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Regional Convergence in Germany. A Geographically Weighted Regression Approach[*]

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Abstract

Regional convergence of German labour markets represents a politically important question. Different studies have examined convergence processes in Germany. We derive equations to estimate the speed of convergence on the basis of an extended Solow model. The technique of geographically weighted regression permits a detailed analysis of convergence processes, which has not been conducted for Germany so far yet. It allows to estimate a separate speed of convergence for every region resulting from the local coefficients of the regression equations. The application of this technique to German labour market regions shows regions moving with a different speeds towards their steady states. The half-live times in the model of conditional convergence disperse less than the same coefficients in the absolute convergence model. Moreover, the speed of convergence is substantially slower in the manufacturing sector than in the service sector.

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1. Introduction

Regional convergence is a politically important question. In the European Community contract the adjustment of the living conditions is explicitly mentioned (s. Lammers, 1998, p. 197). The Basic Constitutional Law of the Federal Republic of Germany (Grundgesetz) mentions uniform living conditions (Art. 72 GG). From this the necessity for an economic policy aligned to convergence can be justified. The Planning Committee for Regional Economic Structure, to which important federal ministers are members, passed a law in 2004 (33. Rahmenplan der Gemeinschaftsaufgabe "Verbesserung der regionalen Wirtschaftsstruktur") about regional policy. In that law regional equalization is explicitly mentioned (cf. Eberstein & Karl, 1996 cont., D II 2, pp. 7, see also Irmen & Strubelt, 1998, p. 2). So, many fiscal programmes aim at a reduction of regional differences.

Because of the high political importance, many studies have dealt with the issue of convergence and divergence. On the one hand, researchers provide surveys on the European level (see for example Neven, 1995; Thomas, 1995; Engel & Rogers, 1996; Thomas, 1996; Helliwell, 1998; Nitsch, 2000; Martin, 2001; Niebuhr, 2002; Fingleton, 2003; Bottazzi & Peri, 2003; Arbia & Paelinck, 2003; Greunz, 2003; López-Bazo & Vayá & Artis, 2004 and Eckey & Kosfeld & Türck, 2005 a).

On the other hand, there are many elaborate analyses of the convergence process in Germany. Smolny (2003) examines the extent to which the poor economic development in East German regions can be explained by a growth model. But he finds no convincing explanation for the low productivity. He assumes that East Germany will not catch up with West Germany soon. The same conclusion is conducted by Ragnitz (2000) who gives several structural reasons for the productivity lag, such as different sectoral patterns, a low capital intensity of production and a weak market position of firms. Klodt (2000) concludes that the fading out of the catching-up process since the mid-1990s has been caused by an inappropriate design of industrial policy, which is concentrated on the subsidy of physical capital.

Kemper (2004) analyses the internal migration in East and West Germany. Before unification there were different ways of migration. While in the GDR there were tendencies towards urbanisation, in West Germany there was deconcentration. The 1990s are represented by a convergent development towards a suburbanisation in both parts of Germany. At the end of the decade there were further tendencies towards divergence in the internal migration.

Other aspects of convergence are the process of specialisation of industries as well as the employment. The paper of Niebuhr (2000) is based on two economic growth equilibriums. First, the development of productivity is explained by the level of production. Second, a regression model analyses the relationship between an indicator of agglomeration and the growth of employment. Both approaches show a convergent development in West Germany's planning regions. Suedekum (2004) does not find a trend towards spatial specialisation or concentration. Only in some regions the specialisation is increasing. These areas benefit from it by an above-average employment growth. Suedekum & Blien (2004) supply an accurate analysis of the distribution of employment. The shift share regression of West German administrative districts yields a negative effect of regional wages on employment growth. Employment growth differs, especially suburban regions gain jobs from the core cities. The study of Görzig & Gornig & Werwatz (2005) shows that the catching-up process of East German wages has slowed down during the last ten years. Bayer & Juessen (2004) conduct a time series approach to find out, whether the unemployment rate in the West German Länder will converge. The used data cover the period from 1960 to 2002. Some tests suggest a convergence process and others not.

An important indicator is also labour productivity. Barrel & Velde (2000) provide empirical evidence for a catching-up process of East Germany compared to West Germany. They estimate unbalanced panel models and identify the emergence of West German firms besides exogenous and endogenous technical processes as important factors. Kosfeld & Eckey & Dreger (2006) estimate a convergence rate of 7.6 % across German regional labour markets. On the basis of an extended Solow model they predict an increase of relative labour productivity from 74 % to 88 % in East Germany in comparison to West Germany in the decade from 2000 to 2010.

Researchers often use the GDP per capita to examine convergence processes. Funke & Strulik (2000) develop a two-region endogenous growth model to study the regional development of the output. The speed of convergence in unified Germany depends on the expansion of the infrastructure. They introduce several scenarios, which all suggest a quite fast convergence process of both parts of Germany. In the most optimistic scenario East Germany will reach 80 per cent of West Germany's GDP per capita after 20 years. Juessen (2005) finds out using descriptive statistics of the GDP per capita that poor regions are catching up. A nonparametric kernel approach provides evidence for regional divergence in the long run.

Some researchers use regression models with income or GDP per capita as the dependent variable. Herz & Röger (1995) find a half-life time of 16 years for 75 West German "Raumordnungsregionen" using the period 1957-1988. Bohl (1998) identifies tendencies towards regional divergence, because the null hypothesis of the unit root test for panel data (Levin Lin test) is not rejected. But the result is limited by the fact that there can be found stationarity in some federal states. Kosfeld & Lauridson (2004) estimate an error-correction mechanism to cover tendencies towards convergence in German labour market regions. The adjustment coefficient is not significant, so they conclude: "At the end of the 20s century only weak local adjustment processes (…) towards a global equilibrium can be established" (Kosfeld & Lauridson, 2004, p. 720). Funke & Niebuhr (2005a) use regression models in order to explain economic growth from West Germany's planning regions. Because the estimations do not fit well, they provide a kernel approach to cluster the regions. They find three convergence clubs, which have different growth equilibriums. Funke & Niebuhr (2005b) provide insights of β-convergence in West Germany's planning regions. For the period of 1976 to 1996 a slow rate of convergence is detected. Kosfeld & Eckey & Dreger (2006) study β-convergence in German functional regions for the period from 1992 to 2000. In an absolute convergence model the speed of convergence amounts to 6.5 %. The convergence rate in a conditional grows model decreases to 4 %.

Beside of β-convergence Barro & Sala-i-Martin (1991, pp. 112) introduced σ-convergence. This concept measures the changing in earning differences. If the gap is closing, there is a tendency towards convergence. Only a few papers use the concept of σ-convergence. Bode (1998) analyses this approach by using Markov chain models. He concludes that West German regions are converging since the 1970s. Kosfeld & Eckey & Dreger (2006) find diminishing variances of income per capita and labour productivity in German labour regions, so the hypothesis of σ-convergence is confirmed.

A new aspect is the calculation of locally different parameters of β-convergence, because the variation of parameters can lead to inconsistent estimators (Temple, 1999, pp. 126). Locally different parameters can be calculated by the technique of geographically weighted regression, which is developed by Brunsdon, Charlton and Fotheringham (see for example Brunsdon & Fotheringham & Charlton, 1998, p. 957; Fotheringham & Brunsdon & Charlton, 2000 and Fotheringham & Brunsdon & Charlton, 1998). Only one convergence study uses this model. Bivand & Brunstad (2005) estimate a geographically weighted regression of Western Europe. Their coefficients have changing signs. They find convergence of some regions and divergence of others.

However, a model, which uses different regression coefficients for German regions, has not been estimated until now. In addition most models of conditional β-convergence, which use the approach of Mankiw & Romer & Weil (1992), assume the same growth rate of technological progress and rate of depreciation in all regions or neglect the term (see for example Islam, 1995; Huang, 2005).

The aim of this paper is to estimate a convergence model with locally different parameters of German regions taking into consideration the problems specified above. The paper is organized as follows. In section 2 we present a neoclassical growth model, which augments the Solow model by human capital. Section 3 outlines the geographically weighted regression. In particular, we show how this approach is estimated and tested. In addition we explain the used data. The estimated models are presented in Section 4. Section 5 concludes.

2. Growth model

We use a model that has been suggested by Mankiw & Romer & Weil (1992). They add human capital, which is stressed in the endogenous growth theory (s. for example Lucas, 1988; Grossmann & Helpman, 1989 and as an overview Frenkel & Hemmer, 1999, pp. 200) to the Solow model. Human capital is important, because this production factor explains tendencies towards convergence in East Germany at the beginning of the 1990s (Barrel & Velde, 2000). The production function of type Cob-Douglas in period t is given by:

$$(1) \qquad Y_t = K_t^{\alpha} \cdot H_t^{\beta} \cdot (A_t \cdot L_t)^{1-\alpha-\beta},$$

where Y is the output, K represents the stock of physical capital, H the stock of human capital, A the level of technology and L the labour (Mankiw & Romer & Weil, 1992, p. 416). Dividing the production function (1) by $A_t \cdot L_t$ yields the equation:

$$(2) \qquad y_t = k_t^{\alpha} \cdot h_t^{\beta},$$

where the lower cases stand for quantities per effective unit of labour, i. e. $y_t = Y_t/(A_t \cdot L_t)$, $k_t = K_t/(A_t \cdot L_t)$ and $h_t = H_t/(A_t \cdot L_t)$. The steady state of output per effective can derived from this production function (s. Romer, 1996, p. 133 and Mankiw & Romer & Weil, 1992, pp. 416):

$$(3) \qquad y^* = \ln\left(\frac{s_k}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot h^{\frac{\beta}{1-\alpha}}$$

with s_k as saving rate of capital, n as growth rate of labour L, g as rate of technological progress and δ as depreciation rate. Barro & Sala-i-Martin (2004, p. 61) have shown that approximating equations (2) and (3) around the steady state yields, if one takes a Taylor series expansion:

$$(4)\qquad \ln y_t - \ln y_0 = -(1-e^{-\lambda t})\cdot \ln y_0 + (1-e^{-\lambda t})\cdot \frac{\alpha}{1-\alpha-\beta}\ln s_k + (1-e^{-\lambda t})\cdot \frac{\beta}{1-\alpha-\beta}\ln s_h - (1-e^{-\lambda t})\cdot \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta)\,.$$

The growth of the output is positively determined by the proportion of output, which is invested in physical and human capital, and negatively affected by the initial level of output as well as the growth rate of labour force, technological progress and depreciation (Mankiw & Romer & Weil, 1992, p. 423). Equation (4) studies conditional convergence. This is a convergence process, where poorer regions grow faster than richer regions after controlling for relevant variables. Then the regression coefficient for the starting level of output will be significantly negative.

The conditional convergence model can be also expressed with the human capital in the steady state instead of the invested share in human capital. The relationship follows from formula (4):

$$(5)\qquad \ln y_t - \ln y_0 = -(1-e^{-\lambda t})\cdot \ln y_0 + (1-e^{-\lambda t})\cdot \frac{\alpha}{1-\alpha}\ln s_k + (1-e^{-\lambda t})\cdot \frac{\beta}{1-\alpha}\ln h^* - (1-e^{-\lambda t})\cdot \frac{\alpha}{1-\alpha}\ln(n+g+\delta)\,.$$

A significant conditional convergence does not necessarily mean that an absolute convergence process takes place. Absolute convergence applies a negative relationship between the initial output and growth of output without using control variables:

$$(6)\qquad \ln y_t - \ln y_0 = -(1-e^{-\lambda t})\cdot \ln y_0\,.$$

In empirical analyses quantities per capita and not per effective unit of labour are usually used, because the level of technology A is unknown. The equations (5) and (6) are given in units per capita as follows (s. Hemmer & Lorenz, 2004, p. 49 and Temple, 1999, p. 122):

$$(7)\qquad \ln\left(\frac{Y_t}{L_t}\right) - \ln\left(\frac{Y_0}{L_0}\right) = -(1-e^{-\lambda t})\cdot \ln\left(\frac{Y_0}{L_0}\right) + (1-e^{-\lambda t})\cdot \ln A_0 + gt\,.$$

and

$$(8)\qquad \ln\left(\frac{Y_t}{L_t}\right) - \ln\left(\frac{Y_0}{L_0}\right) = -(1-e^{-\lambda t})\cdot \ln\left(\frac{Y_0}{L_0}\right) + (1-e^{-\lambda t})\cdot \frac{\alpha}{1-\alpha}\ln s_k + (1-e^{-\lambda t})\cdot \frac{\beta}{1-\alpha}\ln\left(\frac{H}{L}\right)^* - (1-e^{-\lambda t})\cdot \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + (1-e^{-\lambda t})\cdot \ln A_0 + gt\,.$$

Note that the restriction of model (5) of absolute equal coefficients for $\ln s_k$ and $\ln(n+g+\delta)$ leads to the equation:

(9)
$$\ln\left(\frac{Y_t}{L_t}\right)-\ln\left(\frac{Y_0}{L_0}\right)=-(1-e^{-\lambda t})\cdot\ln\left(\frac{Y_0}{L_0}\right)+(1-e^{-\lambda t})\cdot\frac{\alpha}{1-\alpha}\left[\ln s_k-\ln(n+g+\delta)\right]$$
$$+(1-e^{-\lambda t})\cdot\frac{\beta}{1-\alpha}\ln\left(\frac{H}{L}\right)^{*}+(1-e^{-\lambda t})\cdot\ln A_0+gt\,.$$

However, the investments in human capital are difficult to measure, because the foregone labour earnings can hardly be figured out. Mankiw & Romer & Weil (1992) use the percentage of working-age-population that attends secondary school. They assume that their input based indicator is proportional to the investments. So the estimators will not be biased. This input based indicator is criticised by Dinopoulus & Thompson (1999, pp. 141-142). They argue that the indicator from Mankiw & Romer & Weil (1992) will underestimate human capital in poor countries and overestimate it in rich countries.

Dinopoulus & Thompson (1999) point out further reasons for the inadequacy of this indicator. First, human capital involves tertiary education and training on the job, too. Second, the attendance at school does not necessarily imply that human capital is rising. There are differences in the ability of learning. In addition, some educated skills are difficult to use in practice. However, because the human capital stock in the steady state is unknown and there are not available data for the investments in human capital, the human capital stock should be used instead (Hemmer & Lorenz, 2004, p. 158).

Note that in the conditional convergence model of Mankiw & Romer & Weil (1992, p. 411) gt is a constant, because the period t is fixed [s. formula (9)]. Mankiw, Romer and Weil argue that the differences in the technological level i. e. climatic and institutional circumstances can be measured by a constant α and a country-specific error term ε:

(10) $\ln A_0=\alpha+\varepsilon\,.$

Their assumption of noncorrelation between this error term and the independent variables seem not to be convincing (Islam, 1995, p.1134 and Klenow & Rodriguez-Clare, 1997). The technological growth depends rather on institutional characteristics and endowments, which differ across regions (Gundlach, 2005, pp. 553). So we measure gt and A_0 by locally specific constants. However, there is empirical evidence for threshold values of regional convergence or different regional parameters of β-convergence (s. for example Bivand & Brunstad, 2005; Funke & Niebuhr, 2005a; Juessen, 2005; Huang, 2005). Thus we allow also regionally different values for all other parameters to prevent inconsistent estimators (Temple, 1999, p. 126). In addition we do not use the unconvincing assumption of the same growth rate of technological progress and rate of depreciation in all regions (see Temple, 1999, p. 122, Kosfeld & Eckey & Dreger 2006). All regression coefficients, especially the rate of convergence, are estimated separately for all regions. This model of conditional convergence is given by:

$$(11)\qquad \ln\left(\frac{Y_t}{L_t}\right)_i - \ln\left(\frac{Y_0}{L_0}\right)_i = -(1-e^{-\lambda_i t})\cdot\ln\left(\frac{Y_0}{L_0}\right)_i + (1-e^{-\lambda_i t})\cdot\frac{\alpha_i}{1-\alpha_i}\left[\ln s_{k_i} - \ln(n_i + g_i + \delta_i)\right] + (1-e^{-\lambda_i t})\cdot\frac{\beta_i}{1-\alpha_i}\ln\left(\frac{H}{L}\right)_i + (1-e^{-\lambda_i t})\cdot\ln A_{0_i} + g_i t\,.$$

The analogical model of absolute convergence can be expressed as follows:

$$(12)\qquad \ln\left(\frac{Y_t}{L_t}\right)_i - \ln\left(\frac{Y_0}{L_0}\right)_i = -(1-e^{-\lambda_i t})\cdot\ln\left(\frac{Y_0}{L_0}\right)_i + (1-e^{-\lambda_i t})\cdot\ln A_{0_i} + g_i t\,.$$

3. Regression model and data sources

3.1 Geographically weighted regression

The influence between a dependent variable Y and some independent variables X_k differs often across regions (spatial nonstationarity). Therefore our regression models consist of locally different parameters [cf. formulas (11) and (12)]. We use a geographically weighted regression (GWR) which has been developed by Brunsdon, Charlton and Fotheringham in the past ten years (see for example Brunsdon & Fotheringham & Charlton, 1998, p. 957; Fotheringham & Brunsdon & Charlton, 2000 and Fotheringham & Brunsdon & Charlton, 1998).

The global regression model without taking into consideration a spatial dependence is written by the form

$$(13)\qquad y_i = \beta_0 + \sum_{k=1}^{m}\beta_k\cdot x_{ki} + u_i\,,$$

where y_i, i = 1, 2, …, n, are the observation of the dependent variable Y, β_k (k = 0, 1, 2, …, m) represent the regression coefficients, x_{ki} is the *i*th value of X_k and u_i are the error terms. In matrix notation (13) is given by

$$(14)\qquad \mathbf{y} = \beta_0 + \sum_{k=1}^{m}\beta_k\cdot\mathbf{x}_k + \mathbf{u}$$

with $\mathbf{y}$ as vector of the dependent variable, $\mathbf{x}_k$ as vector of the *k*th independent variable and $\mathbf{u}$ as vector of the error term. In geographically weighted regression the global regression coefficients in (13) are replaced by local parameters:

$$(15)\qquad y_i = \beta_{0i} + \sum_{k=1}^{m}\beta_{ki}\cdot x_{ki} + u_i\,,$$

where β_{ki} (k = 0, 1, 2, …, m) is the regression coefficient, which expresses the influence of x_{ki} on y_i. If the β_{ki} are constant for all i = 1, 2, 3, …, n, the global model of equation (13) or (14) respectively holds (cf. Brunsdon & Fotheringham & Charlton, 1996, pp. 282 and Fotheringham & Charlton & Brunsdon, 1997, pp. 62). In model (12) the dependent variable y_i is $\ln(Y_t/L_t)_i - \ln(Y_0/L_0)_i$ and **X** assembles the independent variables in a $n\times 2$-matrix. It contains a column of 1s to estimate the influence of $\ln A_{0_i} + g_i t$ on Y. In the second column stand the values of $\ln(Y_0/L_0)_i$. The conditional convergence model (11) differs only regarding **X** from model (12). The matrix **X** contains two further columns, first $\left[\ln s_{k_i} - \ln(n_i + g_i + \delta_i)\right]$, second $\ln(H/L)_i$.

Thus the global model is a special case of the GWR function. For every region separate parameters are estimated, which is an advantage over the spatial error and the spatial lag model (cf. Anselin, 1988). A spatial dependence in the error term can be caused by a missing spatial varying relationship (Brunsdon & Fotheringham & Charlton, 1999, pp. 497).

How can the GWR parameters be estimated, because there are more unknowns in (15) than degrees of freedom? In the calibration observations are weighted in accordance with its proximity to region i. As the distance between two regions becomes smaller, the weight will be greater. We use the Euclidean distance between two regions d_{ij} to calculate the weights (Gaussian weighting function):

(16) $$w_{ij} = e^{-0{,}5\cdot\left(d_{ij}/\text{bandwidth}\right)^2}.$$

The bandwidth indicates the extent to which the distances are weighted. With a greater bandwidth the smoothing increases. Then regions i and j get a smaller (greater) weight w_{ij}, if they are far from (close to) each other. The bandwidth is computed by cross-validation or minimising the Akaike information criterion (Fotheringham & Brunsdon & Charlton, 2000, pp. 56; Fotheringham & Charlton & Brunsdon, 1998, p. 1910).

The regression coefficients are estimated by weighted least squares (WLS). The values of the independent variables from regions which are nearer to region i have a greater influence, because they are multiplied with the weight matrix $\mathbf{W}_i$ for region i:

(17) $$\hat{\boldsymbol{\beta}}_i = \left(\mathbf{X}'\cdot\mathbf{W}_i\cdot\mathbf{X}\right)^{-1}\cdot\mathbf{X}'\cdot\mathbf{W}_i\cdot\mathbf{y}.$$

$\hat{\boldsymbol{\beta}}_i$ is the GWR estimator for the *i*th region:

(18) $$\hat{\boldsymbol{\beta}}_i = \left(\hat{\beta}_{i0}\quad\hat{\beta}_{i1}\quad\cdots\quad\hat{\beta}_{im}\right)'$$

and $\mathbf{W}_i$ a n by n diagonal matrix, which is denoted by the weights w_{ij}, j = 1, 2, …, n:

(19) $$\mathbf{W}_i = \begin{bmatrix} w_{i1} & \cdots & 0 & 0 \\ 0 & w_{i2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_{in} \end{bmatrix}.$$

However, one should test if the GWR model is appropriate. The global test of nonstationarity compares a regression of $\mathbf{y}$ on $\mathbf{X}$ with sum of squared residuals to a geographically weighted regression. The extra complexity of varying regression coefficients is worthwhile only, if the GWR model supplies a smaller residual sum of squares in comparison to the OLS estimation. The sum of squared residuals from the OLS model can be expressed as:

(20) $$\hat{\mathbf{u}}_0'\cdot\hat{\mathbf{u}}_0 = \mathbf{y}'\cdot\mathbf{R}_0\cdot\mathbf{y}$$

with

(21) $$\mathbf{R}_0 = \left(\mathbf{I}-\mathbf{S}_0\right)'\cdot\left(\mathbf{I}-\mathbf{S}_0\right)$$

and

(22) $$\mathbf{S}_0 = \mathbf{X}\cdot\left(\mathbf{X}'\cdot\mathbf{X}\right)^{-1}\cdot\mathbf{X}'.$$

$\mathbf{S}_0$ is called OLS smoothing operator, because it transfers or "smooths" the observed values $\mathbf{y}$ to the expected values $\hat{\mathbf{y}}$:

(23) $$\hat{\mathbf{y}} = \mathbf{S}_0\cdot\mathbf{y}.$$

The *i*th row of the GWR smoothing operator $\mathbf{S}_1$ is given by

$$(24)\qquad \mathbf{s}_i = \mathbf{x}_i' \cdot \left(\mathbf{X}' \cdot \mathbf{W}_i \cdot \mathbf{X}\right)^{-1} \cdot \mathbf{X}' \cdot \mathbf{W}_i .$$

Letting $\mathbf{R}_1$ be a quadratic matrix computed with the GWR smoothing operator:

$$(25)\qquad \mathbf{R}_1 = \left(\mathbf{I} - \mathbf{S}_1\right)' \cdot \left(\mathbf{I} - \mathbf{S}_1\right),$$

the GWR residuals may be written using the quadratic form of this matrix

$$(26)\qquad \hat{\mathbf{u}}_1' \cdot \hat{\mathbf{u}}_1 = \mathbf{y}' \cdot \mathbf{R}_1 \cdot \mathbf{y} .$$

If we assume **y** has a normal distribution, the ratio

$$(27)\qquad \mathrm{F} = \frac{\left(\hat{\mathbf{u}}_0' \cdot \hat{\mathbf{u}}_0 - \hat{\mathbf{u}}_1' \cdot \hat{\mathbf{u}}_1\right)/\mathrm{v}}{\left(\hat{\mathbf{u}}_1' \cdot \hat{\mathbf{u}}_1\right)/\mathrm{w}},$$

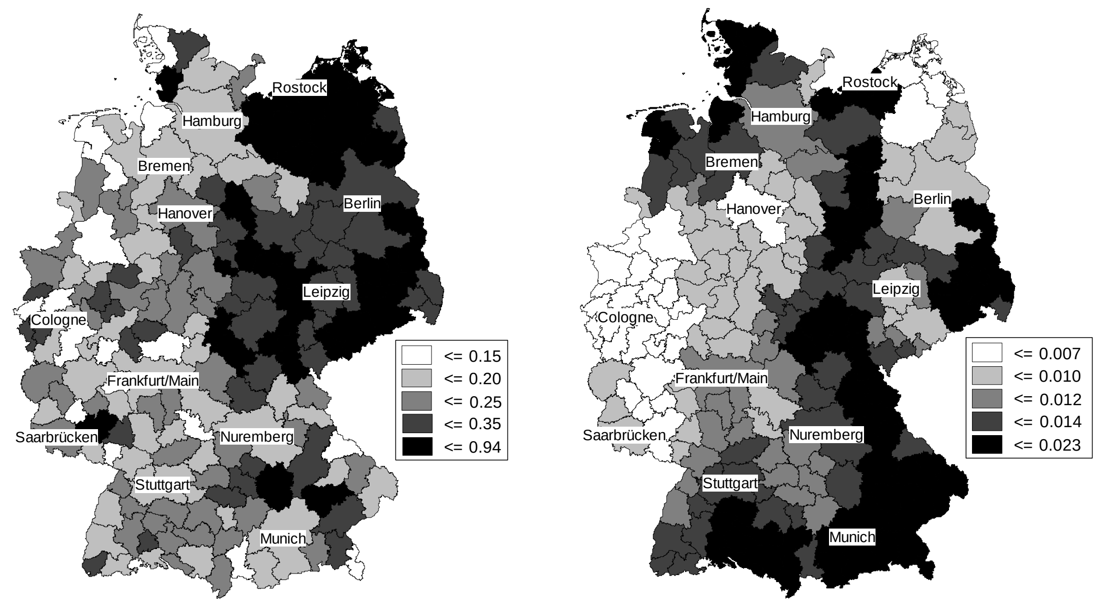
where v denotes the trace of $\mathbf{R}_1 - \mathbf{R}_0$ and w the trace of $\mathbf{R}_1$, is approximative F-distributed (Brunsdon & Fotheringham & Charlton, 1999, pp. 501). If the null hypothesis of stationarity is rejected, the GWR model is appropriate.

Beside the nonstationarity of all regression coefficients one can check if one parameter is nonstationary. The test is based on a Monte Carlo simulation (for details see Fotheringham & Brunsdon & Charlton, 2000, pp. 56). If the null hypothesis of stationarity is rejected for some but not all parameters, a mixed GWR model could be appropriate (Fotheringham & Brunsdon & Charlton, 2000, pp. 65; Mei & He & Fang, 2004). If the global test of nonstationarity suggests using a geographically weighted regression model and the Monte Carlo simulation is not significant for all coefficients, one should also use a GWR approach.

3.2 Sources of data

We estimate an absolute and a conditional convergence model for Germany [cf. formulas (11) and (12)]. As spatial units we do not use administrative units (Kreise). A regression analysis with administrative units can provoke spatial autocorrelation (Keilbach, 2000, pp. 120 and Döring, 2005, p. 100) which is strengthened by suburbanization tendencies (Kühn, 2001; Kaltenbrunner, 2003; Motzkus, 2001, pp. 196 and Schönert, 2003). This spatial autocorrelation would cause an inefficiency of the geographically weighted regression.

Instead our analysis is based on 180 labour market regions, which Eckey defined by commuter flows (Eckey & Horn & Klemmer, 1990; Eckey, 2001). This demarcation worked satisfactorily in different studies (s. for example Kosfeld & Lauridsen 2004, Kosfeld & Eckey & Dreger, 2006; Eckey & Kosfeld & Türck, 2005 and Eckey & Kosfeld, 2005). The official data on the basis of 440 administrative units (Kreise) can be aggregated to labour market regions.



a) Investment rate in physical capital b) Rate of technological progress g

Figure 1. **Investment rate and technological progress per annum (1995-2002)**

Official data are used to estimate the convergence models, which cover the period between 1995 and 2002 (Statistische Ämter des Bundes und der Länder, 2003 and 2004). We focus on labour productivity (Y/L) which is measured by gross value added per employee. The conditional model contains additional variables. The investment rate in physical capital s_k is given by gross investments in physical capital divided by gross value added [s. Figure 1 a)]. Human capital covers the labour force with a degree of an upper school providing vocational education (tertiary education), a university of applied sciences or a university. We use the initial values to prevent an endogeneity bias (s. Temple, 1999, pp. 128). The growth of labour force n is given by the official statistics. The depreciation rate can be computed using the gross investments and the physical capital stock.[1]

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[1] The regional capital stock is not denoted by the official statistics. We use therefore an estimation, which is described in the appendix.

Table 1. Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum
Gross value (Y) 1995	9391.956	14922.431	950.000	88829.000
Gross value (Y) 2002	10882.694	17479.038	1039.000	108565.000
Labour force (L) 1995	207.506	284.761	36.100	1936.900
Labour force (L) 2002	214.839	298.759	30.700	1894.600
Human capital (H) 1995	15.436	28.777	1.100	222.400
Physical capital (K) 1995	48910.661	72357.732	4303.300	452136.500
Physical capital (K) 2002	57657.334	82425.905	6262.300	503232.500
Investment rate in physical capital (s_k) per annum (1995-2002)	0.268	0.131	0.080	0.937
Growth rate of labour force (n) per annum (1995-2002)	0.002	0.010	-0.034	0.026
Growth rate of technological progress (g) per annum (1995-2002)	0.012	0.005	-0.002	0.025
Rate of depreciation (δ) per annum (1995-2002)	0.023	0.002	0.020	0.027

In many studies a constant rate of technological progress is used for all regions (see for example Islam, 1995, p. 1139; Barro, 1999, p. 122 and Kosfeld & Eckey & Dreger, 2006, pp. 759), which is not realistic (Gundlach, 2005, pp. 553). We estimate g with a panel GWR approach of the production function:

$$(28) \qquad Y = f(\text{dummy West/East}, \text{dummy for } g, L, K, H).$$

The dummy variable for estimating g is 1, if the values of 2002 are used. The regression coefficient belonging to this dummy yields the growth rate over the whole period. Figure 1 b) provides a visual impression of the spatial structure. The rate of technological progress is high in some regions around Munich and Stuttgart as well as in East Germany and low in the industrially shaped Ruhr district and Saarland.[2] The average growth rate for Germany corresponds with the estimation of Grömling (2004).[3]

4. Empirical evidence on convergence

4.1 Absolute convergence

At first we estimate an absolute convergence model of the neoclassical growth theory for two reasons. On the one hand, this model, which was developed by Barro and Sala-i-Martin (1992 and 1991, pp. 112), is now a standard model. It is used by many

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[2] In addition we estimated the rate of technological progress with the Solow residual (Barro, 1999 and Barro & Sala-i-Martin, 2004, pp. 434). The regional results of this approach, which is usually used (see for example Grömling, 2001, and Grömling, 2004), do not convey a great deal, because the coefficient g is negative in about 10 % of the regions.

[3] Our estimation averages out 1.1 %.

researchers (see for example Kosfeld & Eckey & Dreger, 2006; Seitz, 1995; Kim, 2003; Cuadrado-Roura, 2001; Martin, 2001; Fingleton, 2003 and Gundlach, 2003) but with the exception of Bivand & Brunstad (2005) only for stationary regression coefficients. This assumption of the same convergence rate of every region is not realistic (Temple, 1999, pp. 126). On the other hand, the absolute convergence model permits a sectoral analysis of the convergence process, because sectoral data are not available for the control variables.

The absolute convergence is estimated with labour productivity, which is measured by gross value added per employee. The average growth of labour productivity is explained by the initial labour productivity level. The GWR equilibrium of this model can be expressed as [s. formulas (12) and (15)]:

$$\text{(29)} \qquad \frac{\ln y_{i,2002} - \ln y_{i,1995}}{7} = \beta_{0i} + \beta_{1i} \cdot \ln y_{i,1995} + u_i \,.$$

The results of the calculations are listed in Table 2. The coefficient of determination R^2 (global OLS estimation of the equilibrium

$$\text{(30)} \qquad \frac{\ln y_{i,2002} - \ln y_{i,1995}}{7} = \beta_0 + \beta_1 \cdot \ln y_{i,1995} + u_i \,)$$

yields a value of 33.7 %. This proportion of explained variation is significant. The regression coefficients have the expected sign. We obtain a level of technology in the base period 1995, which is expressed by the intercept, of 0.137. The negative coefficient of the initial labour productivity level confirms a convergence of German regions. Regions, which have a low labour productivity, grow faster than regions with a high labour productivity. The parameter β_1 is linked to the speed of convergence λ by the following relationship [cf. formulas (9) and (30)]:

$$\text{(31)} \qquad \beta_1 = \frac{-(1 - e^{-7\lambda})}{7} \,.$$

The speed of convergence in the global OLS model,

$$\text{(32)} \qquad \lambda = \frac{1}{7} \cdot \ln(1 + \beta_1 \cdot 7) = \frac{1}{7} \cdot \ln[1 + (-0.032) \cdot 7] = 0.036 [\hat{=} 3.6\,\%] \,,$$

shows quite a fast decline in regional disparities. A 3.6 % convergence rate implies about a:

$$\text{(33)} \qquad t = \frac{-\ln(1/2)}{\lambda} = \frac{-\ln(1/2)}{0{,}036} = 19$$

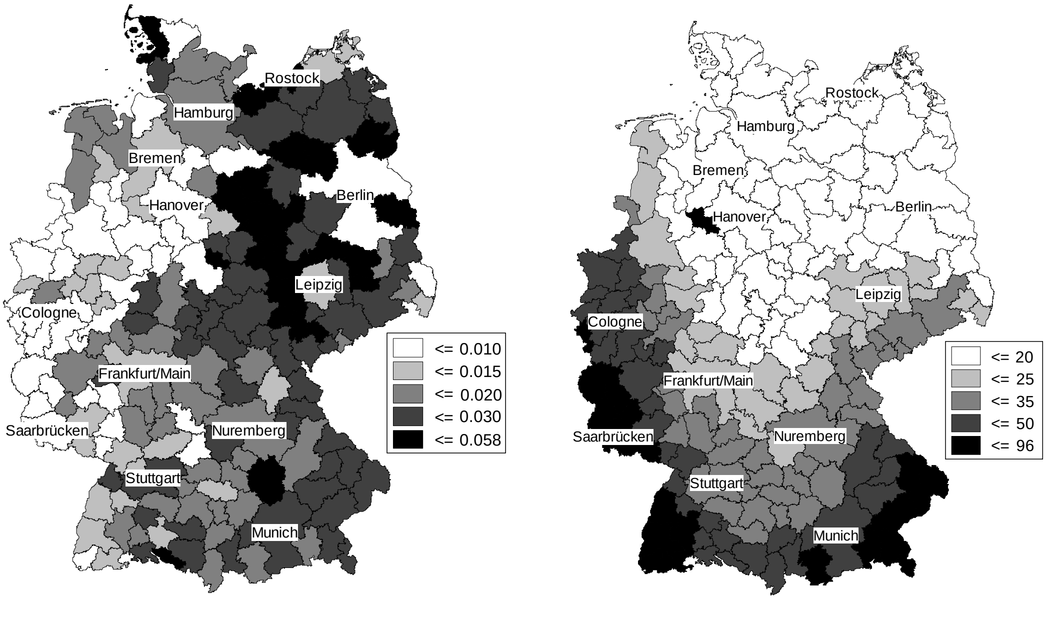
year half-life time of the convergence process.

Table 2. Absolute convergence of the labour productivity

Coefficient	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	Global OLS
β_{0i} or β_0	0.042	0.079	0.110	0.147	0.183	0.137**
β_{1i} or β_1	-0.046	-0.035	-0.025	-0.017	-0.007	-0.032**
R_i^2 or R^2	0.158	0.278	0.333	0.407	0.521	0.337**
AIC = -6.764; Bandwidth = 1.419; Global test of nonstationarity: F = 7.646**						

Notes: R^2 : coefficient of determination; R_i^2 : local coefficient of determination; F: empirical F-value; **: significant at the 1 % level; *: significant at the 5 % level; (*): significant at the 10 % level

Because the null hypothesis of the global test of nonstationarity [s. formula (27)] is rejected, we estimate a GWR model, too.[4] The regression coefficients vary remarkable, but the signs are all the same. Thus the results can be well interpreted. The intercept is always positive and it shows the different extent of using technology. The slope has a negative sign, so German labour regions are converging concerning the labour productivity. The convergence speed covers the range between 0.7 % and 5.5 %.



a) Labour productivity growth

b) Half-life time

Figure 2. Average growth of labour productivity and half-life time of the convergence process 1995-2002

Figure 2 a) shows the distribution of the average labour productivity growth in the period from 1995 to 2002 and the half-life time across German labour regions. Especially regions in the former GDR and in Bavaria have comparably high growth

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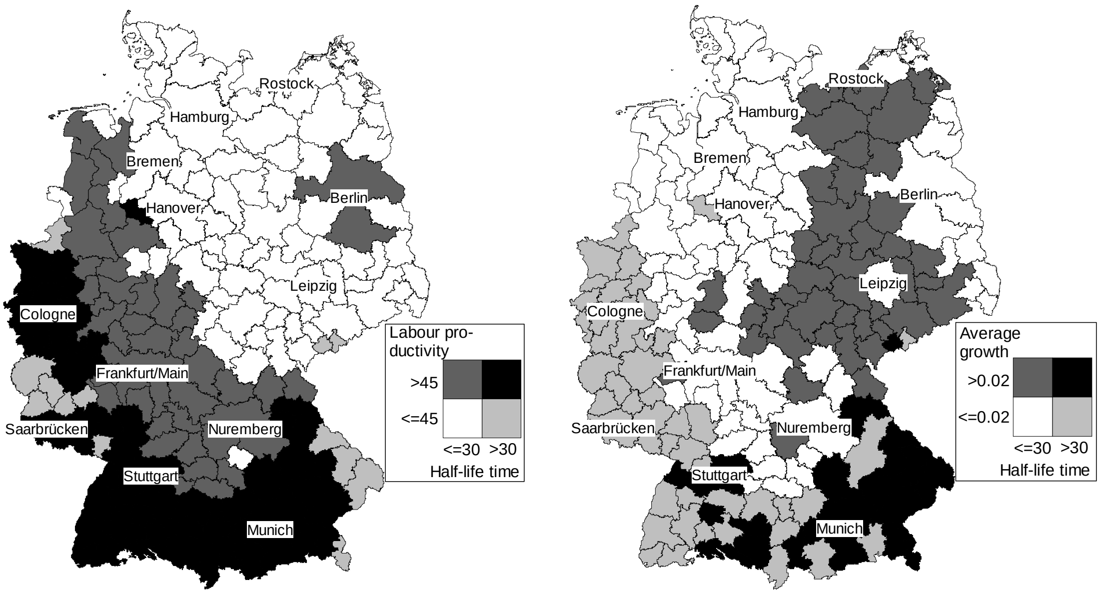
[4] In addition the nonstationarity of the two regression coefficients is checked by Monte Carlo simulation (the p-values are smaller than 0.01). These tests confirm the result of the global test of nonstationarity.

rates. The values increase from the west to the east. The subsidies in the former GDR favoured investments in capital intensive branches (Quehenberger, 2000, pp. 122-123). This process caused a labour-saving technological progress and a high growth in labour productivity.

The half-life time of the convergence process varies in German labour regions [s. Figure 2 b)]. Its value increases from the north to the south. Regions in south Bavaria and Baden-Württemberg as well as in Saarland need more than fifty years to achieve half of the rise in labour productivity to their steady state, while this value lies in Northern Germany at less than 20 years.



a) Half-life time and labour productivity 2002

b) Half-life time and labour productivity growth

Figure 3. Half-life time of the convergence process 1995-2002

Figures 3 a) and 3 b) provide a visual impression of the spatial structure of the half-life time in combination with the labour productivity and the labour productivity growth. The regions in the former GDR have a low labour productivity and a short half-life time. Their steady state of the labour productivity will probably not reach the value of most regions in West Germany, because their relative high growth in the mid 1990s is declining. Some regions in the south of Bavaria and near Stuttgart have a high final labour productivity, an above average growth of this variable and a long half-life time. They will be the most prosperous regions of Germany on a long-term basis.

We also estimate an absolute convergence model of the manufacturing sector and the service sector. For both models the global test of nonstationarity is significant. The explained variance in the approach of the service sector is much higher than the same value of the service sector model (cf. Table 3 and Table 4).

Table 3. **Absolute convergence of the labour productivity (manufacturing sector)**

Coefficient	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	Global OLS
β_{0i} or β_0	0.037	0.089	0.123	0.156	0.325	0.118**
β_{1i} or β_1	-0.080	-0.036	-0.014	-0.017	-0.002	-0.026**
R_i^2 or R^2	0.025	0.278	0.206	0.277	0.471	0.221**
AIC = -5.022; Bandwidth = 1.567; Global test of nonstationarity: F = 4.346**						

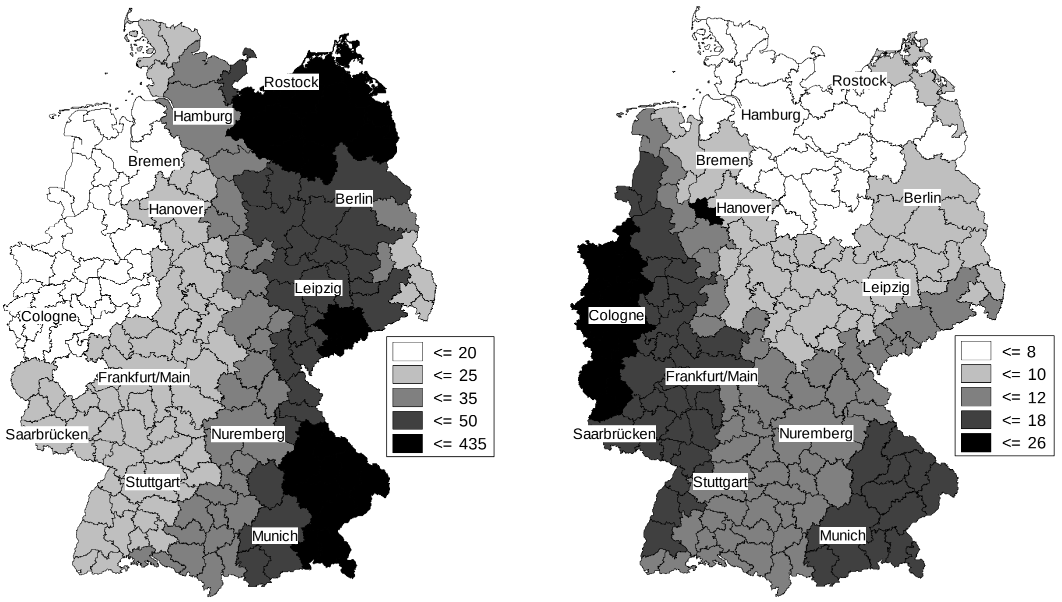
Notes: R^2 : coefficient of determination; R_i^2 : local coefficient of determination; F: empirical F-value; **: significant at the 1 % level; *: significant at the 5 % level; $^{(*)}$: significant at the 10 % level

Table 4. **Absolute convergence of the labour productivity (service sector)**

Coefficient	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	Global OLS
β_{0i} or β_0	0.088	0.173	0.193	0.225	0.278	0.217**
β_{1i} or β_1	-0.073	-0.060	-0.051	-0.046	-0.025	-0.057**
R_i^2 or R^2	0.164	0.337	0.560	0.725	0.815	0.654**
AIC = -6.745; Bandwidth = 1.521; Global test of nonstationarity: F = 4.999**						

Notes: R^2 : coefficient of determination; R_i^2 : local coefficient of determination; F: empirical F-value; **: significant at the 1 % level; *: significant at the 5 % level; $^{(*)}$: significant at the 10 % level

The half-life time of the manufacturing sector exceeds the corresponding value of the service sector (s. Figure 4). The reason is that most regions have similar basic services (Corrado & Martin & Weeks, 2005, p. C145). Note that the spatial pattern of both sectors is different, too. Many regions, which have a long half-life time in one sector, will converge quite fast in the other sector. On an aggregated level this difference will compensate each other.



a) Manufacturing sector b) Service sector

Figure 4. Half-life time of the convergence process 1995-2002 (different sectors)

4.2 Conditional convergence

The conditional model differs from the model of the absolute convergence by the fact that control variables are included. We use a model which was conducted by Mankiw & Romer & Weil (1992). They added the human capital, which is stressed in the endogenous growth theory (s. for example Lucas, 1988; Grossmann & Helpman, 1989, and as an overview Frenkel & Hemmer, 1999, pp. 200) to a Solow model.

The equation of the labour productivity growth model with locally different regression coefficients is given by [cf. formulas (11) and (15)]:

$$(34) \qquad \frac{\ln y_{i,2002} - \ln y_{i,1995}}{7} = \beta_{0i} + \beta_{1i} \cdot \ln y_{i,1995} + \beta_{2i} \cdot \left[\ln s_{k_i} - \ln(n_i + g_i + \delta_i)\right]. \\ + \beta_{3i} \cdot \ln h_i + u_i ,$$

where $y_{i,2002}$ represents the labour productivity 2002 in region i and $y_{i,1995}$ the same quantity in 1995 and all other variables are denoted as before. The global test of nonstationarity suggests using a geographically weighted regression model.[5]

The influence of the control variables is quite small. In the global OLS estimation the coefficient of human capital is not significant at the 10 % level. In the GWR a significance test of the local parameters is not computed, but the coefficients lie all in the proximity of zero. The regression coefficient of the investment rate and the growth rate of labour force and technological progress as well as the rate of depreciation rate is significant at the 5 % level. So the local coefficients of determination are only slightly

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[5] The Monte Carlo simulation does not reject the null hypothesis of stationarity for all regression coefficients in both conditional convergence models. However, the local determination coefficients are higher in the GWR model, so this model is more appropriate.

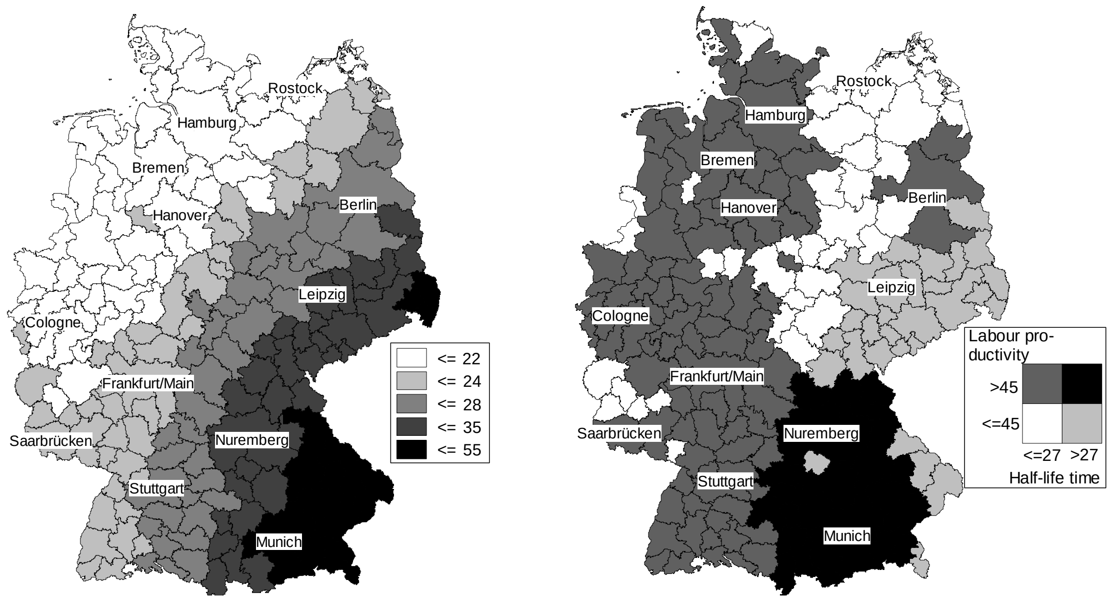
higher than in the model of the absolute convergence, although we use substantially more variables.

Table 5. **Conditional convergence of the labour productivity**

Coefficient	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	Global OLS
β_{0i} or β_0	0.061	0.095	0.110	0.117	0.140	0.110**
β_{1i} or β_1	-0.035	-0.029	-0.027	-0.022	-0.013	-0.026**
β_{2i} or β_2	0.002	0.003	0.003	0.004	0.004	0.003*
β_{3i} or β_3	-0.001	0.000	0.000	0.001	0.001	0.000
R_i^2 or R^2	0.231	0.400	0.444	0.488	0.532	0.360**
AIC = -6.776; Bandwidth = 2.429; Global test of nonstationarity: F = 6.090**						

Notes: R^2 : coefficient of determination; R_i^2 : local coefficient of determination; F: empirical F-value; **: significant at the 1 % level; *: significant at the 5 % level; (*): significant at the 10 % level

The GWR parameters of the initial labour productivity lie in the range between -0.035 and -0.013. The negative signs confirm the result of the absolute convergence model that all regions are converging. The parameters indicate a speed of convergence, which disperse less than the coefficients in the model of absolute convergence.



a) Half-life time

b) Half-life time and labour productivity 2002

Figure 5. **Half-life time of the convergence process 1995-2002**

Figure 5 a) shows the spatial structure of half-life time, which is calculated using the speed of convergence. The half-life time increases from northwest to southeast. Some regions at the east border of Saxony and Bavaria will need more than 35 years to achieve half of the rise in labour productivity to their steady state value. Figure 5 b) gives a visual impression of the half-life time in combination with the labour productivity in 2002. The white shaped regions have a small labour productivity and a short half-life time. They are located peripherally in the Harz, in the north of the former GDR and between Cologne and Saarbrücken. In contrast to the models of absolute convergence many regions of East Germany exhibit an above-average half-life time. Most regions in Bavaria and in Baden-Württemberg have above-average values of labour productivity and half-life time.

5. Conclusion

The assumption of stationarity cannot be founded theoretically for most research questions. The behaviour and attitudes of people as well as the infrastructure vary across regions. That will cause locally different parameters, which is ignored by a global approach. In addition a global estimation may lead to a bias and provoke autocorrelation. To that extent the geographically weighted regression represents an important extension of spatial econometrics.

The technique of geographically weighted regression is applied to a convergence model of German labour market regions. The estimation yields different speeds of convergence of the regions. In particular it showed that Bavarian regions have a long and north German districts a short half-life time. The approach provides evidence that the south German regions with a high labour productivity and a small unemployment rate will be the most prosperous regions in Germany. On the basis of the economic development in the long-run there will be a gap between north and south Germany.

The substantially varying coefficients show that a global convergence model, which was estimated by many researchers (see for example Kosfeld & Lauridson, 2004; Funke & Niebuhr, 2005a; Funke & Niebuhr, 2005b; Kosfeld & Eckey & Dreger, 2006) might be improved by a geographically weighted regression approach. Our paper represents the first step of a local analysis of convergence processes in Germany.

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Appendix: Estimation of the capital stock

Mostly the physical capital stock is estimated with the "perpetual inventory accounting"-method (cf. for example Rovolis/Spence 2002, pp. 67 and Eckey/Kosfeld/Stock 2000, pp. 41-49). This very complex procedure has the disadvantage that the initial capital stock must be specified and the same depreciation rate is used for all regions. Thus we estimate the capital stock with a similar approach to shift analysis. For checking purposes we calibrate our estimation with the official data. Our estimated capital stock was already used in different studies (Eckey/Kosfeld/Türck 2005 b; Eckey/Türck 2005).

We have calculated the physical capital stock on the basis of the gross fixed capital (equipment and other plants) to replacement prices. As usual in a shift analysis (Schätzl 2000, pp. 77, Tengler 1989, pp. 110) we distinguish between the structural and the location component. The structural factor indicates whether, due to the industrial structure of a region, an above or below average capital stock can be expected, thus capital-intensive industries are over- or underrepresented. The location factor expresses that we expect a high capital stock in regions with high investments in the last ten years. Data of the investments and the industry structure are taken from the official statistics. By weighting the German capital stock with the regional structure and location factors we get a first estimation, which is adjusted to west and east differences (the official statistics shows that the capital intensity in West Germany is around 5.1 % higher).

An evaluation of the estimation is possible for the three city states Berlin, Bremen and Hamburg. Our own estimations deviate from the results of the official statistics between 1.4 % and 9 %. Therefore in the last step a correction on regional level is calibrated. The estimated regional capital stocks are weighted in such a way that their sum for the federal states corresponds to the results of the official statistics.

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