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**Hans-Friedrich Eckey  
Christian Dreger  
Matthias Türck**

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# 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 3.5 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. Clusters of convergence can be identified, where regions with high convergence also have high initial income levels.

JEL C21, O47, R11, R15

Keywords: Solow model, regional convergence, spatial lags, spatial filtering

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## **1 Introduction**

The issue on whether poor regions tend to catch up with richer ones plays a prominent role in regional economic policy (Faludi, 2006). The issue has been studied in numerous papers, see Le Gallo and Dall'erba (2006) and Eckey and Türck (2006) for recent surveys. Most authors looked at the concept of absolute convergence in the EU6, EU9 or EU15 regions (Cuadrado-Roura, 2001, López-Bazo, 2003, Fagerberg and Verspagen, 1996, Yin, Zestos and Michelis, 2003, Niebuhr and Schlitte, 2004, Geppert, Happich and Stephan, 2005, Basile, De Nardis and Girardi, 2005). In most cases, convergence is detected, whereas the speed of convergence seems to have increased in the 1990s.

If regional data are employed, one has to control for spatial effects (Cliff and Ord, 1973, Anselin, 1988, Fingleton, 1999). However, appropriate tools have not been used up to recent years, see Rey and Janikas (2005). Some authors have added a spatial error term to the absolute convergence equation, see Baumont, Erthur and Le Gallo (2003), Bräuninger and Niebuhr (2005), Carrington (2003) and Le Gallo and Dall'erba (2006). In addition, only a few papers have used additional variables beyond country dummies. If other variables are important, the absolute convergence regressions suffer from omitted variable bias. Yin, Zestos and Michelis (2003) have controlled for several variables, but they are often not related to theory, like inflation or dummies for political change. According to the Krugman model, Bräuninger and Niebuhr (2005) have employed measures for the degree of agglomeration.

The aim of this paper is to examine regional convergence in the enlarged EU (EU25). The inclusion of the New Member States is important, because the In contrast to the bulk of literature, the Solow model extended by human capital is the point of departure (see Mankiw, Romer and Weil, 1992). Only a few papers have studied convergence in a conditional sense, but the empirical evidence is limited to the EU15 (Badinger, Müller and Tondl, 2004). However, economic cohesion has become even more important, as economic disparities have increased after the enlargement. Moreover, spatial techniques are used to capture regional dependence. Both spatial error models and spatial filtering are applied to obtain robust results. All specifications confirm the presence of convergence with an average speed between 3 and 3.5 percent per annum towards regional steady states. It should be noted, however, that the parameter average gives an

incomplete picture of convergence. By means of a geographically weighted regression approach, evidence for a wide variation in this measure is provided. In particular, convergence tends to be faster in the French and British regions. European regional cohesion funds do not seem to have an impact on this parameter.

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 regressions

Convergence of productivity levels is an important prediction of the neoclassical growth model (Barro and Sala-i-Martin, 1990, 1991, 2004). 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 and Howitt, 1998 and Krueger and Lindahl, 2001). The approach suggested by Mankiw, Romer and Weil (1992) provides a convenient way to incorporate human capital in the neoclassical growth model. As a well known result, a convergence equation of the form

$$(1) \quad \ln \tilde{y}_t - \ln \tilde{y}_0 = -(1 - e^{-\lambda t}) \ln \tilde{y}_0 \\ + (1 - e^{-\lambda t}) \left( \frac{\alpha}{1 - \alpha - \beta} \ln s_k + \frac{\beta}{1 - \alpha - \beta} \ln s_h - \frac{\alpha + \beta}{1 - \alpha - \beta} \ln(n + g + \delta) \right)$$

is implied, where  $\tilde{y}$  is real GDP per unit of effective labour,  $s_k$  and  $s_h$  are time invariant fractions of output invested in physical and human capital, and  $n$ ,  $g$ , and  $\delta$  denote the growth rates of the labour force, technological progress and the depreciation rate of physical and human capital, respectively (Barro and Sala-i-Martin, 2004). The parameters  $\alpha$  and  $\beta$  ( $0 < \alpha < 1$ ,  $0 < \beta < 1$ ) 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. Initial

values are indicated by 0, and  $t$  is time. 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 (2) can be rewritten in terms of quantities per labour (Temple, 1999, Hemmer and Lorenz, 2004)

$$(2) \quad \ln y_t - \ln y_0 = -(1 - e^{-\lambda t}) \ln y_0 + (1 - e^{-\lambda t}) \left( \frac{\alpha}{1 - \alpha} (\ln s_k - \ln(n + g + \delta)) + \frac{\beta}{1 - \alpha} \ln h^* \right) + (1 - e^{-\lambda t}) \ln A_0 + gt$$

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. This leads to the specification

$$(3) \quad \ln y_t - \ln y_0 = -(1 - e^{-\lambda t}) \ln y_0 + (1 - e^{-\lambda t}) \left( \frac{\alpha}{1 - \alpha} (\ln s_k - \ln(n + g + \delta)) + \frac{\beta}{1 - \alpha} \ln h \right) + (1 - e^{-\lambda t}) \ln A_0 + gt$$

that serves as the baseline for the empirical analysis. In particular, the corresponding regression equation is given by

$$(4) \quad (\ln y_{t,i} - \ln y_{0,i}) / T = \beta_0 + \beta_1 \ln y_{0,i} + \beta_2 (\ln s_{k,i} - \ln(n_i + g_i + \delta_i)) + \beta_3 \ln h + u_i$$

where

$$\beta_0 = (1 - e^{-\lambda T}) \ln A_0 + gT, \beta_1 = -(1 - e^{-\lambda T}), \beta_2 = (1 - e^{-\lambda T}) \alpha / (1 - \alpha), \beta_3 = (1 - e^{-\lambda T}) \beta / (1 - \alpha),$$

$i$  is the regional index,  $T$  the number of time periods in the sample and  $u$  the regression error, which fulfils the white noise properties.



### 3 Spatial econometric techniques

Productivity growth is investigated by looking at regional NUTS-2 information. As the economic evolution cannot be expected to be independent across regions, the analysis has to take possible spillover effects into account. For example, they can arise from common or idiosyncratic shocks which spread over the economy. In addition, an areal unit problem might be relevant, since the regions are delineated by administrative borders. They do not reflect the regional structure of economic activities and therefore, additional spatial dependencies might be generated, for example, due to commuter flows.

Spatial autocorrelation in the error term will invalidate standard tests based on equations like (4). 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 coefficient, which is robust against a wide range of concrete autocorrelation patterns (Anselin and Bera, 1998). The test statistic is given by

$$(5) \quad MI = \frac{\hat{u}'W\hat{u}}{\hat{u}'\hat{u}}$$

where  $W$  is a binary ( $n \times n$ ) contiguity matrix for  $n$  regions, with elements equal to 1 if two regions share a common border and 0 otherwise (Moran, 1950a and Moran, 1950b). In order to normalise  $I$  in terms of a correlation coefficient, the elements of  $W$  are row standardised, i.e. they are divided by the sum of the row elements. 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:

$$(6) \quad y = X\beta + \lambda Wu + \varepsilon$$

where  $\lambda$  is a spatial autoregressive parameter (Anselin and Bera, 1998, Durlauf, Johnson and Temple, 2005). This spatial error model can not 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, pp. 106).

The residual of the extended equation (6) should not show spatial autocorrelation anymore, which is checked by the Moran statistic. Otherwise this model is not appropriate.

Second, the variables can be filtered using the Griffith approach (Griffith, 1996, 2000). 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

$$(7) \quad C = (I_n - 1x1'/n)W(I_n - 1x1'/n)$$

where  $I_n$  is the  $n$ -dimensional identity matrix and  $1$  is a vector of ones (see Tiefelsdorf and Boots, 1995 as well as Griffith 1996). The separation between spatial and nonspatial components is done by the eigenvectors of the  $C$  matrix, which represent almost orthogonal map patterns. Thus spatial dependencies are modelled by a set of relevant eigenvectors. The eigenvectors are used in a cross section regression

$$(8) \quad y = X_1\beta_1 + \Omega\gamma + \varepsilon$$

where  $X_1$  holds the nonspatial part of the initial regressors, and  $\Omega$  the relevant eigenvectors to explain spatial effects in the dependent variable. 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 latter might differ from the eigenvectors important for the endogeneous variable.

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  $MI$  values of the eigenvectors to their maximum ( $MI_{max}$ ) a qualitative assessment of spatial autocorrelation is obtained. The eigenvectors are of potential relevance, if the  $MI/MI_{max}$  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 (2005), 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 and 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,

$$(9) \quad v_{ij} = e^{-0.5(d_{ij}/b)^2}$$

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 and Charlton, 2000). 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

Conditional convergence of productivity is analysed using annual data of 233 NUTS-2 European regions from 23 Member States for the 1995-2003 period. Islands like Malta and Cyprus have been excluded, as they do not have common borders to other regions. Most data are taken from Eurostat and the Cambridge Econometrics Database. Labour productivity is real GDP per unit of labour force. Possible indicators for human capital include the percentage of working-age-population that attends secondary school or the average years of schooling, see for example Bassani and Scarpetta (2002) and Aiginger

and 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. Therefore, human resources in science and technology are used to proxy the human capital stock.

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. Depreciation rates are calculated as the difference between gross and net investments divided by the capital stock for the EU15 members. Data from the Baltic International Center for Economic Policy Studies are used for the Baltic States (BICEPS, n.d.). The Polish depreciation rate is taken from Gradzewicz and Kolasa (2004) and the rate for the Czech Republic from Hájek (2005). 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. Regarding technological progress, country specific rates have been reported by Eurostat for the EU15 and by the United Nations Economic Commission for Europe (UNECE) secretariat for the New Member States (Dobrinsky, Hesse and Traeger, 2006).

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

*-Figure 1 about here-*

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 (figure 2). Some regions with high savings regions are also

located in the UK and Italy. Human capital per unit of labour force is especially high in the East German regions and the northern countries.

*-Figure 2 about here-*

Labour force growth is particularly low in the New Member States (figure 3), due to migration towards Western Europe and a low fertility rate (Krieger, 2004, Haug, 2005, Rühl, 2005). High growth rates of this measure can be detected in prosperous areas like Hamburg, Munich, Vienna, London, Dublin and Marseilles. There is also an increase in the southern regions of France and in some regions of the Iberian Peninsula. One reason is migration of retirees, who move from northern Europe to areas with a warm climate and create jobs because of their consumption demand. In addition, immigration from African countries seems to be important (Kreienbrink, 2004 and 2005, Beer, 2005). Low depreciation rates are observed in Finland, the UK, Ireland and Greece, while high rates are detected for the New Member States. The rate of technological progress is especially high in many New Member States with the exception of Slovakia (figure 4). In Italy, the Iberian Peninsula and in Slovakia almost no technological progress is observed in the sample period.

*-Figures 3 and 4 about here-*

## **5 Empirical analysis of the convergence pattern**

In evaluating convergence regressions, a simultaneity bias could occur, because regions with high growth rates of human and physical capital tend to be characterised by great values of labour productivity growth (Islam, 2003, Durlauf, Johnson and Temple, 2005). Therefore initial values for  $s_k$  and  $h$  are used (Temple, 1999).

As a starting point, a model with no spatial effects is estimated via OLS, see table 1. The restriction of equal, but opposite signed coefficients for  $\ln s_k$  and  $\ln(n+g+\delta)$  is embedded, as it is not rejected (Wald test=1.744,  $p$ -value=0.188). The significant value

of initial productivity gives evidence for convergence across EU regions. The average speed is 3.7 per cent per annum,

$$\lambda = \ln(1 - \hat{\beta}_1) = 0.037$$

implying that productivity gaps between poor and rich regions have a half life of almost 20 years. The other variables do not appear to be significant. However, the Moran coefficient indicates strong spatial autocorrelation patterns.

*-Table 1 about here-*

The robust LM test suggests to include a spatial lag of the error term in the regression equation. The results of the ML estimation of this spatial error model are shown in the right column of table 1. The speed of convergence is nearly unchanged compared to the OLS regression. Moreover, the other variables are significant.

*-Tables 2 and 3 about here-*

Next, the spatial filtering method is applied. The Moran coefficients are significant for all variables in the analysis, see table 2. Thus, the independent variables have to be filtered before the convergence equation is run. The filtered growth regressions are computed on the basis of the spatially filtered regressors as well as substantial eigenvectors, see table 3. The Moran coefficient shows that the spatial filtering procedure is successful, as no spatial autocorrelation can be detected anymore in the residuals. The spatial filtering approach leads to a slightly slower convergence rate of 3 percent per annum. The impact of the control variables is weaker than in the spatial error model.

Finally it is examined whether locally different speeds of convergence occur, see table 4. The global F-test of nonstationarity proves that the estimation of regionally different regression coefficients is appropriate. The regression coefficient of initial labour

productivity is well behaved for nearly all regions. The highest rate of convergence with 8.9 percent per annum is detected for the Normandy.

*-Table 4 about here-*

The variation in the speed of convergence gives empirical evidence to heterogeneous convergence across the EU. Nearby located areas show a similar speed of convergence (see figure 5). Many regions of Italy for example have a convergence rate between 3 and 3.5 per cent, and these values do not differ substantially.

*-Figure 5 about here-*

Regions with a similar convergence rate might be interpreted as convergence clubs. Their conditions are not very different, and therefore they converge to the same steady state. A convergence club is also detected by an approach of Le Gallo and Dall'erba (2006) using a sample of EU25 states and an absolute convergence approach. But, they only identify two convergence clubs, which are not stable over time.

Regions around the British 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.

## **6 Conclusions**

In this paper economic convergence is investigated for the EU25 countries. The analysis refers to the augmented Solow model with human capital. Country specific rates of depreciation and technological progress are used. Spatial effects are taken into account. A special focus is the robustness of the results.

Convergence of productivity can be established by different methods. On average, the speed of convergence ranges between 3 and 3.5 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 British 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.



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Figure 1: Labour productivity growth (left) and initial (1995) productivity levels

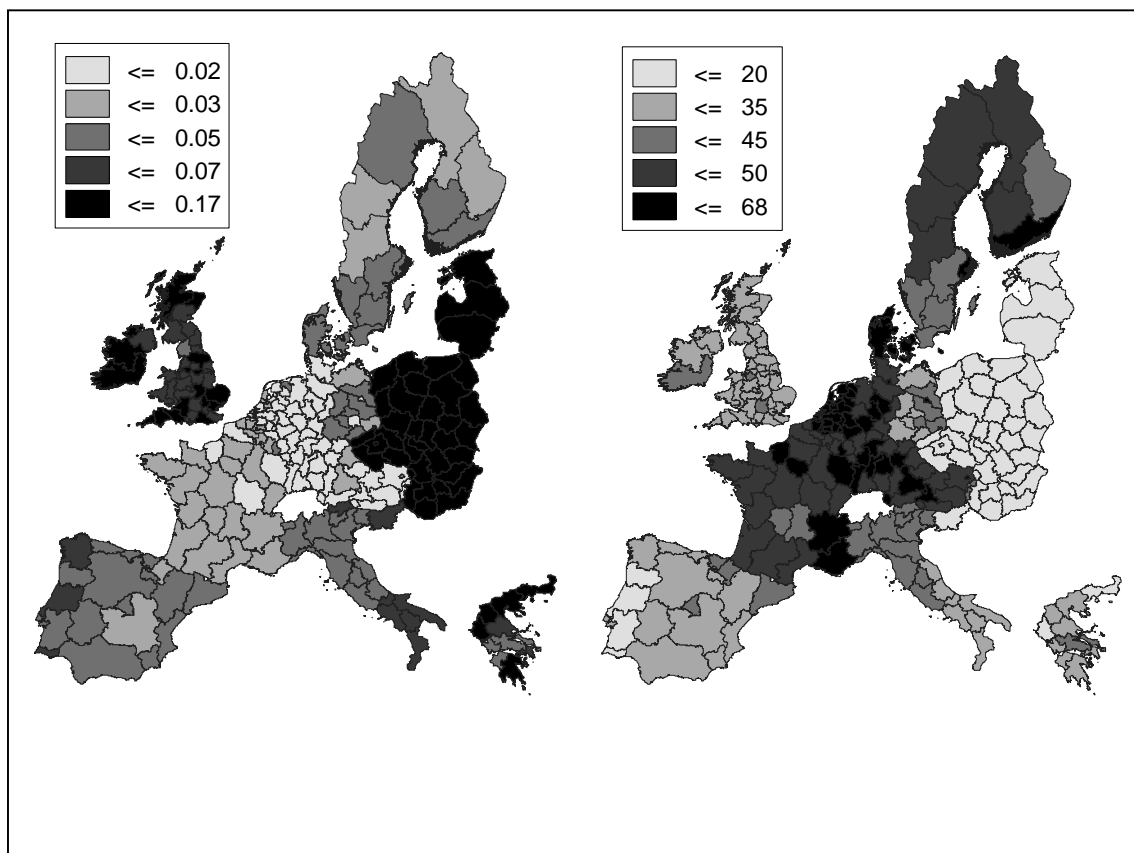


Figure 2: Savings rate for physical capital (left) and human capital per unit labour force

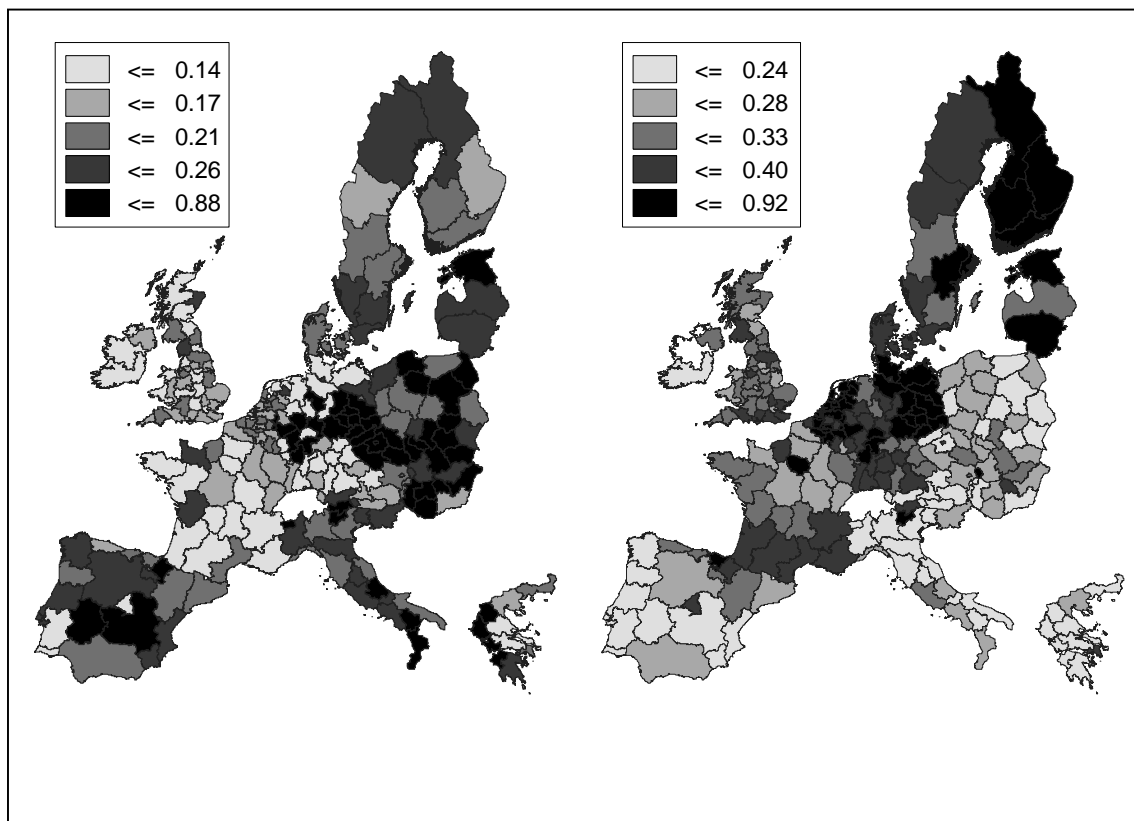


Figure 3: Growth rate of labour force (left) and capital depreciation rate

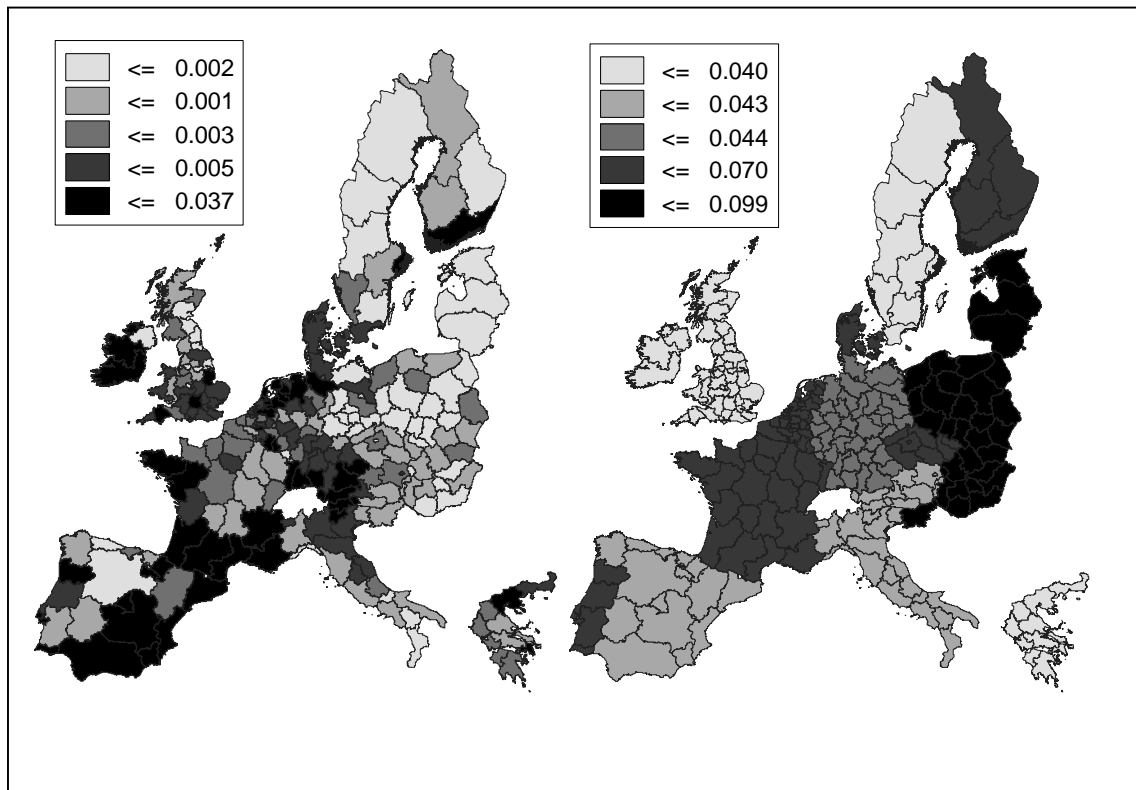




Figure 4: Growth of total factor productivity

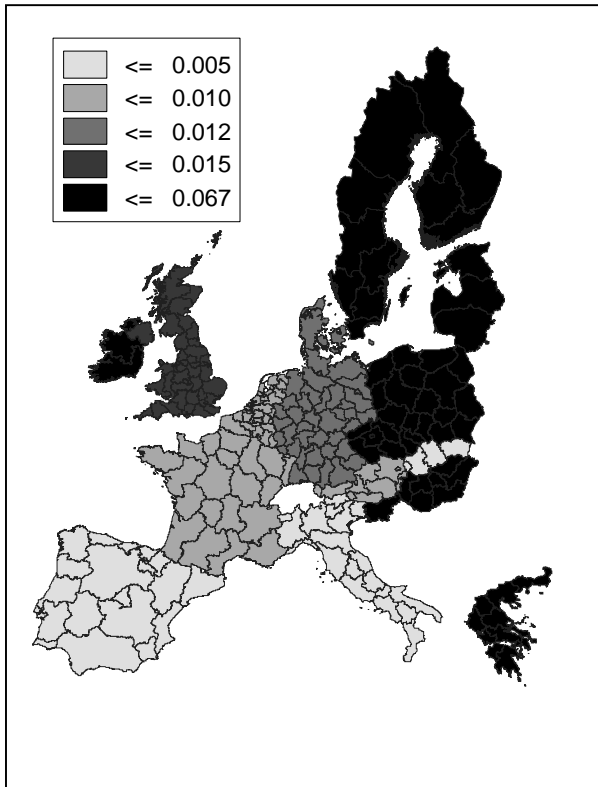


Figure 5: Speed of convergence alone (left) and together with initial labour productivity

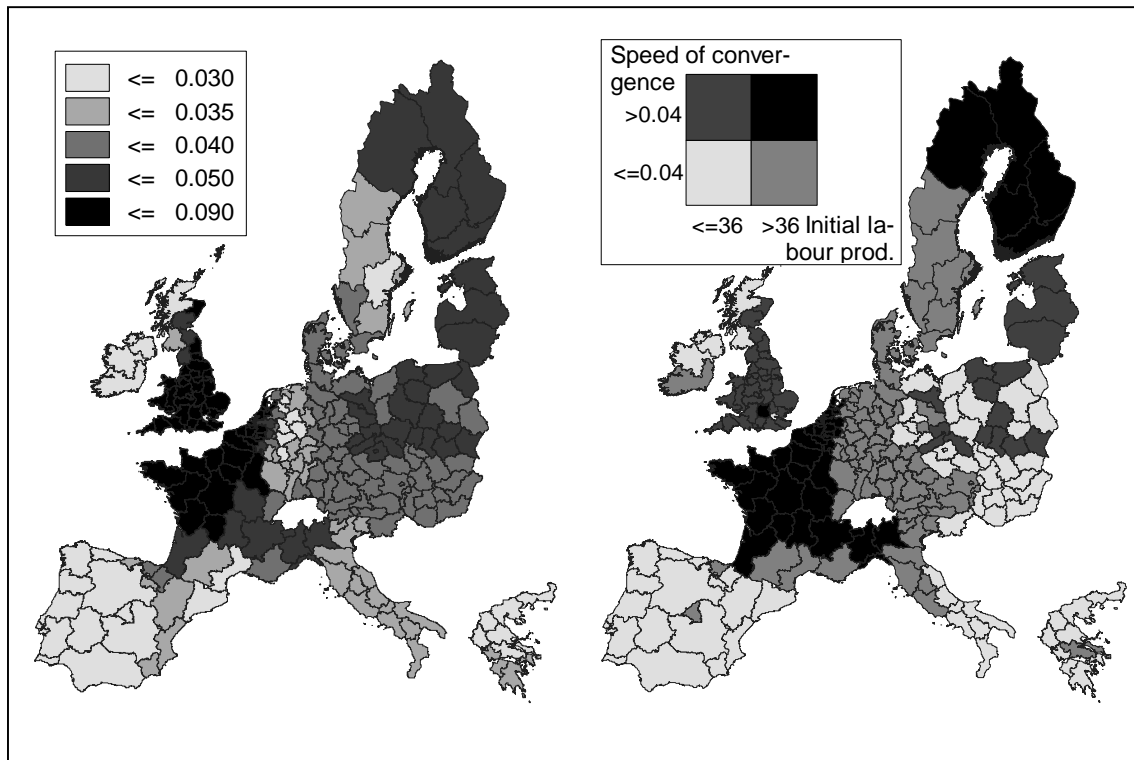


Table 1: Estimation of the convergence equation

	OLS estimation		ML estimation	
	Coefficient	t-value	Coefficient	z-value
Const.	0.172*	20.951	0.155*	17.136
$\ln y_{1995}$	-0.038*	-26.911	-0.036*	-15.987
$\ln s_k - (n+g+\delta)$	0.000	-0.111	0.004*	2.486
$\ln h$	0.001	0.775	0.002*	2.576
Spatial error parameter $\lambda$			0.714*	15.359
Global tests	$R^2 = 0.761^*$ , MI = 0.648*		$R^2 = 0.671^*$	
	LM= 59.420*; LM(lag)=0.062			

Note:  $R^2$ : coefficient/pseudo coefficient of determination; MI: Moran's I statistic; LM: robust LM test; LM(lag): robust LM(lag) test; \* indicates significance at least at the 0.05 level.

Table 2: Test for spatial autocorrelation of the variables in the analysis

	Moran coefficient	z-value
$\ln(y_{2003}/y_{1995})/8$	0.851*	18.438
$\ln y_{1995}$	0.891*	19.295
$\ln s_k$	0.312*	6.810
$\ln (n+g+\delta)$	0.789*	17.095
$\ln s_k - \ln (n+g+\delta)$	0.382*	8.327
$\ln h$	0.165*	3.643

Note: \* indicates significance at least at the 0.05 level.

Table 3: Spatial filtered model

	OLS estimation	
	Coefficient	z-value
Const.	0.046*	81.251
$\ln y_{1995}$	-0.030*	-10.508
$\ln s_k - \ln (n+g+\delta)$	0.005*	2.541
$\ln h$	0.002	1.810
Global tests	$R^2 = 0.942^*$ , MI = -0.111	

Notes:  $R^2$ : coefficient of determination; MI: empirical value of the Moran's I statistics; \*: significant at least at the 0.05 level.

Table 4: Geographically weighted regression approach

Coefficient	Lower			Upper		Global OLS
	Minimum	Quartile	Median	Quartile	Maximum	
$\beta_{0i}$ or $\beta_0$	0.082	0.128	0.158	0.200	0.332	0.172*
$\beta_{1i}$ or $\beta_1$	-0.093	-0.047	-0.039	-0.034	0.004	-0.038*
$\beta_{2i}$ or $\beta_2$	-0.017	-0.002	0.003	0.004	0.031	0.000
$\beta_{3i}$ or $\beta_3$	-0.008	-0.001	0.002	0.007	0.017	0.001
$R^2$ or $R^2_i$	0.373	0.687	0.825	0.907	0.996	0.761*

Bandwidth = 2.716, Global test of nonstationarity:  $F = 12.0976^*$

Note:  $R^2$ ,  $R^2_i$  global, local coefficient of determination; \*: significant at least at the 0.05 level.