European Regional Convergence in a Human Capital Augmented Solow Model[*]

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Abstract: In this paper, the process of productivity convergence is investigated for the enlarged European Union using regional (NUTS-2) data. The Solow model extended by human capital is employed as a workhorse. Alternative strategies are proposed to control for spatial effects. All specifications confirm the presence of convergence with an annual speed between 3 and 4 percent towards regional steady states. Furthermore, a geographically weighted regression approach indicates a wide variation in the speed of convergence across the regions, where a higher speed is striking in particular in France and the UK. We identify several convergence clusters consisting of contiguous regions that have similar initial conditions and convergence rates. It should be noted that the clusters cross the borders of Member States.

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1. Introduction

European economic integration, which began in the 1950s with the European Economic Community and the European Atomic Energy Community, has always been accompanied by the idea of a social cohesion (cf. Cuadrado-Roura/Parellada 2002; Tondl 2004 and Faludi 2006). Due to financial straits regional convergence is a central question, since important funds aim at diminishing disparities (Faludi 2006). Numerous papers have studied European convergence. The β-convergence framework, which was introduced by Barro and Sala-i-Martin (1990, 1991, 2004), is, for instance, the most often used approach.

Most authors examine absolute β-convergence, which explains the labour productivity or GDP per capita with its initial values (cf., for example, Fagerberg/Verspagen 1996; Basile/de Nardis/Girardi 2005; Cuadrado-Roura 2001; Cuadrado-Roura/Mancha-Navarro/Garrido-Yserte 2002; López-Bazo 2003; Thomas 1996; Martin 2001; Yin/Zestos/Michelis 2003; Niebuhr/Schlitte 2004; Fingleton 2003; Fingleton/López-Bazo 2006 and Paas/Schlitte 2006). In most cases, convergence is detected, whereas the speed of convergence seems to have increased since the 1990s.

While the absolute β-convergence model assumes that all regions converge to the same steady state value, the convergence clubs model suggests clusters of regions with the same equilibrium (cf. Corrado/Martin/Weeks 2005 and Graham/Temple 2006). There are different methods to analyse convergence clubs. Some researchers use kernel density function (cf. López-Bazo et al. 1999; Castro 2003; Geppert/Happich/Stephan 2005 and Magrini 1999). In recent European convergence studies (Ertur/Le Gallo/Baumont 2006; Le Gallo/Dall'erba 2006; Ertur/Koch 2006 and Fischer/Stirböck 2006) researchers identify convergence clubs with local indicators of spatial association (LISA). In particular, the Getis/Ord (1992, 1996) statistics allows identifying clusters of neighbouring regions with above average values of the georeferenced variable ("hot spots") or a spatial concentration of low x-values ("cold spots"). Some researchers also employ an absolute β-convergence model on the clusters (cf., for example, Le Gallo/Dall'erba 2006 and Fischer/Stirböck 2006). If the slope of the initial values is different for the groups, then the existence of convergence clubs is proven.

However, European regions are different in there initial welfare and growth characteristics. Therefore some researchers employ the conditional β-convergence model, which augments an absolute β-convergence with control variables to capture the different initial conditions of regions (within country convergence). Many researchers add country specific dummies to a β-convergence approach (Armstrong 1995; Fagerberg/Verspagen 1996; Fingleton 1999a; Geppert/Happich/Stephan 2005; Basile/de Nardis/Girardi 2005; Martin 1999; Tondl 2001; Neven 1995 and Cappelen et al. 2003).

If other variables than country dummies are important for the economic development, the within country convergence regressions suffer from omitted variable bias. Nevertheless, European regions reveal economic differences beyond the Member State level, especially in large countries. Therefore, the control of the different initial conditions with several variables seems meaningful, even if ones considers that only a few researchers use such models. Yin, Zestos and Michelis (2003) include several control variables, like investment ratio, inflation rate, cabinet change etc., which are not deduced from theory. Bräuninger and Niebuhr (2005) refer to the Krugman model and include variables to measure the degree of agglomeration. Because there is empirical evidence that a lot of regressors are significant in growth regressions (Temple 1999, p. 128), the theoretical foundation of the growth model becomes relevant. Badinger, Müller and Tondl (2004) transform a Solow model into a panel data regression and estimate this model using the period of 1985-1999 for EU-15. It should be noted that they use a fix value for depreciation rate and rate of technological progress.

If regional data are used in the regression framework, one has to control spatial autocorrelation (cf. Anselin 1988, 57; Fingleton 1999b and Cliff/Ord 1973, 90). Rey and Janikas claim that only recently the spatial econometric tools are used for convergence studies (Rey/Janikas 2005, 156). Because there is empirical evidence for a spatial dependency in European convergence regressions, some researchers add a spatial error or a spatial lag term to convergence equations (cf. Baumont/Erthur/Le Gallo 2003; Bräuninger/Niebuhr 2005; Carrington 2003 and Le Gallo/Dall'erba 2006). Another way to treat regional autocorrelation in regression models is through spatial filtering. As far as we know, spatial filtering is not used in convergence studies. Nevertheless, the adjustment of spatial autocorrelation is an alternative to the well-known spatial lag and spatial error models. This spatial filtering approach has an advantage over the spatial error and the spatial lag model, because it includes positive and negative patterns of spatial autocorrelation simultaneously. A negative spatial autocorrelation in some areas could occur due to regional competitive activities (Griffith 2006).

Regional heterogeneity might also be a problem of heterogeneous samples like European Member States (Corrado/Martin/Weeks 2005; Durlauf/Johnson 1995). The geographically weighted regression (GWR) (cf. Brunsdon/Fotheringham/Charlton 1998 and Fotheringham/Brunsdon/Charlton 2002) is by far more flexible in dealing with heterogeneity than the methods of LISA, which imply the use of threshold values. Recently, the GWR is introduced into convergence research by Bivand/Brunstad (2005) for the European agricultural sector and by Eckey/Kosfeld/Türck (2007) for Germany. Both researcher groups find different regression coefficients and regionally varying half lives of the absolute and conditional β-convergence process.

However, economic cohesion has become even more important, as economic disparities have increased after the enlargement. The aim of this paper is to examine regional convergence in the enlarged EU (EU-25). Contrary to recent research of the enlarged EU (Ertur/Koch 2006; Fischer/Stirböck 2006 and Paas/Schlitte 2006), we control for different initial conditions of regions, employ new spatial econometric methods and refer to a longer examining period. In contrast to the bulk of literature of European convergence research, the Solow model extended by human capital is the point of departure (cf. Mankiw/Romer/Weil 1992). Only a few papers have studied convergence in a conditional sense, but the empirical evidence is limited to the EU-15. Moreover, spatial techniques are used to capture regional dependence. Following the above mentioned studies we expect a significant speed of convergence that is robust towards different specification of the regional dependency (spatial error model and spatial filtering). It should be noted, however, that the parameter average gives an incomplete picture of convergence and that there is empirical evidence of convergence clubs. By means of a geographically weighted regression approach, we suppose different speeds of convergence due to the inhomogeneous sample concerning the initial economic conditions and the growth patterns.

The rest of the paper is organised as follows: Section 2 reviews the convergence framework. Section 3 discusses the econometric methods needed to control for spatial effects. Data issues are addressed in section 4. Section 5 holds the empirical results. Some concluding remarks are offered in section 6.

2. Convergence model

Convergence of productivity levels is an important prediction of the neoclassical growth model (Barro/Sala-i-Martin 1990, 1991, 2004). Although the neoclassical growth approaches were criticised by Williamson (1965) amongst others and more sophisticated theoretical models are outlined by the endogenous growth theory (cf, for example, Romer 1986; Romer 1990 and Rivera-Batiz/Romer 1991), β-convergence is still the standard model of convergence research. This approach is theoretically well-founded, can be estimated with the regression framework and allows the calculations of the half life of the convergence process.

Because of diminishing marginal returns of input factors in a production function with constant returns to scale, regions should converge to a dynamic steady state, where the evolution is solely driven by the rate of technological progress. Several authors have emphasised the important role of human capital for productivity growth (Islam 2003, Aghion/Howitt 1998 and Krueger/Lindahl 2001). The approach suggested by Mankiw, Romer and Weil (1992) provides a convenient way to incorporate human capital in the neoclassical growth model.

The production function of that model is given by a Cobb-Douglas specification:

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

where Y represents the Output, K the physical capital stock, H the human capital stock, A the level of technology and L the labour (Mankiw/Romer/Weil 1992, 416). The index t stands for the reporting period t. The parameters α and β ($0 < \alpha < 1, 0 < \beta < 1$) show the production elasticities of physical and human capital, and $1 - \alpha - \beta > 0$ is the elasticity of ordinary labour input. The elasticities also reflect income shares because of the constant returns to scale assumption.

We denote the quantities per effective unit with lower cases and tilde, i. e. $\tilde{y}_t = Y_t/(A_t \cdot L_t)$, $\tilde{k}_t = K_t/(A_t \cdot L_t)$ and $\tilde{h}_t = H_t/(A_t \cdot L_t)$. The production function measured in effective units can be expressed as:

(2) $$\tilde{y}_t = \tilde{k}_t^{\alpha} \cdot \tilde{h}_t^{\beta}.$$

We assume a closed economy, where the investments in physical and human capital are equal to the savings of the same factor. If the depreciation rate δ of physical and human capital takes the same value, the production factors evolve by the equations

(3) $$\dot{\tilde{k}}_t = s_k \cdot \tilde{y}_t - (n + g + \delta) \cdot \tilde{k}_t$$

and

(4) $$\dot{\tilde{h}}_t = s_h \cdot \tilde{y}_t - (n + g + \delta) \cdot \tilde{h}_t$$

with s_k as saving rate of physical capital and s_h as the same value of human capital. We use dots above the variables to denote time derivatives. Labour and technological progress are assumed to grow exogenously at the rate of n and g. These accumulation equations (3) and (4) show that the physical or human capital stock rises, if the investments are higher than the quantities of n, g and δ multiplied with $\tilde{k}_t$ and $\tilde{h}_t$ respectively.

Now, we have to discuss the steady state conditions. In the steady state the evolution of $\tilde{k}$, $\tilde{y}$ and $\tilde{h}$ is zero. However, the final equation must be derived using a Taylor series extension, which yields (Barro/Sala-i-Martin 2004, 61):

(5) $$\ln(\tilde{y}_T - \tilde{y}_0) = -(1-e^{-\lambda T}) \cdot \ln \tilde{y}_0 + (1-e^{-\lambda T}) \cdot \frac{\alpha}{1-\alpha-\beta} \ln s_k - (1-e^{-\lambda T}) \cdot \frac{\alpha+\beta}{1-\alpha-\beta} \ln(n+g+\delta) + (1-e^{-\lambda T}) \cdot \frac{\beta}{1-\alpha-\beta} \ln s_h \,.$$

Thus, $\ln(\tilde{y}_T - \tilde{y}_0)$ is the growth rate of productivity in efficiency units over the sample period, which should be long enough to exclude business cycle dynamics. The parameter $\lambda > 0$ is the speed of convergence.

Quantities per effective unit and the share of human capital are unknown. Therefore equation (5) can be rewritten in terms of quantities per labour (cf. Temple 1999 and Hemmer/Lorenz 2004)

(6) $$\ln(y_T - y_0) = -(1-e^{-\lambda T}) \cdot \ln y_0 + (1-e^{-\lambda T}) \cdot \frac{\alpha}{1-\alpha} \cdot [\ln s_k - \ln(n+g+\delta)] + (1-e^{-\lambda T}) \cdot \frac{\beta}{1-\alpha} \ln h^* + (1-e^{-\lambda T}) \cdot \ln A_0 + gT \,,$$

where y is real GDP per worker, A_0 the initial index of technology and h^* the human capital per worker in the steady state. In addition, the restriction of equal, but opposite signed parameters of the $\ln s_k$ and $\ln(n+g+\delta)$ terms has been set. As the steady state level of the human capital variable is not observable, it is replaced either by its initial value or an average over the sample period. In addition, many researchers refer to the average growth rate and divide (6) by T. These considerations lead to the specification

(7) $$\frac{1}{T} \cdot \ln(y_T - y_0) = -(1-e^{-\lambda T})/T \cdot \ln y_0 + (1-e^{-\lambda T})/T \cdot \frac{\alpha}{1-\alpha}[\ln s_k - \ln(n+g+\delta)] + (1-e^{-\lambda T})/T \cdot \frac{\beta}{1-\alpha} \ln h + (1-e^{-\lambda T})/T \cdot \ln A_0 + g$$

that serves as the baseline for the empirical analysis.

3. Spatial econometric techniques

Relationship (7) is the basic equation of our empirical analysis. We add a stochastic error term u to (7) because of measurement errors and the omission of relevant variables. We assume that u fulfils the white noise properties. The regression coefficients of the empirical model are denoted with β. Because we have regional data, we must add the index i for the *i*th region. In particular, the corresponding regression equation reads:

$$(8)\qquad \frac{1}{T}\cdot \ln(y_{T,i} - y_{0,i}) = \beta_1 + \beta_2 \cdot \ln y_{0,i} + \beta_3 \cdot [\ln s_{k,i} - \ln(n_i + g_i + \delta_i)] + \beta_4 \cdot + \ln h_i + u_i$$

with

$$(9)\qquad \beta_1 = (1 - e^{-\lambda T})/T \cdot \ln A_0 + g,\quad \beta_2 = -(1 - e^{-\lambda T})/T,\quad \beta_3 = (1 - e^{-\lambda T})/T \cdot \frac{\alpha}{1-\alpha},$$
$$\beta_4 = (1 - e^{-\lambda T})/T \cdot \frac{\beta}{1-\alpha}.$$

Equation (8) can be expressed in a more compact form when we use matrix notation:

$$(10)\qquad \mathbf{y} = \boldsymbol{\beta} \cdot \mathbf{X} + \mathbf{u}.$$

Spatial autocorrelation in the error term will invalidate standard tests based on equations like (8). Even more seriously, the results would suffer from an omitted variable bias (Anselin 1988). Whether or not spatial effects are relevant in the residual process is an empirical issue. It can be decided on grounds of the Moran (1950a 1950b) coefficient, which is robust against a wide range of concrete autocorrelation patterns (Anselin/Bera 1998). These calculations are based on a contiguity matrix $\mathbf{W}^*$:

$$(11)\qquad w^*_{ij} = \begin{cases} 1, \text{ if i und j share a comon border and } i \neq j \\ 0 \text{ otherwise} \end{cases}.$$

$\mathbf{W}^*$ is a binary $(n \times n)$ matrix for *n* regions. Researchers usually calculate row-standardised $\mathbf{W}$,

$$(12)\qquad w_{ij} = \frac{w^*_{ij}}{\sum_{j=1}^{n} w^*_{ij}},$$

for statistical reasons. The test statistic of the Moran coefficient is given by

$$(13)\qquad I = \frac{\hat{\mathbf{u}}' \mathbf{W} \cdot \hat{\mathbf{u}}}{\hat{\mathbf{u}}' \cdot \hat{\mathbf{u}}}.$$

If the null hypothesis cannot be rejected, the regression error does not exhibit significant signs of spatial autocorrelation. Otherwise, two distinct strategies are available to include spatial effects. First, the ordinary regression can be extended by spatial lags of the error term. The first order spatial error for example takes the form:

(14) $\mathbf{y} = \boldsymbol{\beta} \cdot \mathbf{X} + \gamma \cdot \mathbf{W} \cdot \mathbf{u} + \boldsymbol{\varepsilon}$.

where γ is a spatial autoregressive parameter (Anselin/Bera 1998; Durlauf/Johnson/Temple 2005). This spatial error model cannot be estimated with OLS, because the dependence in the error term leads to a nonspherical error covariance matrix. Instead we have to use a maximum likelihood function, which calculates the regression coefficients using an iterative algorithm (Anselin 1988, 106). The residual of the extended equation (14) should not show spatial autocorrelation anymore.

Second, the variables can be filtered using the Griffith approach (Griffith 1996, 2000, 2003). The spatial filtering approach has the advantage over the spatial error model, because it includes positive and negative patterns of spatial autocorrelation. A negative spatial autocorrelation in some areas may occur due to regional competitive activities (Griffith 2006). Filtering is based on a decomposition of the Moran coefficient, which is an overall measure of the spatial autocorrelation present in the data. The Moran statistic can be expressed as a weighted sum of the eigenvalues of the matrix

(15) $\mathbf{C} = \left(\mathbf{I} - \mathbf{1} \cdot \mathbf{1}'/\mathrm{n}\right) \cdot \mathbf{W}^* \cdot \left(\mathbf{I} - \mathbf{1} \cdot \mathbf{1}'/\mathrm{n}\right)$.

where $\mathbf{I}$ is the *n*-dimensional identity matrix and $\mathbf{1}$ is a vector of ones (see Tiefelsdorf/Boots 1995 as well as Griffith 1996). The separation between spatial and nonspatial components is done by the eigenvectors of the $\mathbf{C}$ matrix, which represent almost orthogonal map patterns. Thus, spatial dependencies are modelled by a set of relevant eigenvectors.

The nonspatial part of the regressors is obtained as a residual from a regression of the original variables (X) on the significant geographical patterns. The substantial eigenvectors are elements of the matrix **E**. We assume that all independent variables of the convergence equation are spatially autocorrelated. If the *h*th independent variable is stored in the vector $\mathbf{x}_h$, the filtering procedure is conducted using an OLS estimation of the following equation:

(16) $\mathbf{x}_h = \mathbf{E} \cdot \boldsymbol{\beta} + \mathbf{x}_h^*$.

In addition, we have to filter the dependent variable, which is the growth of GDP per capita or labour productivity. If all spatial filtered variables are collected in the matrix $\mathbf{X}^*$, the regression equation reads:

(17) $$\mathbf{y} = \mathbf{X}^* \cdot \boldsymbol{\beta}_1 + \mathbf{E} \cdot \boldsymbol{\beta}_2 + \mathbf{u}.$$

To ensure a parsimonious specification only a subset of eigenvectors should constitute the spatial filter. The eigenvectors must represent substantial spatial patterns. If one relates the Moran coefficients of the eigenvectors to their maximum (I_{max}) a qualitative assessment of spatial autocorrelation is obtained. The eigenvectors are of potential relevance, if the I/I_{max} ratio exceeds a lower bound of 0.25 (Griffith 2003). From the set of candidate vectors, the significant eigenvectors can be selected by stepwise regression.

Finally, the coefficients in a convergence regression might differ across the regions. For example, speeds of convergence could depend on structural characteristics, like the sectoral decomposition. See Canova and Marcet (1995), Bivand and Brunstad (2005), Funke and Niebuhr (2005), Juessen (2005), Huang (2005), Eckey, Kosfeld and Türck (2007), Eckey, Döring and Türck (2006) and Le Gallo and Dall'erba (2006) for some empirical evidence on this point. Furthermore, regional funds aim to achieve some equalisation of income and productivity and can speed up convergence. Similar arguments can be made for the other model parameters, like saving rates.

The geographically weighted regression approach provides a convenient way to explore this issue (Brunsdon/Charlton/Fotheringham 1998). The regression coefficients of the *i*th region are weighted in accordance with the regional distance. The latter is measured by the distance between economic centres, which are operationalised by the city in each region with most inhabitants. The estimation procedure is built on the Gaussian distance decay function,

(18) $$v_{ij} = e^{-0{,}5 \cdot \left(d_{ij}/b\right)^2},$$

where d_{ij} is the distance between two regions, v_{ij} the weighting, and b a bandwidth parameter to smooth the distances. In order to compute the bandwidth, the AIC is minimised (see Fotheringham/Brunsdon/Charlton 2002). The v_{ij} constitute a diagonal weighting matrix of dimension *n*, which is then employed to estimate the regression parameters in a GLS fashion.

4. Data

We examine regional convergence of 233 European regions on NUTS-2 level from 23 Member States. Islands like Malta and Cyprus have been excluded, as they do not have common borders to other regions.[46] We use the period from 1995 to 2004, because there are no structural breaks and data of all 233 regions are available. The collapse of Communism and the transformation from a central planned economy to a market-based economy provide good reasons for why the data of the beginning of the 1990s is not comparable to the data of the following periods (see Vintrová 2005). Thus, the examining period begins with 1995, which is standard of empirical studies including the New Member States from Central and Eastern Europe (cf., for example, Ertur/Koch 2006 and Fischer/Stirböck 2006).

β-convergence models can be calculated using gross domestic product (GDP) per capita as well as labour productivity. It should be noted that there is a stronger association between GDP and labour force than between GDP and population. This argument is supported by empirical papers, which show a higher explicative power in convergence studies, if labour productivity is used (cf., for example, Kosfeld/Eckey/Dreger 2006 and Basile/Nardis de/Girardi 2005). Furthermore, we conduct control calculation using GDP per capita. The results are mainly the same, although the speed of convergence is a little smaller.

The regional distribution of labour productivity growth and initial labour productivity is displayed in Fig. 1. Labour productivity growth is high in the New Member States, especially in economic centres (Jasmand/Stiller 2005) as well as in Greece and Ireland.

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46 The standardisation of the contiguity matrix **W*** is not possible, if one region has no border with another region. Therefore, the EU Member States Cyprus and Malta are excluded. Islands are dropped from the analyses for the same reason.

Together with Spain and Portugal these countries have also the lowest levels of initial productivity. On the other hand richer regions with productivity levels above 50,000 € per person are mostly located in the centre of Europe – in Germany, Austria, and France. They are also characterised by the lowest productivity growth. Hence, the graphical evidence is broadly in line with convergence.

- Fig. 1 around here-

In evaluating convergence regressions, a simultaneity bias could occur, because regions with high growth rates of physical and human capital tend to be characterised by great values of labour productivity growth (cf. Islam 2003 and Durlauf/Johnson/Temple 2005). Temple (1999) states: "To avoid simultaneity, researchers often make use of initial values", because "in general there is a shortage of good instruments (Temple 1999, 129). Hence, we use the initial values of s_k and h to deal with this problem.

In line with other studies and the assumption of the Mankiw-Romer-Weil (1992) model that the savings are equal to the investments, we calculate the saving rate as fraction of investments and gross value (cf. Mankiw/Romer/Weil 1992; Badinger/Müller/Tondl 2004 and Eckey/Kosfeld/Türck 2007). In particular, we use the investments of the industrial sector, because industrial investments are strongly related to the physical capital stock (Kosfeld/Eckey/Dreger 2006, 759). The savings rate in physical capital is high especially in the Iberian Peninsula as well as in Eastern Germany and some of the New Member States like Slovakia, the Czech Republic and Estonia [cf. Fig. 2 a)]. A study of the investigation motives in Central and Eastern Europe found out that in particular the accession to the European Union in combination with the low wages encouraged entrepreneurs to build plants in the New Member States (Middleton/Fifield/Power 2007). Other important factors are the relative high fraction of human capital and skilled labour as well as institutional factors (Carstensen/Toubal 2004). Many French, Austrian and British areas have a comparably small amount of industrial investments.

- Fig. 2 around here-

There are different indicators to approximate the human capital stock (cf. the overview articles of Le/Gibson/Oxley 2003 and Wößmann 2003). Mankiw, Romer and Weil (1992) use the percentage of working-age-population that attended secondary school. Other researchers refer to the years of schooling of working age population (cf. Bassani/Scarpetta 2002 and Aiginger/Falk 2005). Nevertheless, schooling variables miss the mobility of the high qualified, which is above the average. Many graduates move into the prosperous areas after they have finished college or university education (Haas/Möller 2001). For this reason areas with a large number of college and university graduates do not need to have many highly-qualified employed persons.

It should be noted that only the employed high-qualified population has a substantial influence on regional production. EUROSTAT regional database contains different indicators of highly-qualified employed persons. We use the indicator "human resources in science and technology", because this variable is also used by other researchers (cf. Bivand/Brundstad 2006) and is available for all included 23 European Member States. The indicator includes professionals and technicians employed in the science and technology sector.

If we divide human capital by labour force, we obtain the relative distribution of human capital [cf. Fig. 2 b)]. It should be noted that Eastern German regions and the Northern European countries as well as the Low Countries have a high share of human capital. A relative high share of human capital can be found in many attractive economic centres, like Paris, Madrid, Amsterdam, Rotterdam, Cologne, etc. as well.

In particular, the growth rate of labour takes small values in the New Member States [cf. Fig. 3 a)], because a comparably high share inhabitants migrate in Western European countries and the fertility rate is below average (cf. Krieger 2004, 4; Haug 2005 and Rühl 2005). Labour force usually rises in prosperous areas like Hamburg, Munich, Vienna, London, Ireland and Marseilles. Nevertheless, we find also a demographic increase in regions in the south of France and some areas of the Iberian Peninsula. One reason for this migration is the retirees, who move from Northern Europe to these areas with a warm climate. It should be noted that retirees create a job demand by their consumption. Another reason for this growth is the immigration, especially from African countries (cf. Kreienbrink 2004; Kreienbrink 2005 and Beer 2005).

- Fig. 3 around here-

Most studies use constant values for technological progress g and the depreciation rate δ (cf. Badinger/Müller/Tondl 2004; Temple 1999, 122; Mankiw/Romer/Weil 1992, 413; Islam 1995, 1139; Kosfeld/Lauridson 2004; Kosfeld/Eckey/Dreger 2006 and Fuente 2000, 34). In contrast to the bulk of literature rates of depreciation and technological progress are allowed to vary across countries. They are assumed to be equal within the regions of the same country.

Because there might be quite a significantly variation between European Member States concerning g, we refer to country-specific estimations conducted by EUROSTAT for EU-15[47] and by the United Nations Economic Commission for Europe (UNECE) secretariat for the New Member States (Dobrinsky/Hesse/Traeger 2006, 37).[48] The rate of technological progress is especially high in many New Member States with the exception of Slovakia due to the relative high amount of industrial investments [cf. Fig. 2 a) and Fig. 3 b)]. In Italy, the Iberian Peninsula and in Slovakia almost no technological progress is observed in the examining period.

Görzig has emphasised, that "depreciation levels in the EU 15 countries vary considerably" (Görzig 2005, 22). The depreciation rate is calculated using data from the Ameco database of the European Commission. [49] For the Baltic States we refer to estimations of the Baltic International Center for Economic Policy Studies (BICEPS n.d.). The depreciation rate of Poland is taken from Gradzewicz/Kolasa (2004, 6) and of

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47 The data of EU-15 for calculating g and δ are available at the following website: http://ec.europa.eu/economy_finance/indicators/annual_macro_economic_database/ameco_contents.htm (2006-08-02).

48 These estimations are in line with calculations of the World Bank [http://siteresources.world-bank.org/INTECA/Resources/EU8-QER-Feb06-Special-Topic.pdf (2006-08-02)], of Skoczylas and Tissot (2005), of Grömling (2001, 2004) as well as of Döbeli and Koasa (n. d.).

49 Net capital stock, gross investments and net investments are extracted from Ameco database of the European Commission. We calculated depreciations as a deviation between gross and net investments. This value is divided by gross capital stock. Gross capital stock is defined as net capital stock plus depreciations
[cf. http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en/gl008237.htm (2006-08-09)].

the Czech Republic from Hàjek (2005 9). As there is no information available for other New Member States, their depreciation rate is proxied by the average value of the Baltic States, Poland and Czechia. From Fig. 4 it follows that the depreciation rate takes the lowest values in Sweden, the United Kingdom, Ireland and Greece, whereas the highest values are found in the New Member States.

- Fig. 4 around here-

5. Empirical analysis

In this section we present the empirical analysis beginning with the OLS estimation of model (8). In a first step, we estimate the stationary models with equal regression coefficients for every region. The restriction of the Mankiw/Romer/Weil (1992) model – equal regression coefficients for $\ln s_k$ and $\ln(n+g+\delta)$ – is tested using the Wald F-Test (cf. Vogelvang 2005, 105 and Greene 2003, 175). Because the null hypothesis of different parameters cannot be rejected ($F_{1,228} = 1.652$), we calculate a model with one regression coefficient for the two expressions $\ln s_k$ and $\ln(n+g+\delta)$.

As a starting point, a model with no spatial effects is estimated via OLS, see first column of Table 1. The fraction of explained variance amounts 69.5 %. The F-Test confirms that this value is substantial. The significant regression coefficient of the initial labour productivity gives evidence for a convergence process of EU regions. The speed of convergence amounts to 3.8 % per annum implying that productivity gaps between poor and rich regions have a half life of about 18 years.

- Table 1 around here-

However, the Moran coefficient proves a spatial autocorrelation. Thus, the regression coefficients of the OLS estimation are biased or the significance tests are invalid (cf. Anselin 1988, 57; Fingleton 1999b and Cliff/Ord 1973, 90). The robust LM(error) test proposes including a spatial error term in the regression equation. The results of the Maximum Likelihood estimation of this spatial error model are given in the second column of Table 1.

The pseudo coefficient of determination represents the proportion of explained variation, which takes a value of 66.0 %. The impact of the control variables is more pronounced than in the OLS model. All three regression coefficients are significant at the 1 % level. The parameter λ measures the effect of a spatial error or stochastic component. Due to its positive value, factors not included in the neighbouring regions have a positive influence on the growth rates.

There are two main theoretical approaches that suggest a positive spatial dependency of neighbouring regions. Jacobs (1969) assumes that an agglomeration and spatial proximity have a positive impact on the development and the exchange of knowledge and new ideas. In his considerations the spillover effects between different economic sectors are of particular importance. The cooperation between economic actors of different sectors, for example, financing services from a bank, research activities from a Research and Development enterprise and the equipment of a factory, lead to the development and diffusion of innovations. These urbanisation effects are also termed Jacobs externalities. Alongside this approach of urbanisation, Marshall, Arrow and Romer (Marshall 1920; Arrow 1962 and Romer 1986) have introduced the concept of localisation or MAR externalities. These MAR effects arise from contacts, spying and other forms of knowledge transmission from firms of the same sector in agglomerated areas.

The regression coefficient of initial labour productivity remains nearly unchanged, if we include a spatial error term. This result indicates a robustness of the estimations. The significant slope confirms the conditional convergence hypothesis. The regression coefficient for the initial labour productivity corresponds to a speed of convergence of 3.6 %. This value is quite high compared with the studies of the convergence process in different countries. Barro and Sala-i-Martin (1990, 1991, 1992), for example, find convergence rates around 2 % (see also Durlauf/Johnson/Temple 2005, 585 and Dobson/Ramlogan/Strobl 2006). The 2 %-rate of convergence is also "discovered as a 'natural constant'" (Abreu/de Groot/Florax 2005b, 390). Researchers, who use regions from 15 European countries, usually detect absolute convergence rates in the 1990s even below 2 % (cf. Yin/Zestos/Michelis 2003 and Cuadrado-Roura 2001 amongst others). Even for the enlarged European Union the estimated speed of convergence does not take such high values (Paas/Schlitte 2006).

How can we explain the convergence rate of 3.6 %? We can state one important reason for this relatively fast convergence process: First, there is empirical evidence for a rising convergence speed in the 1990s in comparison with the 1980s (cf., for example, Niebuhr/Schlitte 2004; Geppert/Happich/Stephan 2005; Yin/Zestos/Michelis 2003 and Basile/de Nardis/Girardi 2005). If this trend has continued, then the results are plausible. Second, Dobson, Ramlogan and Strobl (2006) have shown with a meta analysis of other studies that the control of investments leads to a higher convergence speed.

The spatial filtering framework is another way to guard against spatial autocorrelation. The filtered growth regressions are computed on the basis of the spatially filtered regressors as well as substantial eigenvectors. The spatial structure of the first four eigenvectors, which have an extreme positive autocorrelation, is given in Fig. 5.

- Fig. 5 around here-

The maximum of the first and the forth eigenvectors displays a peak in German and Polish regions (cf. Fig. 5). The greater the distance to that peak, the weaker the values are. By contrast, the third eigenvector has two centres with high values, located in the south of Germany, in Austria and in the north of Italy as well as in England. The three peaks of the second eigenvector can be found on the Iberian Peninsula, in Germany and around London.

The eigenvectors contain the spatial structure of the European Union. 172 eigenvectors have a ratio I/I_{max} that is higher than 0.25. The stepwise regression is employed to select substantial eigenvectors from this sample of 172 eigenvectors. First, we remove the spatial components from the independent variables (cf. Table 2). The initial labour productivity contains the most spatial components, because spatial eigenvectors explain more than 90 % of its variance. The other two control variables are filtered with a considerably lower amount of eigenvectors.

- Table 2 around here-

The spatial filtered independent variables and substantial eigenvectors are included to estimate the spatial filtered conditional β-convergence model. Table 3 shows the results of that procedure. The F-test proves that the model is adjusted to the data. The Moran coefficient shows that the spatial filtering procedure is successful, as no spatial autocorrelation can be detected anymore in the residuals. All variables are significant at the 5 %-level, which stands in line with the spatial error estimation. The spatial filtering approach leads only to a slightly slower convergence rate of 3.0 percent per annum than the two models of Table 1. Therefore, the stationary models provide robust empirical results of a comparably fast convergence process in the enlarged European Union.

- Table 3 around here-

Durlauf and Johnson (1995) have provided evidence that in a heterogeneous sample a Mankiw/Romer/Weil (1992) model with different regression equations for clusters might be better fitted than the ordinary specification with one regression function. Therefore, we examine if there are locally different speeds of convergence. Because the Wald test, calculated for filtered and unfiltered OLS models, suggests including the parameter restriction, we estimate the following equation:

$$\text{(19)} \qquad \frac{1}{9} \cdot \ln(y_{04,i} - y_{95,i}) = \beta_{1i} + \beta_{2i} \cdot \ln y_{95,i} + \beta_{3i} \cdot [\ln s_{k,i} - \ln(n_i + g_i + \delta_i)] + \beta_{4i} \cdot \ln h_i + u_i .$$

As we see in Table 4 the global F-test of non-stationarity proves that the estimation of regionally different regression coefficient is better fitted to the data than the global OLS estimation. The GWR approach is not only based on locally different regression coefficients, but also on spatially varying coefficients of determinations. Table 4 reports that the model has a high explanatory power, because 75 % of the regions have a proportion of explained variance which exceeds 66.3 %.

- Table 4 around here-

The local varying regression coefficients for the initial labour productivity and the control variables are characterised by a changing sign. This result is also detected by Bivand and Brunstad (2005) for the European agricultural sector. We are in particular interested in the variation of speed of convergence. The parameters β_{2i} confirm a convergence process of nearly all European regions. The variation in the speed of convergence provides empirical evidence of heterogeneous convergence across the EU. Nearby located areas show a similar speed of convergence (cf. Fig. 6). The highest convergence speed is found at the English Chanel with a value of 15.8 % per annum. Eight areas, which have a positive coefficient β_{2i}, are especially concentrated at the Atlantic coast of the Iberian Peninsula. Nevertheless, these values do not substantially differ from zero.

- Fig. 6 around here-

Altogether it can be stated that neighbouring regions have similar speeds of convergence, growth patterns and initial values. Their conditions are not very different, and therefore they converge to the same steady state. This result indicates equal steady state values of labour productivity of clusters that consist of contiguous regions (convergence clubs).

Regions around the English Channel show the highest speed of convergence. The lowest values of this parameter can be found in the Iberian Peninsula and in Greece as well as in some German and Swedish regions. Most regions in France and the south of Britain have high levels of initial productivity and high speeds of convergence, while in many south and east European regions the opposite occurs. They are less wealthy, and are characterised by a small convergence speed. If the New Member States continue to realise high growth rates, these areas would achieve an above average productivity level because of the long half lives predicted. Overall, the results indicate that the EU regions are unlikely to achieve equal conditions in the near future.

A convergence club is also detected by an approach of Le Gallo and Dall'erba (2006) using a sample of EU-25 states and an absolute convergence approach. In contrast to our analysis, they only identify two convergence clubs, which are not stable over time. One reason for the missing robustness might be that the convergence clubs are delineated over a too large area.

6. Resume

In this paper economic convergence is investigated for the EU-25 countries over the period of 1995-2004. In contrast to other studies of the enlarged European Union we control the different initial conditions of areas using the saving rate, growth of labour, technological progress, depreciation rate and human capital. The control variables are significant in the models without spatial autocorrelation. Therefore the control of different initial conditions in a heterogeneous sample like the European Union seems to be essential to obtain interpretable results. The analysis refers to the human capital augmented Solow model.

Convergence of productivity can be established by different methods. On average, the speed of convergence ranges between 3 and 4 per cent per annum. If the assumption of equal regression coefficients across the regions is relaxed, markedly varying speeds of convergence can be identified. The highest speed of convergence is found in rich regions in the centre of Europe, around the English Channel, in France and the UK. It seems that there are several convergence clubs, as regions within an area are faced by similar conditions and speeds of convergence.

The detected convergence clubs sometimes cross national borders. Therefore, the influence of Member State borders seems to become smaller concerning the economic development in the long run. Our analysis reveals that there are considerably high variations concerning the convergence speeds of different regional clusters. The European Union should design regional policy programmes for the whole area of a convergence club.

The significant regression coefficient of human capital in most regression models with removed spatial autocorrelation confirms the finding of other studies (cf. Islam 2003; 317; Canova 2004; Badinger/Tondl 2005; Bassanini/Scarpetta 2002 and Martin 2001) that highly-qualified employees have a major influence on regional growth. Therefore, a successful cohesion policy in underdeveloped areas operates in two directions:

- On the one hand, measures for high-tech enterprises are needed in order to stimulate further investments by infrastructure projects, the support of the development of sectoral cluster, start-ups, etc.
- On the other hand, the qualification (for example, university degrees and advanced vocational training) and the mobility of human capital must be encouraged.

For this reason, cohesion funding should be focused on human capital and innovative activities in "problem clusters". This might reveal high growth impulses and diminish the gap of the growth paths in the long run. It should be noted that the efficiency of an innovation-oriented policy is not determined by the degree of centrality. An investigation by Fritsch (2003) proves innovative activities in less agglomerated areas. However, these measures are limited to a critical geographic area due to the existence of knowledge transmission. Empirical studies show that personal contacts are important for exchanging tacit knowledge (Bretschger 1999, 252). However, some detected convergence clusters may exceed this critical distance, because the average distance between patent collaborators is around 210 kilometres (Johnson/Siripong/Brown 2006).

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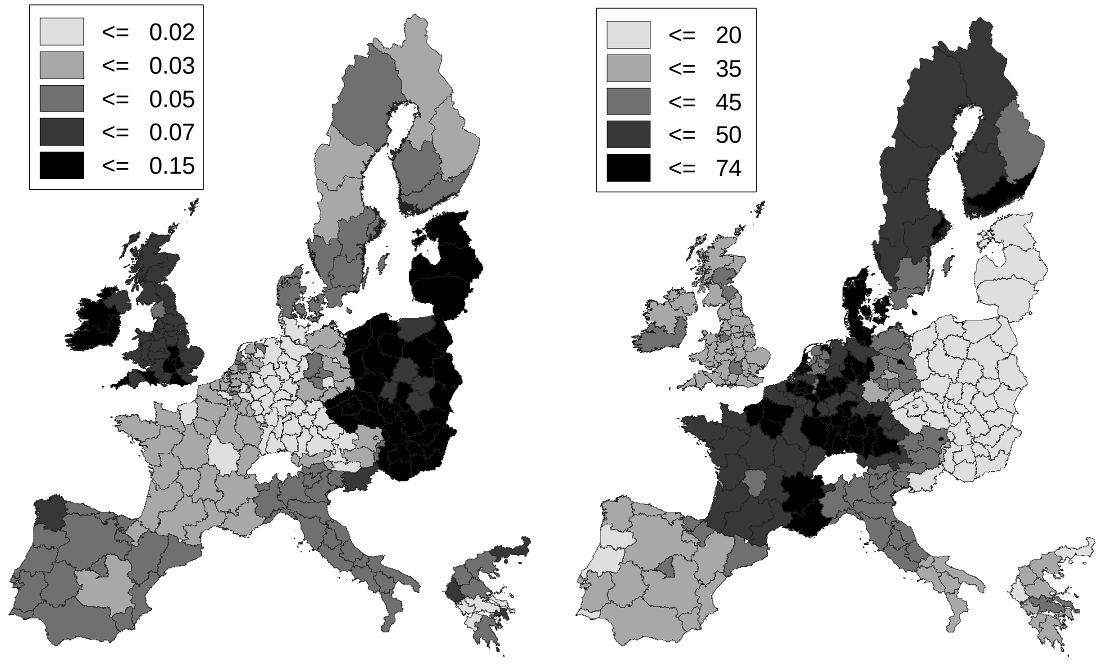
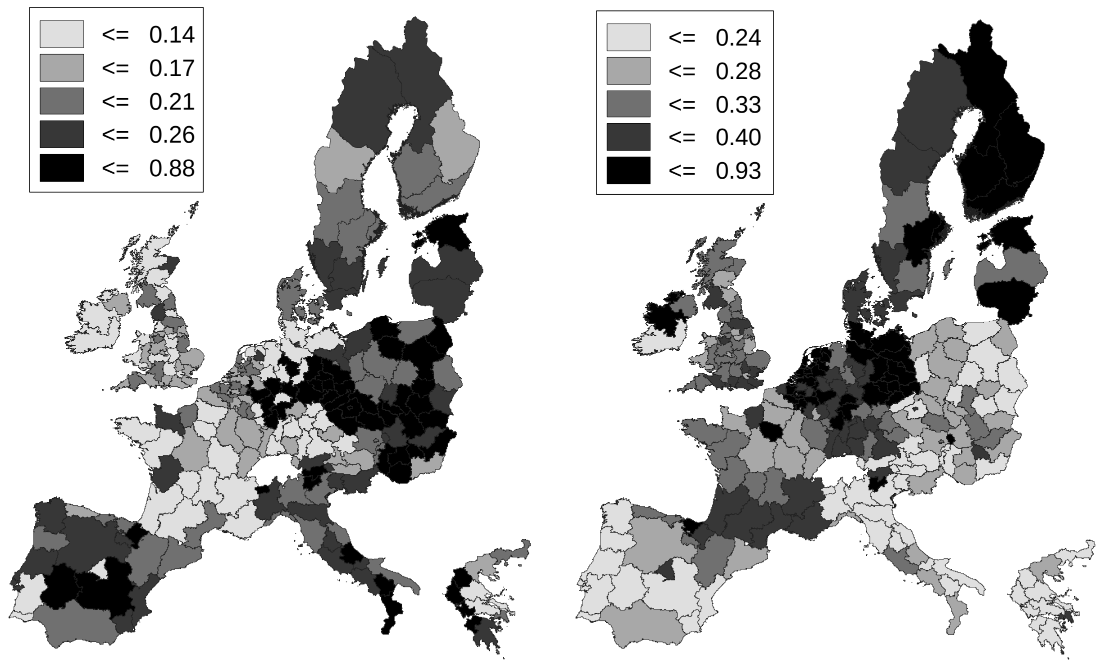
Tables and figures

Fig. 1: Labour productivity



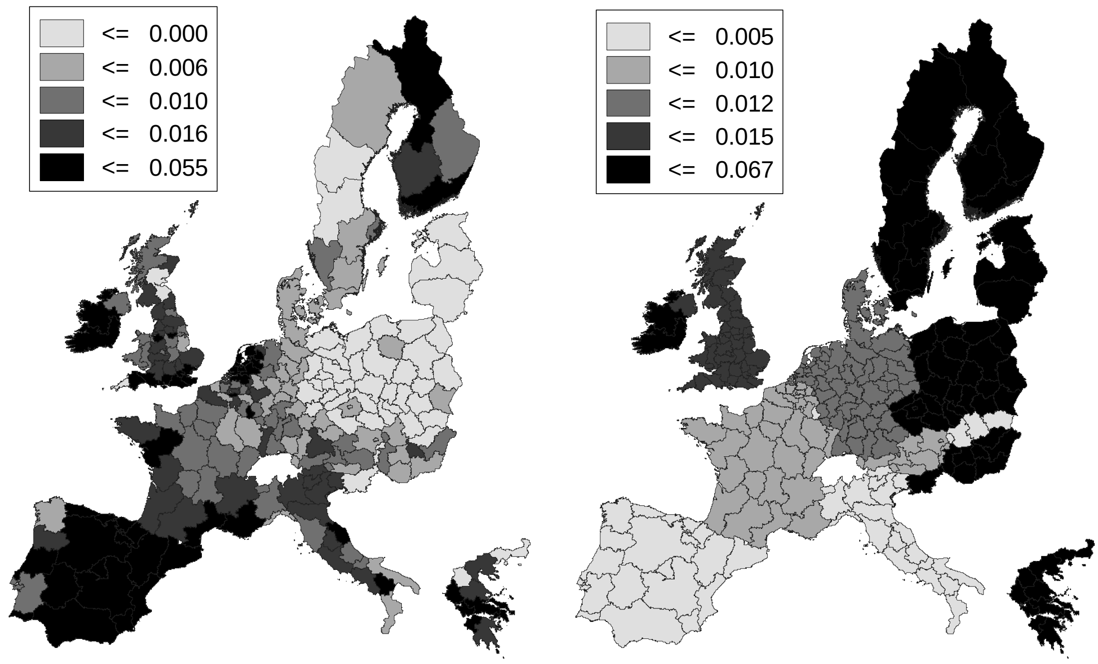
a) Labour productivity growth b) Initial labour productivity 1995

Fig. 2: Physical and human capital



a) Saving rate in physical capital 1995 b) Human capital 1995 divided by labour

Fig. 3: Growth of labour und technological progress



a) Growth of labour n

b) Technological progress g

Fig. 4: Depreciation rate

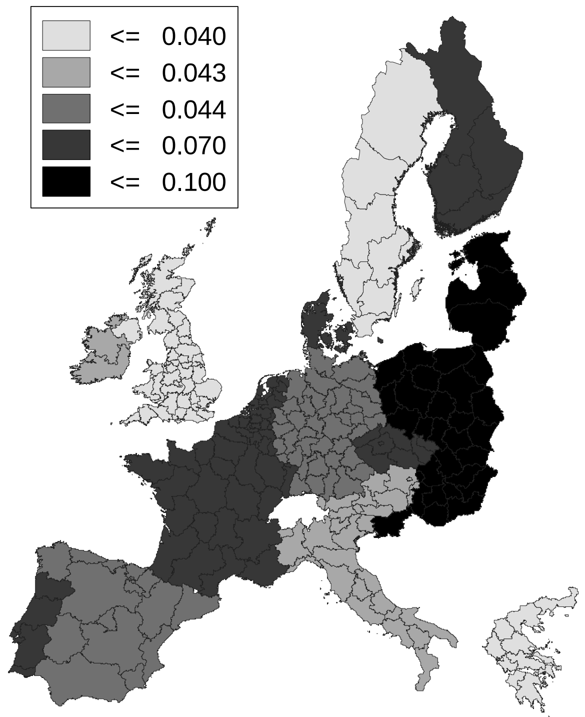


Table 1: Unfiltered stationary model

	OLS estimation		ML estimation	
	Regression coefficient	t-value	Regression coefficient	z-value
Constant	0.138**	17.748	0.123**	14.010
$\ln y_{1995}$	-0.032**	-22.833	-0.031**	-13.928
$\ln s_k - \ln(n+g+\delta)$	-0.001	-0.540	0.004**	2.762
$\ln h$	0.003*	2.361	0.004**	5.403
Spatial error parameter λ			0.730**	16.399
Global tests	R^2 = 0.695**; I = 0.630**; LM(err) = 180.813**; LM(lag) = 0.035		R^{*2} = 0.660**	

Notes: R^2: coefficient of determination; R^{*2}: pseudo coefficient of determination; LM(err): LM(error) test; LM(lag): Robust LM(lag) test; **: significant at the 1 % level; *: significant at the 5 % level; (*): significant at the 10 % level

Fig. 5: Spatial structure of the first four eigenvectors

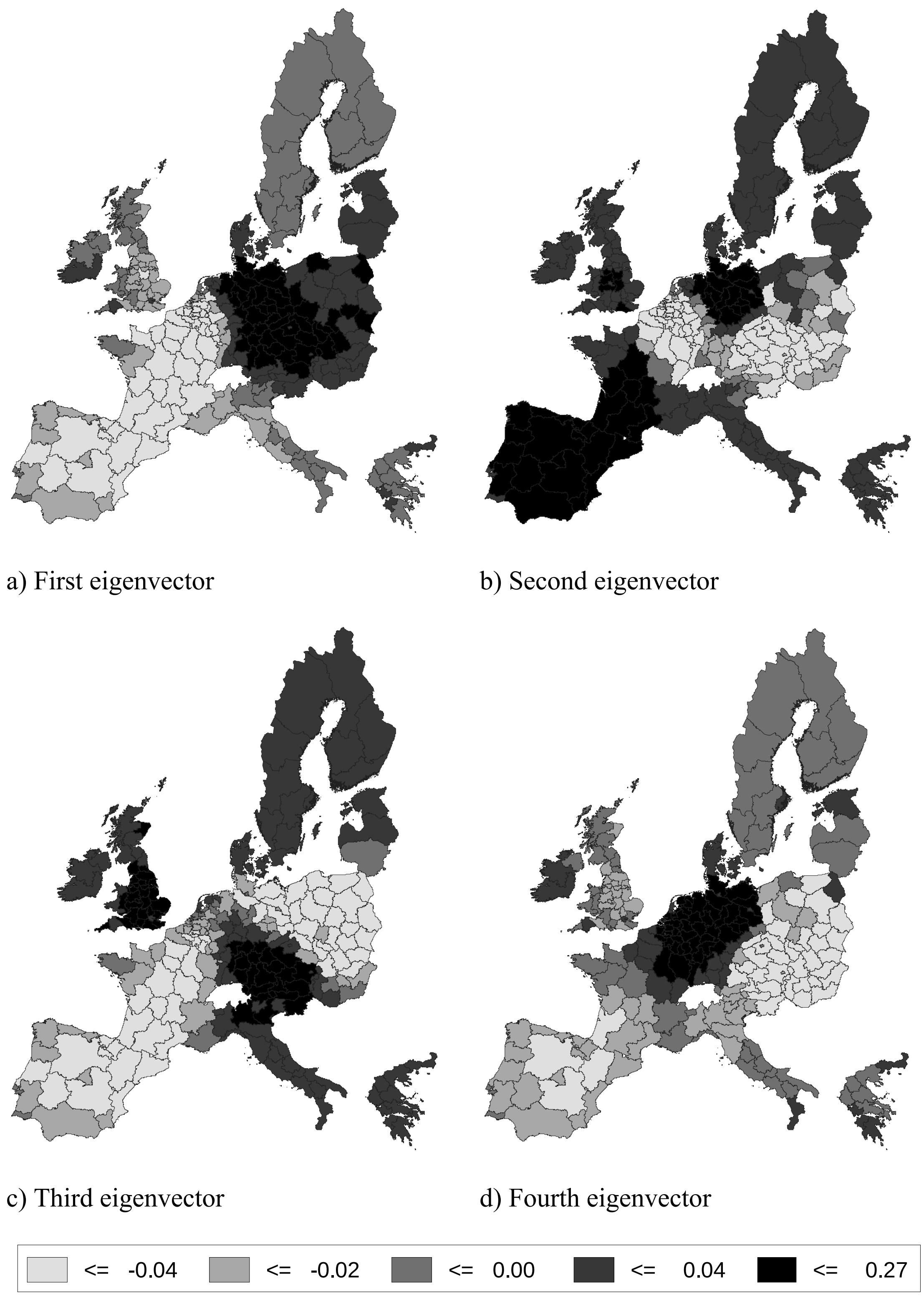


Table 2: Filtering of the independent variables

	Filtering of		
	$\ln y_{1995}$	$\ln s_k - \ln(n+g+\delta)$	$\ln h$
Constant	3.396**	1.160**	5.180**
Significant eigenvectors	E2,E4,E1,E5,E7, E132,E150,E22, E122,E17,E3,E20, E28,E85,E38,E44, E111,E21,E53, E130,E134,E18, E42,E27,E125, E137,E16,E25, E113,E6,E36,E128, E49,E61,E15	E12,E10,E1,E4, E38,E182,E17,E8, E128,E125,E13, E27,E21,E3,E55, E103,E98,E100, E169,E137,E101, E61,E206,E20, E130,E48	E29,E25,E2,E104, E10,E23,E93,E102, E83,E11,E97,E206
Global tests	R^2 = 0.905**	R^2 = 0.551**	R^2 = 0.242**

Notes: R^2: coefficient of determination; **: significant at the 1 % level; *: significant at the 5 % level; (*): significant at the 10 % level

Table 3: Filtered stationary model

	Regression coefficient	t-value
Constant	0.042**	77.344
$(\ln y_{1995})^*$	-0.026**	-9.802
$[\ln s_k - \ln(n+g+\delta)]^*$	0.003*	1.678
$(\ln h)^*$	0.003**	3.396
Significant eigenvectors	E2,E4,E122,E150,E22,E132,E7,E113,E85,E20,E1,E130,E17, E128,E111,E91,E38,E25,E3,E134,E16,E53,E27,E93,E13, E61,E9,E42,E107,E11,E84,E21,E159,E172,E182,E32,E29, E24,E56,E49	
Global tests	R^2 = 0.922**; I = -0.074	

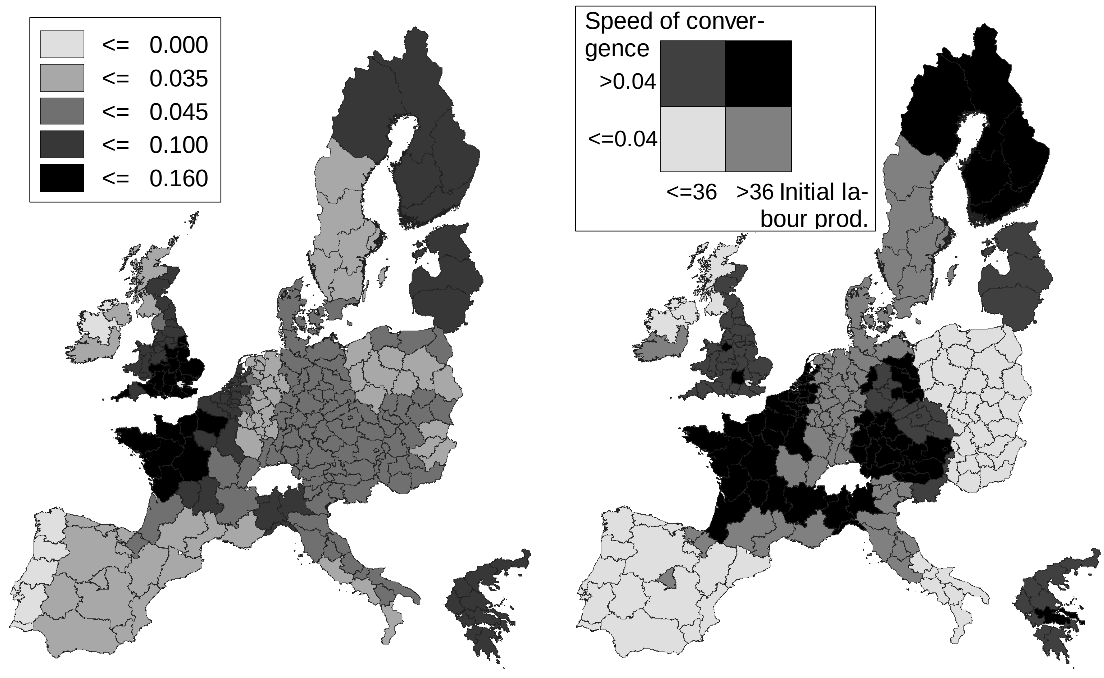
Notes: R^2: coefficient of determination; R^{*2}: pseudo coefficient of determination; **: significant at the 1 % level; *: significant at the 5 % level; (*): significant at the 10 % level

Table 4: Instationary GWR estimation

Coefficient	Minimum	Lower Quartile	Median	Upper Quartile	Maximum	Global OLS
β_{1i} or β_1	0.006	0.119	0.144	0.171	0.305	0.138**
β_{2i} or β_2	-0.085	-0.045	-0.034	-0.029	0.015	-0.032**
β_{3i} or β_3	-0.022	-0.001	0.003	0.006	0.039	-0.001
β_{4i} or β_4	-0.005	-0.001	0.002	0.006	0.025	0.003*
R_i^2 or R^2	0.387	0.663	0.797	0.885	0.998	0.695**
Bandwidth = 289 km; Global test of nonstationarity: F = 11.304**						

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

Fig. 6: Convergence process



a) Speed of Convergence

b) Speed of convergence and initial labour productivity.