at a certain  
26 location may stimulate knowledge spillover between actors. However, if more  
27 measures for regional specialization in certain industries are included, the  
28 impact of the share of R&D employment becomes slightly weaker. This is  
29 particularly the case for the share of regional employment in electrical  
30 engineering (*ELECTRICAL*). The average amount of third-party funds from  
31 private sector sources per university professor (*TPF-PRIV*) has a positive  
32 impact on RIS efficiency, suggesting that the intensity of university-industry  
33 linkages, as indicated by the money paid by private firms for university R&D,  
34 is conducive to regional innovation activity. Substituting *TPF-PRIV* by other  
35 university-related indicators, such as the number of academic personnel,  
36 shows hardly any statistically significant impact for the respective variable  
37 and results in a considerable reduction of the log-likelihood of the model.  
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7 These results clearly confirm previous findings for the role of academic  
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9 research on innovation activity in Germany (FRITSCH and SLAVTCHEV, 2007,  
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11 2008).  
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16 A positive impact can also be found for nonuniversity public research  
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18 establishments as indicated by the number of research institutes of the Max-  
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20 Planck Society (*MPG*) and of the Fraunhofer Society (*FhG*). These results  
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22 suggest that there are knowledge spillovers from both types of research—  
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24 basic research conducted at the Max-Planck-Institutes and more applied  
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26 research as typically carried out by the institutes of the Fraunhofer Society—  
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28 which increase the technical efficiency of a RIS.<sup>16</sup> Regions with a high  
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30 efficiency of innovation activity are characterized by pronounced  
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32 technological proximity between public and private R&D, as measured by the  
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34 *PROXTECH*-variable.<sup>17</sup> A possible explanation for this finding is that the  
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36 knowledge exchange between the two sectors becomes more likely as public  
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38 and private research operate in similar technological fields.  
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7 The positive coefficient for population density (*POPDEN*) indicates the  
8 presence of urbanization economies. This suggests that densely populated  
9 regions provide a variety of opportunities for interaction and rich supplies of  
10 inputs, as well as a comprehensive physical and institutional infrastructure  
11 that is advantageous for innovation activity.  
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21 The coefficient for the share of service sector employment (*SERVICE*)  
22 indicates a negative impact on RIS efficiency, meaning that despite their  
23 supporting function, resources allocated to the service sector are less  
24 efficient in terms of patenting than in manufacturing. This confirms previous  
25 results of BODE (2004), who found a negative impact of service-  
26 manufacturing ratio on regional innovation output. As indicated by the  
27 significantly negative coefficient for average firm size (*SIZE*), patenting  
28 efficiency tends to be lower in regions characterized by a high share of large  
29 establishments. This result is in line with other studies, which find that the  
30 number of patents per unit of R&D input is higher in smaller firms than in  
31 larger ones (ACS and AUDRETSCH, 1990; COHEN and KLEPPER, 1996).  
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33 According to the positive and highly significant coefficient of the dummy  
34 variable for location in West Germany (*WEST*), innovation activities in  
35 regions located in the western part of the country are more efficient than  
36 those in East Germany. This result suggests that there are still considerable  
37 differences in the efficiency of the innovative process in the two parts of the  
38 country even after reunification in 1990. There are at least two possible  
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7 explanations for this difference. First, a relatively pronounced industrial  
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9 monostructure<sup>18</sup> and a concentration on less innovative industries may cause  
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11 a technological shortfall in East Germany. Second, such an efficiency gap  
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13 may result from a relatively low convergence speed due to slow learning and  
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15 path-dependent innovation processes. The estimated coefficient for the  
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17 dummy variable for regions located on the periphery of Germany is not  
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19 statistically significant.  
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26 The local presence of industries with relatively high patent intensity has a  
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28 positive impact on RIS efficiency (at the 10 percent significance level) only  
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30 with respect to electrical engineering (*ELECTRICAL*). Nevertheless,  
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32 controlling for industry structure in the region appears important for at least  
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34 two reasons. First, introducing the share of the electrical engineering industry  
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36 significantly increases the goodness of fit (squared correlation, log likelihood)  
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38 of the model. Second, the parameter of spatial dependence  $\lambda$ , that is  
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40 otherwise significant, becomes insignificant if a control for the size of this  
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42 industry in the region is included.  
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## 49 **6. Summary and conclusions**

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54 The objective of this paper is to provide an answer to the question of what  
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56 factors can explain differences in RIS efficiency. For this purpose, we first  
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58 introduce two measures for RIS efficiency based on the concept of a KPF.  
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7 These approaches for assessing RIS efficiency lead to virtually identical  
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9 results. In particular, the spatial distribution of efficiency estimates turns out  
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11 to be very similar under both approaches.  
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16 We found a number of factors that have an effect on RIS efficiency. Our  
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18 results suggest that knowledge spillovers within the private sector as well as  
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20 those that occur between public research institutions (universities as well as  
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22 nonuniversity research institutes) and actors in the private sector have a  
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24 positive impact on private sector innovation activity. The presence of  
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26 universities and other public research institutes and their interaction with  
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28 private sector firms also proves to be conducive. This effect is particularly  
29  
30 strong when the technological fields of research pursued in public research  
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32 institutes correspond to those of innovation activity in the private sector.  
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34 Population density has a positive effect on innovation performance, indicating  
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36 that R&D activity is more productive in agglomerations than in rural areas.  
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38 The negative effects of the employment share in the service sector and of  
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40 average establishment size correspond with the relatively low patent intensity  
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42 in the service industries and in larger firms, which has been found in other  
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44 empirical studies. RIS in West Germany are considerably more efficient than  
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46 those in the eastern part of the country, even after controlling for all other  
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48 influences that have a significant effect. There is no indication for lower  
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50 efficiency of innovation activity in regions located at the periphery of the  
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52 country. All in all, our results are consistent with the view that RIS  
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7 performance is strongly influenced by the level and the quality of interaction  
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9 and exchange between their different elements. To put it differently, a  
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11 pronounced division of innovative labor leads to relatively high efficiency.  
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16 Our results raise some important questions for further research. One of  
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18 the most important of these has to do with *how* knowledge transfers occur  
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20 between different actors. A policy that aims at improving RIS efficiency  
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22 should be able to identify the most efficient means of knowledge transfer and  
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24 how such transfers can be stimulated. What stimulates knowledge spillover  
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26 and the division of innovative labor between the elements of a RIS? What are  
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28 the impediments in this respect? Lastly, regarding the role of industrial  
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30 specialization for innovation, more information about the role of the industrial  
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32 structure of a region for the efficiency of innovation activity would be helpful  
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34 in order to design appropriate policy. The low efficiency of RIS in East  
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36 Germany indicates that there may be a considerable degree of path  
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38 dependency that shapes performance in this part of the country. This implies  
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40 that it may take a fairly long time until a policy aimed at improving RIS  
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42 performance produces significant results.  
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Table 1: Descriptive statistics for distribution of technical efficiency in  
German planning regions

No.	Variable	Mean	Median	Min.	Max.	Std. Dev.	Pearson correlation coefficient		
							1	2	3
1	$TE_i^{DEI}$	0.434	0.452	0.067	1.000	0.203	1.000		
2	$TE_i^{SFA}$ (half-normal)	0.514	0.558	0.091	0.920	0.244	0.987	1.000	
3	$TE_i^{SFA}$ (truncated normal)	0.539	0.599	0.097	0.922	0.249	0.981	0.999	1.000
4	$TE_i^{SFA}$ (exponential)	0.571	0.651	0.104	0.921	0.253	0.969	0.995	0.998

Notes: Number of observations (regions) = 93.

Table 2: Definition of variables and expected sign of coefficient

Variable	Operational definition	Expected sign
R&D	Share of R&D employees in the private sector; source: Social Insurance Statistics.	+
TPF-PRIV	Third-party funds per university professor (including Fachhochschulen) in 1,000s of Euro; source: German University Statistics.	+
MPG	Number of institutes of the Max Planck Society; source: BUNDESMINISTERIUM FUER BILDUNG UND FORSCHUNG (2004).	+
FhG	Number of institutes of the Fraunhofer Society; source: BUNDESMINISTERIUM FUER BILDUNG UND FORSCHUNG (2004).	+
PROXTECH	Correspondence of the technological fields of public and private sector R&D; source: own calculation based on patent statistics (GREIF and SCHMIEDL, 2002).	+
POPDEN	Population density; source: BUNDESAMT FUER BAUWESEN UND RAUMORDNUNG - BBR.	+
SERVICES	Employment share in the service sector; source: Social Insurance Statistics.	+ / -
SIZE	Average number of employees per establishment; source: Social Insurance Statistics.	-
WEST	Dummy for location in West Germany (yes = 1; no = 0)	+
PERIPHERY	Dummy for location of a planning region at the border of the country (yes = 1; no = 0)	-
TRANSPORT	Employment share in transportation engineering; source: Social Insurance Statistics.	+
ELECTRICAL	Employment share in electrical engineering; source: Social Insurance Statistics.	+
OPTICS	Employment share in optics and measurement engineering; source: Social Insurance Statistics.	+
CHEMICALS	Employment share in chemistry; source: Social Insurance Statistics.	+

Table 3: Descriptive statistics for independent variables

Variable	Mean	Median	Minimum	Maximum	Standard Deviation
R&D	0.019	0.016	0.006	0.044	0.008
TPF-PRIV	11.062	7.195	0.000	97.067	14.735
MPG	0.860	0.000	0.000	12.000	1.839
FhG	0.849	0.000	0.000	10.000	1.763
PROXTECH	0.623	0.659	0.200	0.837	0.139
SERVICES	0.321	0.312	0.220	0.523	0.056
SIZE	13.204	13.308	8.529	18.266	1.696
POPDEN	336.990	180.675	53.425	3,886.292	507.559
TRANSPORT	0.043	0.031	0.010	0.226	0.037
ELECTRICAL	0.035	0.029	0.004	0.123	0.023
OPTICS	0.009	0.005	0.002	0.055	0.009
CHEMISTRY	0.017	0.010	0.001	0.180	0.023

Notes: Number of observations (regions) = 93.

Table 4: Determinants of RIS efficiency

	Technical efficiency according to the deterministic frontier approach, $TE_i^{DET}$							Technical efficiency according to the stochastic frontier approach, $TE_i^{SFA}$						
Constant	0.074 (1.321)	0.091 (1.305)	-0.036 (1.361)	-0.130 (1.268)	-0.191 (1.205)	-0.360 (1.283)	0.192 (1.262)	-0.040 (1.152)	-0.034 (1.141)	-0.145 (1.171)	-0.200 (1.115)	-0.319 (1.050)	-0.518 (1.095)	0.038 (1.062)
R&D [ln]	0.307** (0.112)	0.302** (0.113)	0.279* (0.116)	0.286** (0.108)	0.274* (0.115)	0.259* (0.105)	0.286* (0.111)	0.249* (0.104)	0.247* (0.106)	0.226* (0.107)	0.233* (0.101)	0.215* (0.104)	0.203* (0.094)	0.233* (0.100)
TPF-PRIV [ln]	0.051* (0.022)	0.051* (0.022)	0.046* (0.023)	0.048* (0.021)	0.052* (0.022)			0.054** (0.019)	0.054** (0.019)	0.050* (0.020)	0.052** (0.018)	0.055** (0.019)		
MPG [ln]						0.112* (0.054)							0.107* (0.049)	
FhG [ln]						0.104* (0.049)							0.099* (0.050)	
PROXTECH [ln]							0.295* (0.142)							0.275* (0.128)
POPDEN [ln]	0.317** (0.076)	0.316** (0.076)	0.286** (0.075)	0.306** (0.075)	0.314** (0.076)	0.232** (0.069)	0.245** (0.079)	0.280** (0.070)	0.279** (0.071)	0.253** (0.067)	0.272** (0.069)	0.276** (0.071)	0.203** (0.059)	0.214** (0.071)
SERVICES [ln]	-1.367** (0.230)	-1.344** (0.245)	-1.300** (0.228)	-1.318** (0.230)	-1.371** (0.227)	-1.460** (0.243)	-1.172** (0.212)	-1.242** (0.212)	-1.233** (0.225)	-1.190** (0.214)	-1.207** (0.214)	-1.245** (0.207)	-1.327** (0.228)	-1.054** (0.197)
SIZE [ln]	-1.615** (0.399)	-1.621** (0.393)	-1.545** (0.411)	-1.499** (0.386)	-1.552** (0.362)	-1.431** (0.401)	-1.392** (0.388)	-1.425** (0.344)	-1.428** (0.340)	-1.364** (0.349)	-1.338** (0.338)	-1.358** (0.313)	-1.230** (0.334)	-1.196** (0.323)
WEST	1.253** (0.129)	1.244** (0.129)	1.170** (0.130)	1.214** (0.133)	1.224** (0.153)	1.242** (0.103)	1.159** (0.129)	1.165** (0.117)	1.161** (0.117)	1.092** (0.117)	1.136** (0.121)	1.134** (0.135)	1.165** (0.092)	1.084** (0.116)
PERIPHERY	-0.113 (0.073)	-0.114 (0.073)	-0.097 (0.073)	-0.104 (0.072)	-0.106 (0.073)	-0.079 (0.070)	-0.085 (0.073)	-0.107 (0.066)	-0.107 (0.066)	-0.093 (0.066)	-0.100 (0.065)	-0.100 (0.065)	-0.072 (0.063)	-0.078 (0.066)
TRANSPORT [ln]		0.014 (0.043)							0.006 (0.037)					
ELECTRICAL [ln]			0.125 (0.075)			0.131 (0.072)	0.118 (0.078)			0.112 (0.066)			0.116 (0.061)	0.105 (0.067)
OPTICS [ln]				0.072							0.053			

	(0.050)							(0.044)						
CHEMICALS [ln]					0.023 (0.040)							0.024 (0.033)		
$\lambda$	0.485** (0.129)	0.487** (0.129)	0.379* (0.195)	0.462** (0.133)	0.498** (0.126)	0.287 (0.232)	0.319 (0.214)	0.463** (0.136)	0.464** (0.136)	0.353 (0.201)	0.444** (0.138)	0.477** (0.130)	0.264 (0.225)	0.288 (0.212)
Squared corr.	0.80	0.80	0.82	0.81	0.80	0.84	0.83	0.82	0.82	0.84	0.82	0.82	0.85	0.84
Log-likelihood	-12.79	-12.76	-11.19	-11.83	-12.57	-9.07	-11.02	-1.97	-1.96	-0.34	-1.30	-1.65	1.59	-0.66
Wald ( $\lambda = 0$ )	14.07	14.26	3.74	12.15	15.59	1.52	2.23	11.62	11.63	3.08	10.35	13.43	1.38	1.85
LM-error ( $\lambda = 0$ )	8.69	8.72	3.39	8.73	8.78	1.86	2.46	7.89	7.88	3.15	7.99	8.11	1.83	2.25

Notes: Robust standard errors in parentheses; \* significant at 5% level; \*\* significant at 1% level. Critical value for the Wald test-statistic and LM-error is 3.48 ( $p = 0.05$ ); spatial weights are row-standardized:  $W$  is 1<sup>st</sup> order contiguity matrix. Number of observations (regions) = 93.

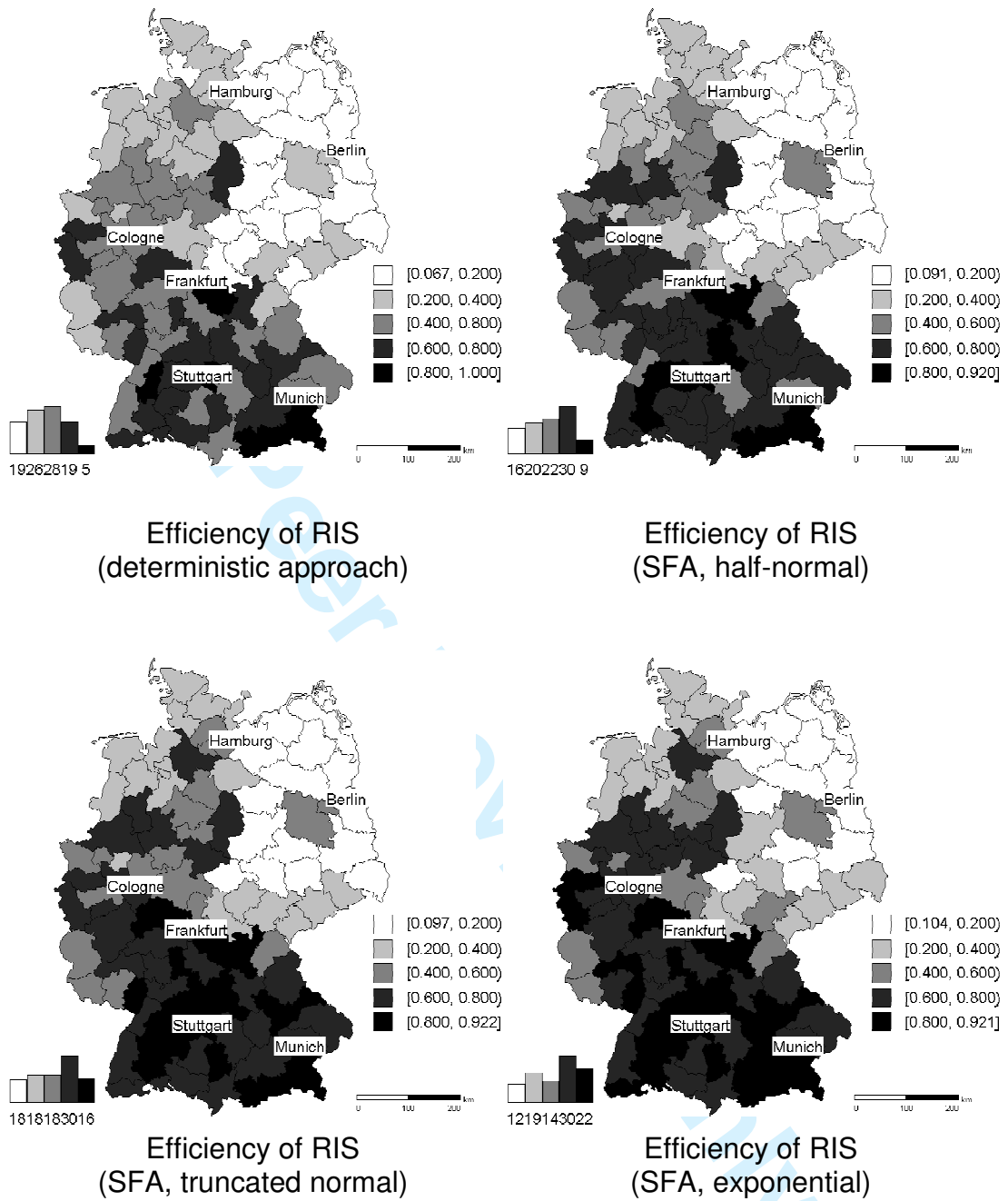


Figure 1: The spatial distribution of RIS efficiency in Germany

## Appendix

Table A1: Descriptive statistics of private sector R&D output and input

Variable	Mean	Median	Minimum	Maximum	Standard Deviation
PAT <sub>PRIV</sub>	291.465	165.950	1.500	3,143.322	408.519
R&D	6,674.016	3,690.000	649.000	48,968.000	8,724.051

Notes: Number of observations (regions) = 392.



Table A2: Correlation between variables

No. Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 $TE_i^{DET}$ [ln]	1.000														
2 $TE_i^{SFA}$ (half-normal) [ln]	0.998	1.000													
3 $TE_i^{SFA}$ (truncated normal) [ln]	0.996	0.999	1.000												
4 $TE_i^{SFA}$ (exponential) [ln]	0.993	0.998	0.999	1.000											
5 R&D [ln]	0.092	0.075	0.077	0.071	1.000										
6 TPF-PRIV [ln]	0.153	0.165	0.175	0.184	0.284	1.000									
7 MPG [ln]	0.047	0.042	0.047	0.050	0.439	0.396	1.000								
8 FhG [ln]	0.084	0.075	0.080	0.083	0.483	0.377	0.427	1.000							
9 PROXTECH [ln]	0.473	0.471	0.475	0.478	0.296	0.340	0.265	0.271	1.000						
10 SERVICES [ln]	0.026	0.027	0.037	0.049	0.327	0.387	0.488	0.356	0.150	1.000					
11 SIZE [ln]	-0.033	-0.032	-0.026	-0.024	0.604	0.302	0.341	0.244	0.193	0.142	1.000				
12 POPDEN [ln]	0.328	0.327	0.336	0.343	0.549	0.372	0.528	0.420	0.472	0.538	0.563	1.000			
13 TRANSPORT [ln]	0.387	0.385	0.384	0.382	0.112	0.059	-0.121	-0.035	0.151	-0.072	0.069	0.066	1.000		
14 ELECTRICAL [ln]	0.651	0.646	0.645	0.641	0.260	0.103	0.050	0.124	0.429	-0.053	0.163	0.262	0.229	1.000	
15 OPTICS [ln]	0.453	0.438	0.432	0.425	0.097	-0.013	0.072	-0.030	0.309	-0.059	-0.142	0.049	0.090	0.415	1.000
16 CHEMISTRY [ln]	0.465	0.468	0.473	0.476	0.351	0.149	0.237	0.151	0.220	0.344	0.066	0.421	0.075	0.157	0.169

## Notes

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1. A regional innovation system is commonly understood as a set of all those local actors, formal institutions, and other organizations that jointly or individually contribute to the generation, use, accumulation, and diffusion of knowledge and technologies (ASHEIM and GERTLER, 2005; COOKE, URANGA and ETXEBARRIA, 1997).

2. This classification is provided by the World Intellectual Property Organization (WIPO).

3. Patent applications by private companies account, on the average, for about three-quarters of all patent applications.

4. If a patent has more than one inventor, the count is divided by the number of the inventors involved and that fraction assigned to each inventor's region of residence. Hence, the number of regional patents may not always be a whole number.

5. For example, COHEN, NELSON and WALSH (2002) as well as SCHARTINGER, SCHIBANY and GASSLER (2001) provide evidence for the

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11 greater importance of cooperations and informal university-industry linkages  
12 (e.g., information trading) as compared to channels of knowledge transfer  
13 such as licenses, prototypes, etc.  
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21 6. Assuming such a time lag also helps avoid potential problems of  
22 endogeneity between R&D inputs and output. FRITSCH and SLAVTCHEV (2007,  
23 2008), in their analysis for Germany, use a time lag of three years between  
24 patent applications and innovative input. FISCHER and VARGA (2003) use a  
25 two-year lag and RONDE and HUSSLER (2005) link the number of patents  
26 between 1997 and 2000 to R&D efforts in 1997. ACS, ANSELIN and VARGA  
27 (2002) report that U.S. innovation records in 1982 result from inventions  
28 made 4.3 years prior.  
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42 7. BODE (2004) also uses a time lag of one year when relating patent  
43 output to R&D employment across German planning regions.  
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49 8. For this definition of the planning regions, see Federal Office for  
50 Building and Regional Planning (BUNDESAMT FUER BAUWESEN UND  
51 RAUMORDNUNG - BBR, 2003).  
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9. Hence, there is the danger that an extremely high output value that is due to stochastic disturbances is mistaken as the benchmark for the measurement of efficiency.

10. ARORA and GAMBARDELLA (1994, 1998); ARORA, GAMBARDELLA and RULLANI (1997); COCKBURN ET AL. (1999); ARORA, FOSFURI and GAMBARDELLA (2001).

11. The existence of such a positive impact of interaction and exchange between regional actors on innovation activity is a main hypothesis in the literature on industrial districts (cf. PORTER, 1998; PYKE, BECCATINI and SENGENBERGER, 1990), innovation networks (cf. CAMAGNI, 1991; GRABHER, 1993), and “innovative milieux” (CREVOISIER, 2004; RATTI, BRAMANTI and GORDON, 1997). In this literature, it is argued that regional differences in interaction behavior are responsible to a considerable degree for differences with regard to innovation activity, particularly the efficiency of R&D. One main reason given for such a positive effect is that the interaction between actors may work as an important medium for knowledge spillovers. Knowledge spillovers play a significant role in recent approaches to growth theory (cf. KRUGMAN, 1991; ROMER, 1994), as well as in the concept of (national or

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11 regional) innovation systems (cf. LUNDVALL, 1992; NELSON, 1993; EDQUIST,  
12 1997; COOKE, URANGA and ETXEBARRIA, 1997).

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18 12. Based on a survey of about 2,300 private enterprises in Germany,  
19 BEISE and STAHL (1999) found that about 60 percent of the firms that had  
20 introduced university-based innovations were located at a distance of up to  
21 100 km from the particular knowledge source. When technical colleges were  
22 the source of knowledge, the figure was about 80 percent. Similar findings are  
23 provided by econometric studies on the spatial scope of university-industry  
24 linkages. By using third-party funds from private firms as an indicator for  
25 university-industry linkages, FRITSCH and SLAVTCHEV (2007, 2008) found  
26 spillovers from universities at a distance of up to 50 km. Because most  
27 universities in Germany are located in relatively large cities, which are usually  
28 also considered the core city of their planning region, these results suggest  
29 that, for the most part, both university-private sector cooperation partners will  
30 be located in the same planning region.  
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51 13. See GREIF and SCHMIEDL (2002) for a definition of the 31  
52 technological fields.  
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12 14. In the period 1995–2000, about 9.6 percent of all patent applications  
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14 were submitted in the field of transportation engineering, 13 percent in  
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16 electrical engineering, and 7.4 percent in measurement engineering/optics  
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18 (GREIF and SCHMIEDL, 2002).  
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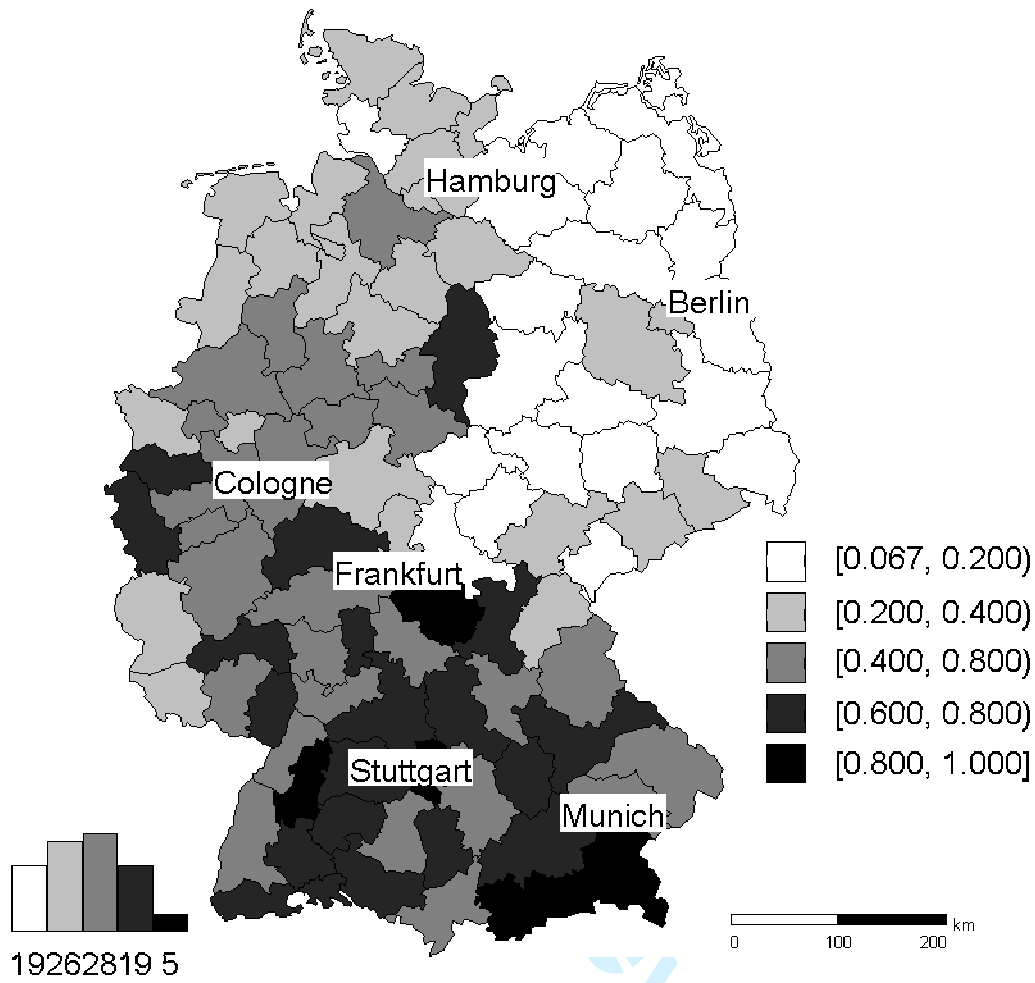
24 15. The results for the truncated normal distribution and the exponential  
25  
26 distribution differ only slightly from those for the half-normal distribution and  
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28 are, therefore, not reported here.  
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34 16. The variable for the third-party funds from the private sector per  
35  
36 university professor (*TPF-PRIV*) has been excluded here due to  
37  
38 multicollinearity problems when the number of Max Planck (*MPG*) and  
39  
40 Fraunhofer institutes (*FhG*) are included in the model.  
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46 17. When the impact of *PROXTECH* is analyzed, *TPF-PRIV*, *MPG*, and  
47  
48 *FhG* are excluded from the model because *PROXTECH* measures the  
49  
50 potential knowledge spillovers between all types of public research  
51  
52 institutions and the private sector. Hence, the effects of universities and  
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54 institutes of the Max-Planck or Fraunhofer-Society are already included.  
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12 18. Two sample mean comparison test suggests significantly less  
13 industrial diversity in East Germany (1.404) than in West Germany (1.527).  
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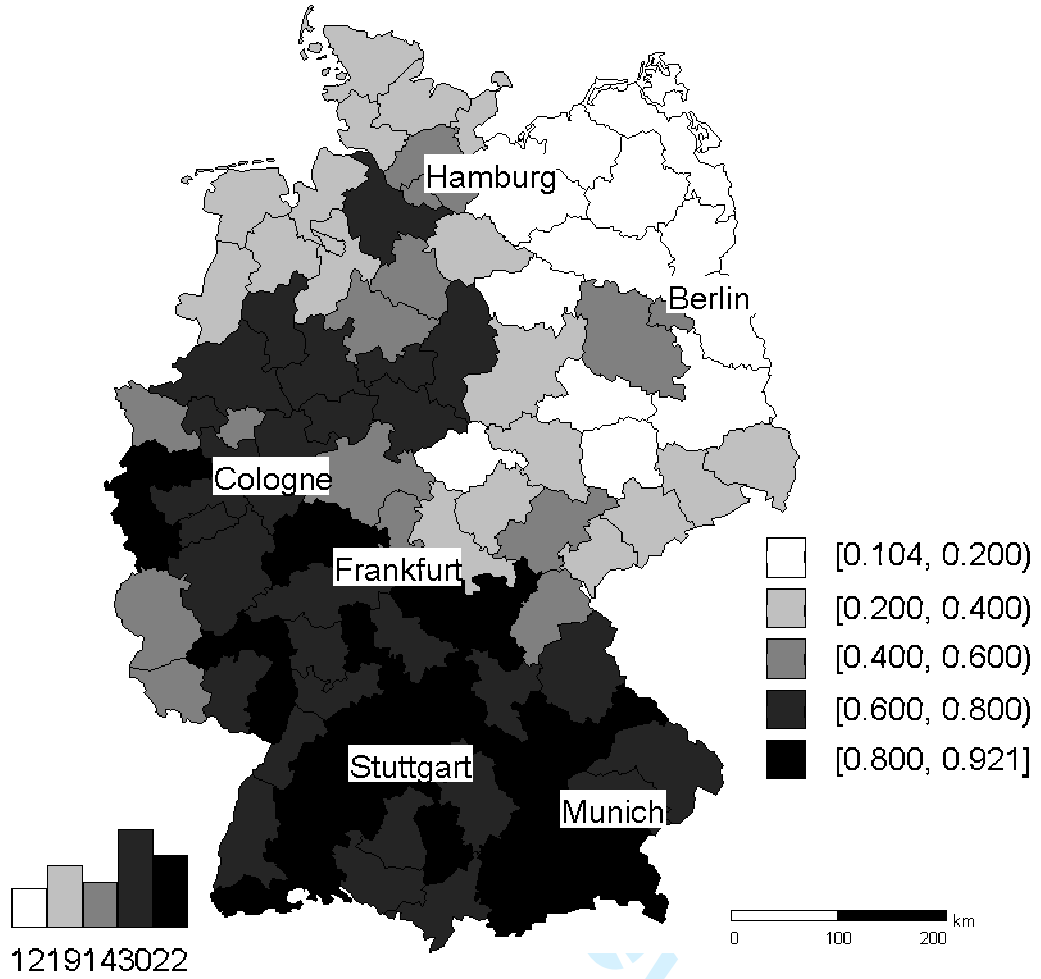


RIS efficiency deterministic approach (file name: te\_det.tif)

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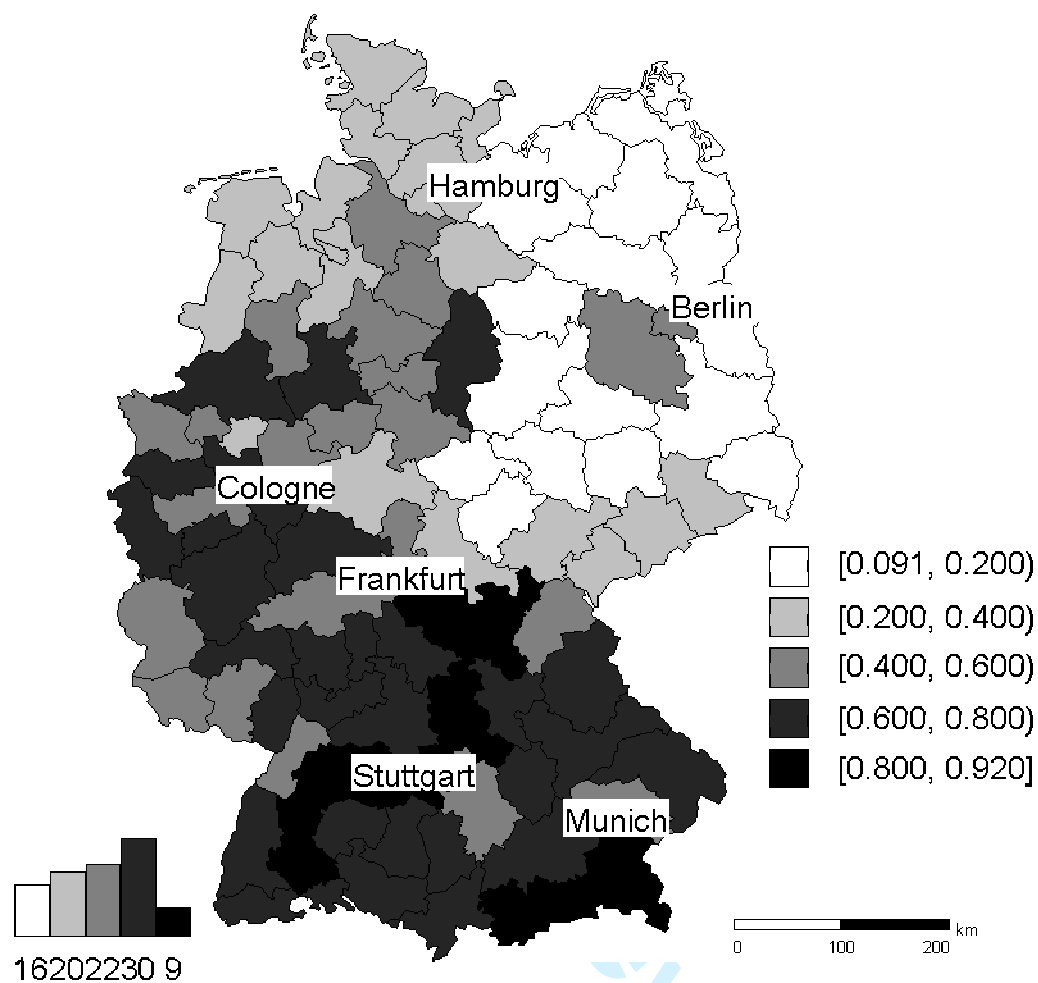
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RIS efficiency stochastic frontier approach with exponential distributed efficiency term (file name: te\_sfae\_.tif)

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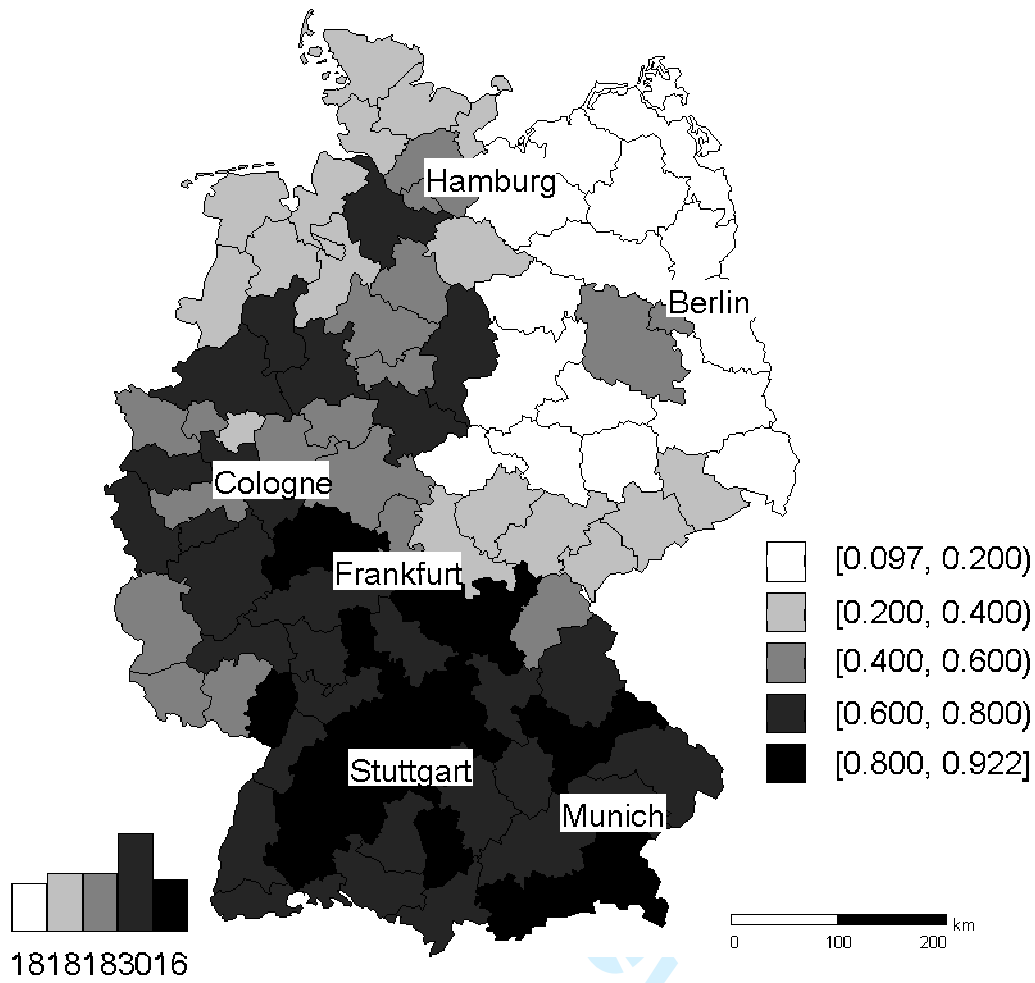


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RIS efficiency stochastic frontier approach with half-normal distributed efficiency term (file name: te\_sfah\_.tif)

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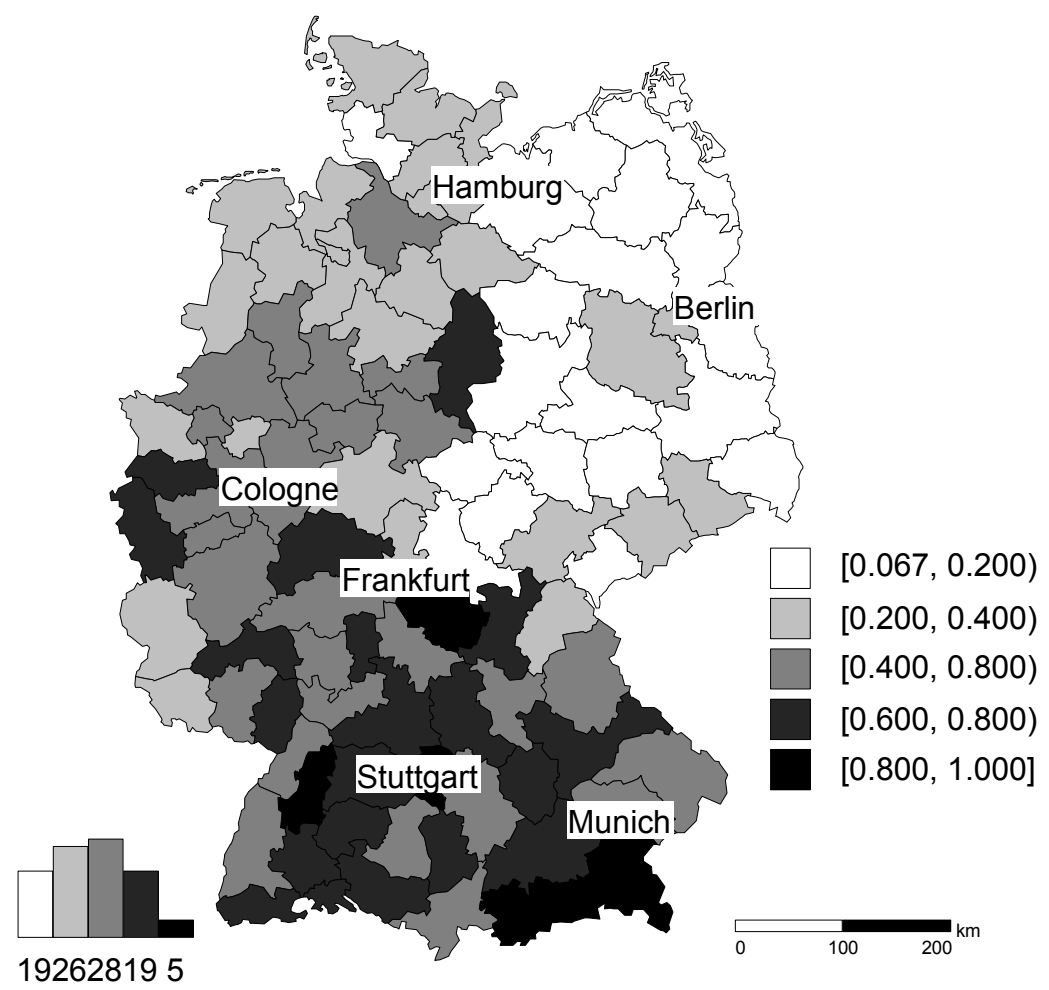
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RIS efficiency stochastic frontier approach with truncated-normal distributed efficiency term  
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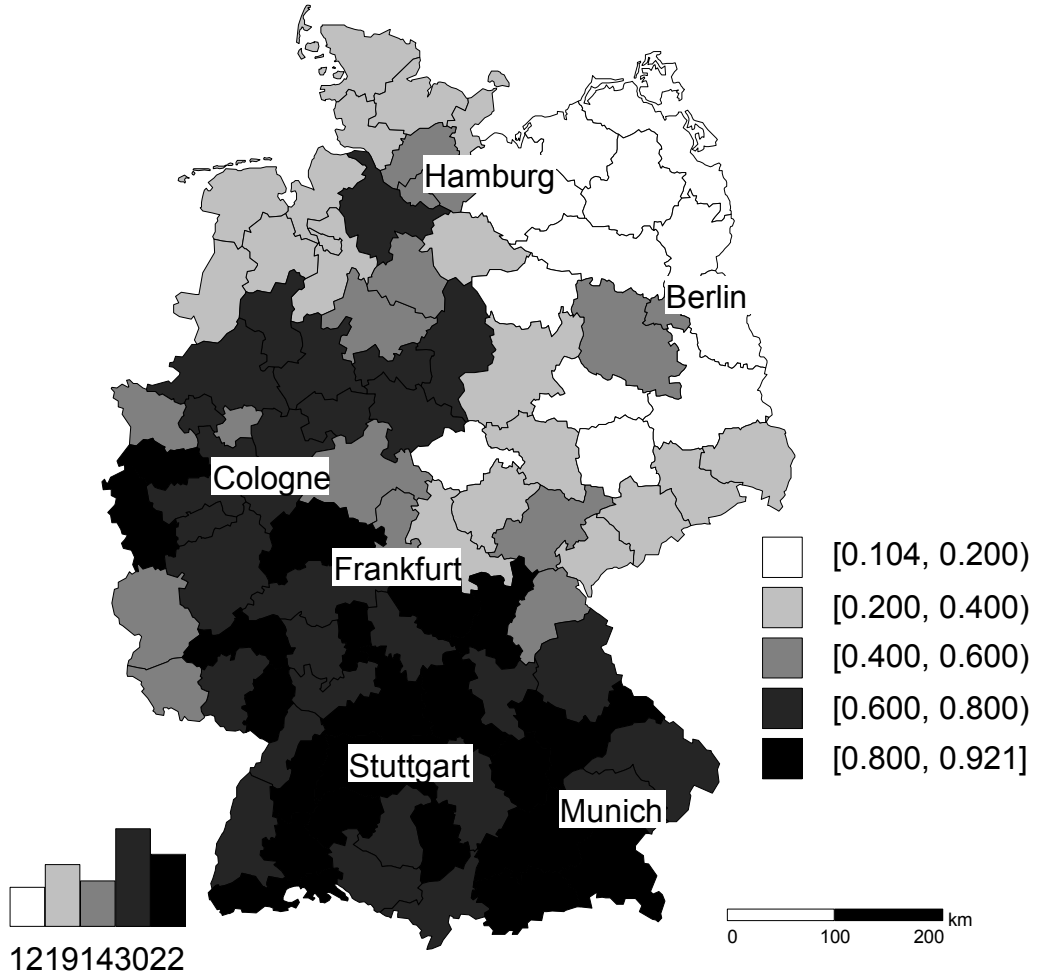
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RIS efficiency deterministic approach (file name: te\_det\_.wmf)

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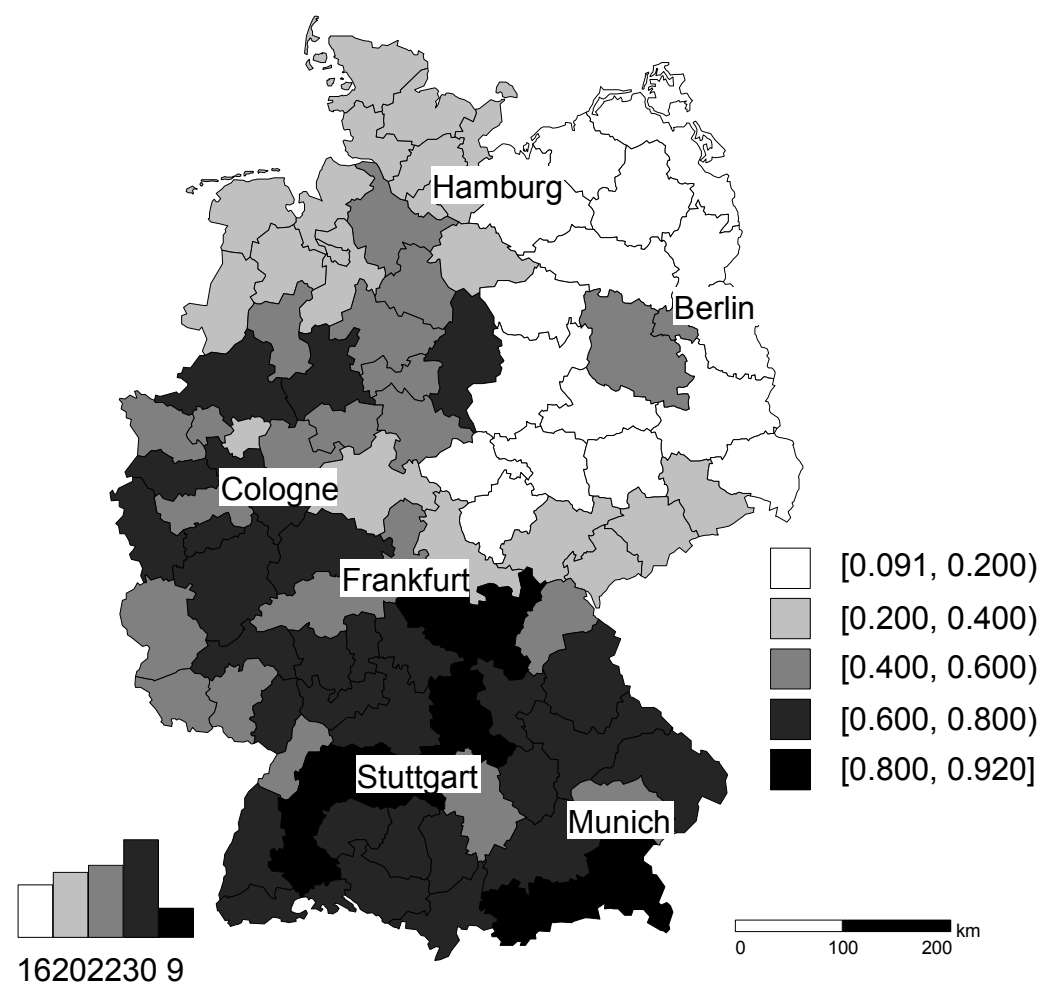
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RIS efficiency stochastic frontier approach with exponential distributed efficiency term (file name: te\_sfae\_.wmf)

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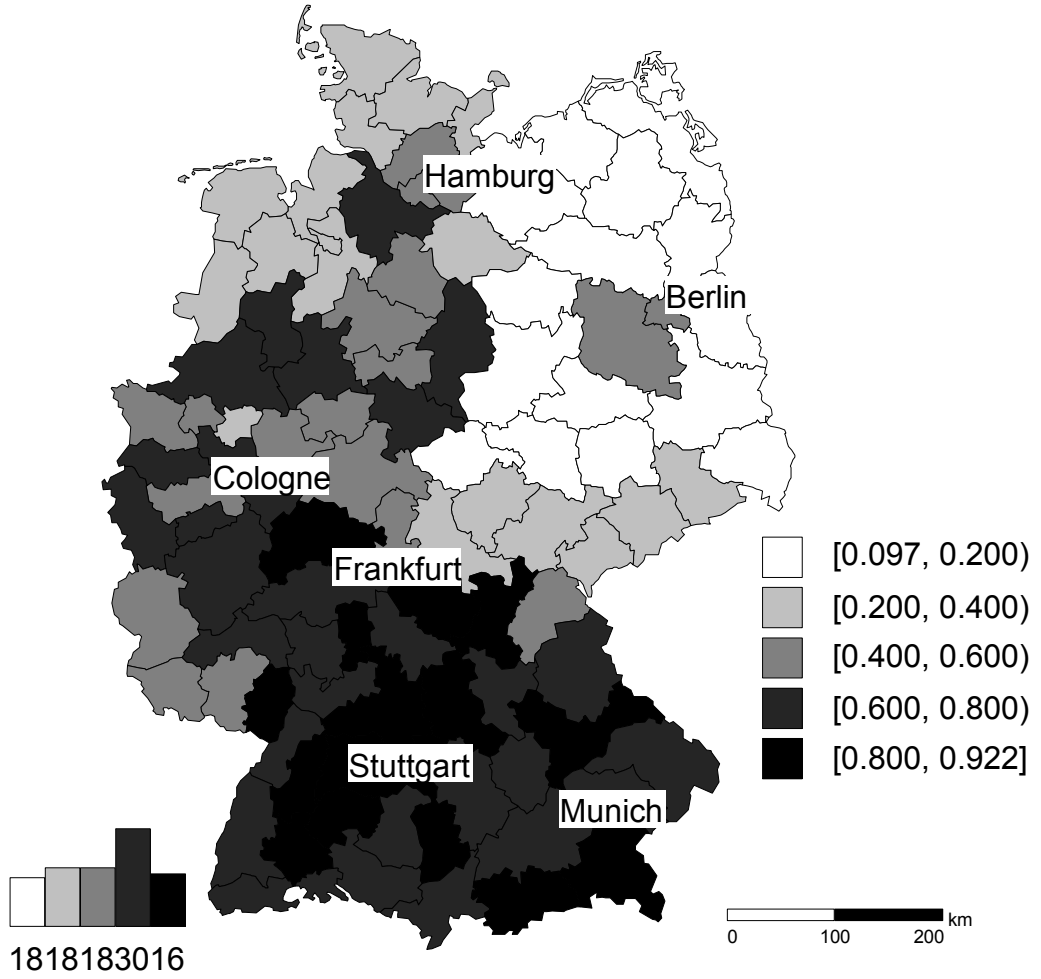
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RIS efficiency stochastic frontier approach with half-normal distributed efficiency term (file name: te\_sfah\_.wmf)

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RIS efficiency stochastic frontier approach with truncated-normal distributed efficiency term  
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