REGIONAL ECONOMIC GROWTH AND STEADY STATES WITH FREE FACTOR MOVEMENT: A THEORETICAL MODEL WITH EVIDENCE FROM EUROPE

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Abstract - *This paper develops a spatial theoretical growth model in order to study the impact of physical and human capital relocations on the growth of open economies. Analytical and simulation results show how the respective neighbours determine an economy's development, why convergence and divergence may alternate in the medium run, and that interregional migration as a consequence of interregional wage inequalities causes disparities to prevail in the long run. The empirical part applies spatial econometric specifications for European regions on the NUTS2 level for the observation period 2000-2013. The estimations underline the importance of human capital endowments and its relation with spatial location.*

Key-words - NEOCLASSICAL GROWTH THEORY, HUMAN CAPITAL, INTERREGIONAL MIGRATION, CONVERGENCE, DIVERGENCE, EUROPEAN INTEGRATION

JEL Classification - F43, R11, C31

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1. INTRODUCTION

Studies released in the 1990s and 2000s generally display a trend of interregional convergence in Europe (Sala-i-Martin 1996, Paci and Pigliaru 2002, Fischer and Stirböck 2006, Pfaffermayr 2009), although some point out that this process is not consistent but rather changing over time (Neven and Gouymte 1995, Tondl 2001). This issue is of particular importance for the European Union, where differences in levels of gross regional product (GRP) per capita reach up to 30fold, which is extreme by any standard. If the famous two per cent rule of β-convergence speed applies, then interregional disparities would halve in around 35 years. Although this may be considered as rather slow, β-convergence and σ-convergence were considered as robust empirical results (see Islam 2003) – at least until recently.

In addition to the well-known problems with growth equations,[1] some problems regarding the empirics of interregional development in Europe continue to exist. By considering only medium run observation periods, empirical results are often biased because of disequilibria and/or shocks which appear shortly before or during the observation period. In particular, recessions and subsequent recoveries, such as the transitions of formerly centrally planned economies or financial crises, may lead to interpretations which depend mostly on the observation period considered.

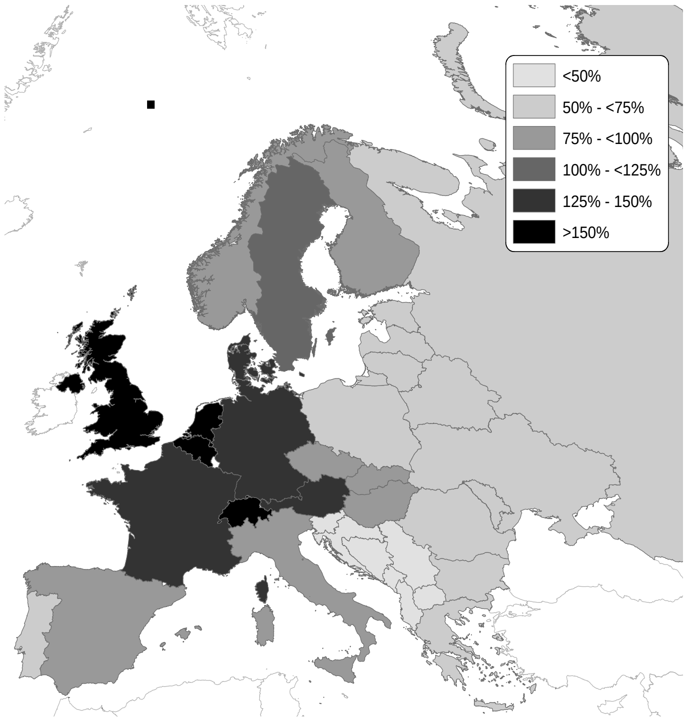
In the European context, the two decades before the current crises were characterised by high growth rates in the cohesion countries (Greece, Ireland, Portugal, Spain) as well as in the former centrally planned economies which accessed the EU during the 2000s. However, the cohesion countries simultaneously have enjoyed substantial financial support from the EU's structural funds since the late 1980s, which probably supported their high growth numbers during the 1990s. In addition, the introduction of the euro led to unprecedented low interest rates which in turn led to unsustainable private debt and, consequently, high growth during the 2000s until the start of the ongoing crises 2007/2008. At the same time, most empirical studies which include former members of the Council for Mutual Economic Assistance (Comecon) start only at 1995. During the early 1990s, these countries suffered severe recessions due to the transition process, and the high growth numbers afterwards at least partly reflect merely catching-up processes to their long run growth paths.

Taking on a long run perspective, the maps in Figures 1, 2 and 3 display gross domestic product (GDP) for European countries at purchasing power parities (PPP) in percentage to the European mean for 1900, 1960 and 2008, respectively. In particular, when comparing 1900 to 1960, a period during which countless economic transitions took place, it is remarkable how little has changed. Apart from an apparent catching-up process in Northern European countries, which matters visually due to the area size but not so much economically,

[1] Acemoğlu (2009) mentions three major problems, namely (i) endogeneity of explanatory variables and growth, (ii) ambiguity regarding an explanatory variable's magnitude of impact and (iii) ignoring the openness of considered economies and their interactions.

a core-periphery pattern is persistent over the decades: Central western European countries are the most advanced, while the southern, eastern and far western European countries lag behind. The picture hints at club-convergence, as discussed by Baumol (1986). According to his study, the western market economies as well as the eastern centrally planned economies would not converge towards each other but rather form two clubs, differing substantially from each other. Shortly after Baumol's study, the eastern European economies opened themselves to migration, investment and trade-flows from and to the west. In this context, it seems interesting to note that Alexiadis (2013) finds comparable geographical patterns of club-convergence within the EU now that economic systems are more similar than ever before. Indeed, the picture of 2008 differs insofar as the divide between the west and the east is even more pronounced from 1900 and 1960.

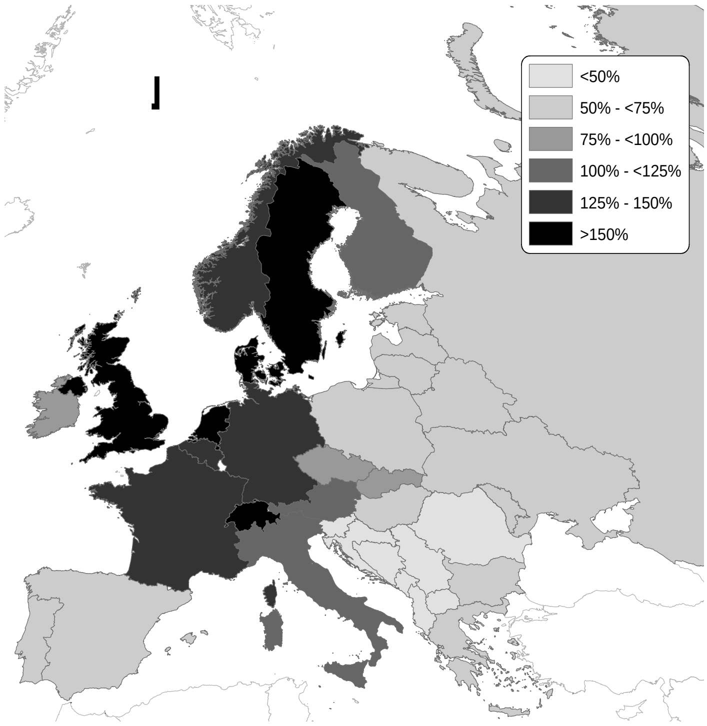
Figure 1. GDP at PPP per inhabitant relative to the European mean, 1900



Notes: Total European GDP including Russia, excluding Cyprus and Turkey, European white areas indicate missing data. Data source: World Economics (www.worldeconomics.com)

As of today, more than two thirds of the European population live in member states of the European Union, where capital, people, goods and services are free to move. Figure 4 displays GRP per inhabitant at market prices relative to the EU's mean on the regional NUTS2 level. It can be seen that within Italy and Spain, those regions which lie geographically close to the core are also the most advanced. In contrast, the peripheral regions within these countries are lagging behind. Hence it may be stated that 200 years after the industrialisation of continental Europe commenced, almost 60 years after the foundation of the European Union, and 25 years after the transition of the former Comecon, the European core's economic advance appears to be as robust as ever.

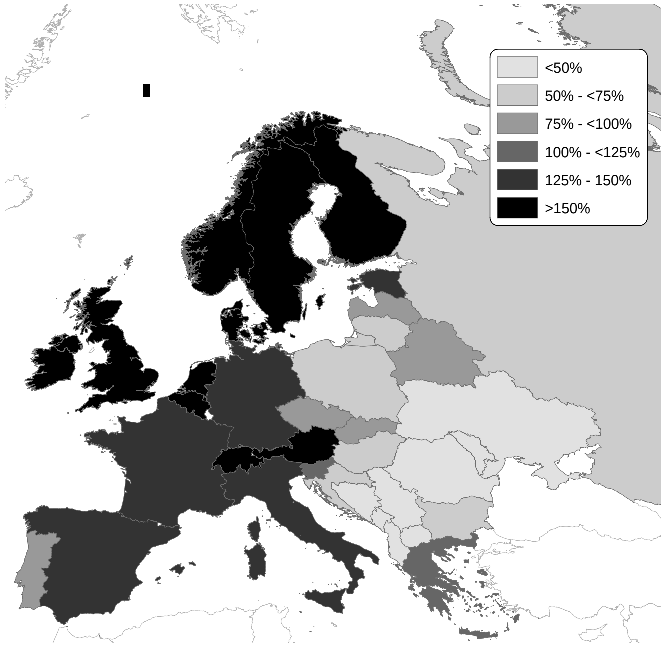
Figure 2. GDP at PPP per inhabitant relative to the European mean, 1960



Notes: See Figure 1.

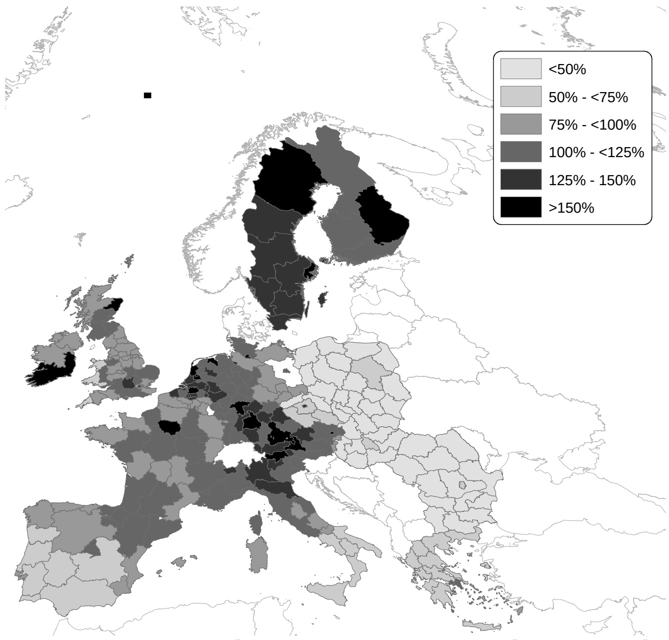
A recent report by the European Bank for Reconstruction and Development (2013) casts doubts on whether the countries and regions which lag behind economically will ever converge to their peers. The report notes that the transition economies of central and eastern Europe achieved impressive growth rates from the mid-1990s until the outbreak of the crises in 2007/2008. According to the report, the high growth rates were fuelled by a rapid catching-up with respect to productivity in the wake of opening their economies to western technology – a process which has now come to an end, with long run growth-problems on prospects of future convergence dynamics. In addition, brain drain has proven to be an obstacle for socio-economic development, and the EU's new member states' brain drain has even accelerated after their accessions in 2004 and 2007. The report (pp. 63) argues that for transition economies to converge towards their mature economy peers, human capital's returns within the former need to be comparable to or even greater than within the latter.

Figure 3. GDP at PPP per inhabitant relative to the European mean, 2008



Notes: See Figure 1.

Figure 4. GRP per inhabitant relative to the EU's mean, 2010



Notes: Data corresponds to GRP at current market prices; data source: Eurostat (epp.eurostat.ec.europa.eu).

As discussed by many authors (North 1990, Landes 1998, Acemoğlu and Robinson 2012), improving institutions is a means of improving economic performance. Whether the report's proposed solution of improving the institutional environment in these countries is enough to stop human capital outflows and to enforce convergence is, however, questionable. It seems too simple to regard an improvement of institutional settings as a cure-all, as it is implausible that if institutional environments within two given economies are identical, then the dynamics between these economies would come to a halt. Rather, dynamics between two economies with similar institutions may be to the advantage of one as it is to the disadvantage to the other if productivity levels differ. To illustrate the case, it is hard to believe that the population decrease of 15.5 per cent within the territory of the former German Democratic Republic since German unification – of which most migrated within Germany – is solely caused by inferior institutional environments.

The aim of this paper is to develop a neoclassical growth model for a system of regional economic growth which takes into account that physical as well as human capital relocations tend to decrease with geographical distance. The quality of institutions and access to technology are assumed to be identical for all regional economies that are part of the system. It is shown that under these conditions, steady state levels depend on geographical location as well as initial conditions. Furthermore, medium run developments can be quite turbulent and do not necessarily allow for conclusions regarding long run development, which may show a completely different pattern. Finally, by means of spatial econometrics, the model's predictions are confronted with interregional developments of the EU before and after the crises. It is argued that possibly the system of the EU's regional economies currently moves towards a new equilibrium which is not caused by the financial and euro crises but rather economic integration of the recent past.

The paper is set up as follows. The theoretical model is presented in the next section. After that, the model's dynamics are described by means of differential equations and simulations. The spatial econometric specifications, data and regions as well as the results are discussed in the fourth section. The final section concludes.

2. THE MODEL

2.1. Theoretical background

In the neoclassical growth model as developed by Solow (1956) and Swan (1956), different steady states result from variations in the determinants of growth within the economy, e.g. the saving rate. Since then, the notion that growth is also shaped by relations to other economies has been considered by a number of theoretical models, which is of particular relevance for issues related to globalisation as well as regional economies. Models in the tradition of the Solow model have incorporated the effects of labour migration (Borts and Stein 1964), trade (Thirlwall 1979), knowledge spillovers (Ertur and Koch 2007), investment flows (Sardadvar 2012), agglomeration effects (De Dominicis 2014) or public capital (Dall'erba and Llamosas-Rosas 2015).

In addition, human capital is acknowledged as a key driver of economic growth at least since the release of Mankiw, Romer and Weil's (1992) influential essay. However, because human capital is embodied in workers, the integration of human capital relocations and its interplay with other factors becomes more complex. Maybe for this reason, theoretical models which integrate human capital relocations show no clear results regarding economic disparities. For instance, in a model of national economies by Barro and Sala-i-Martin (1995, 2004), immigration of human capital suppliers to highly productive economies leads to physical capital dilution and hence accelerates the convergence processes. In contrast, Docquier and Rapoport (2012) consider the benefits of sending and receiving countries. Since it is usually the wealthy economies that attract human capital, the authors' main concern is the extent to which sending countries suffer from negative effects due to brain drain. In a model of regional development by Gennaioli et al. (2013), human capital suppliers migrate from unproductive to productive regions, where the latter may become even more productive as a matter of human capital externalities. In equilibrium, regional economies fall either into the productive or unproductive category, where the former benefits from migration from the latter. As a result, disparities persist also in equilibrium.

Ertur and Koch (2007) develop a spatial growth model where national economies benefit from the knowledge in neighbouring economies, which is embodied in physical capital. The model results in individual steady states, but the economies are not open in the strict sense of the word as factor relocations are not allowed for. In contrast, Sardadvar (2012) considers regional economies and allows for physical capital relocations which depend on human capital stocks relative to neighbouring regions, with possible divergence in the medium run but convergence to identical steady states in the long run. Sardadvar (2013) shows at the example of two economies that the introduction of human capital relocations may further strengthen economies which are already richly endowed with human capital.

Against this background, the aim of the present paper is to provide a theoretical model that is able to explain the persistence of economic and geographic disparities in an integrating economic system such as the European Union. Special attention is paid to (i) the double role of human capital, which is considered as a type of capital but embodied in workers, and (ii) the role of distance, which is assumed to have an impact on factor's mobility. The research question of the paper may be expressed as follows: If an economic system with free but spatially bounded factor movement is integrated to an extent where institutional environments among its regional economies are comparable, which long run pattern of economic development will emerge?

2.2. The Production Function

Consider a neoclassical growth model in the spirit of Mankiw, Romer and Weil (1992) for a finite set of regional economies $i = 1, 2, ..., N$, over continuous time t. Output per unit of effective labour $q_{i,t}$ is assumed to be produced via a Harrod-neutral production function with constant returns to scale

$$q_{i,t} = f(k_{i,t}, h_{i,t}) \tag{1}$$

where the inputs are physical capital per unit of effective labour $k_{i,t}$, and human capital per unit of effective labour $h_{i,t}$. It is assumed that the current level of technology is available everywhere within the superordinate economy, so that $A_{i,t} = A_{j,t} \ \forall i, j, t$, where A symbolises technology.

In addition, in order to facilitate calculations it is assumed that population sizes are identical, that is $L_{i,t} = L_{j,t} \ \forall i, j, t$.

Hence at any t, total regional stocks of factors equal $K_{i,t} = k_{i,t} A_{i,t} L_{i,t}$, $H_{i,t} = h_{i,t} A_{i,t} L_{i,t}$ and thus $Q_{i,t} = f(K_{i,t}, H_{i,t}, A_{i,t} L_{i,t})$.

Since constant returns are assumed, it follows that $Q_{i,t} = q_{i,t} A_{i,t} L_{i,t}$.

In addition, the basic assumptions of the Solow model (continuity, differentiability, positive and diminishing marginal products) apply.

The regions are part of a superordinate economy, whose output is simply the sum of the N regional economies, $\sum_{i=1}^{N} Q_{i,t}$. Since population sizes are assumed to be identical in each region, the superordinate economy's output per unit of effective labour equals the arithmetic mean of the individual regional economies' output values, or simply:

$$\bar{q}_{i,t} = \frac{\sum_{i=1}^{N} Q_{i,t}}{N A_{i,t} L_{i,t}} = \frac{\sum_{i=1}^{N} q_{i,t}}{N} \tag{2}$$

2.3. Evolutions of Stocks of Factors

Factor mobility takes place between directly connected regions and depends on individual choices based on future expectations. Connectivity between any two regions i and j is captured by the term w_{ij}. If $w_{ij} > 0$ for any two regions $i \neq j$ then they are directly connected and considered as neighbours. If they are not considered as neighbours then $w_{ij} = 0$. Note that according to this definition neighbours neither have to share a common physical border, nor do the values $w_{ij} > 0$ have to be identical among pairs of regions.

Expected future profits from investments in physical capital equal their marginal productivity and depend on geographical proximity. The assumption of identical population sizes allows to express the evolution of the physical capital stock as

$$\dot{k}_{i,t} = s_k \mu_{k,t} q_{i,t} \prod_{i \neq j}^{N} \left(\frac{\partial q_{i,t} / \partial k_{i,t}}{\partial q_{j,t} / \partial k_{j,t}} \right)^{\lambda w_{ij}} - (n + g + d) k_{i,t} \tag{3}$$

where the dot over k denotes its derivation with respect to time. s_k is the saving rate, n is the population growth rate, g is the technology growth rate, and d is the rate of depreciation, all of which are exogenously given and assumed to be identical for each region. It can be seen how differences in marginal productivity determine investment flows between the two regions i and j. The size of net investment flows is influenced by λ, a measure of the degree of integration, and the respective value of w_{ij}. $\mu_{k,t}$ is a variable that ensures that the sum of investment outflows equals inflows within the superordinate economy at any t.

In contrast to physical capital investments, expected income of human capital suppliers does not solely depend on human capital's current marginal product but rather on the wage a worker with human capital receives. Therefore, the evolution of the human capital stock per unit of effective labour takes the form

$$\dot{h}_{i,t} = s_h \mu_{h,t} f(k_{i,t}, h_{i,t}) \prod_{i \neq j}^{N} \left(\frac{v_{h,i,t}}{v_{h,j,t}} \right)^{\lambda w_{ij}} - (n + g + d) h_{i,t} \tag{4}$$

where $v_{h,i,t}$ is the wage of human capital suppliers in i at t. s_h is the education expenditure rate (or, equivalently, the saving rate for human capital), which is assumed to be determined by the superordinate economy and hence identical for all regions, while $\mu_{h,t}$ ensures that the sum of regional outflows of human capital within the superordinate economy equals the sum of inflows at any t. From the assumptions of identical technology and population sizes it follows that $\dot{K}_{i,t} = \dot{k}_{i,t} A_{i,t} L_{i,t}$ and $\dot{H}_{i,t} = \dot{h}_{i,t} A_{i,t} L_{i,t}$.

For simplicity, the superordinate economy is assumed an open economy which constantly runs a balanced current account, or, alternatively, simply a closed economy. In that case, the actual superordinate economy's net investment at t including the intraregional flows must equal the sum of all net investments of all regions at t:

$$\sum_{i=1}^{N} \left(s_k Q_{i,t} - dK_{i,t} \right) = \mu_{k,t} \sum_{i=1}^{N} \dot{K}_{i,t} \tag{5}$$

where dividing both sides by $A_{i,t} L_{i,t} = A_{j,t} L_{j,t} \forall i, j, t$ and expressing by $\mu_{k,t}$ yields

$$\mu_{k,t} = \frac{\sum_{i=1}^{N} q_{i,t}}{\sum_{i=1}^{N} \left(q_{i,t} \prod_{i \neq j}^{N} \left(\frac{\partial q_{i,t} / \partial k_{i,t}}{\partial q_{j,t} / \partial k_{j,t}} \right)^{\lambda w_{ij}} \right)} > 0 \tag{6}$$

Likewise, for simplicity it is assumed that net human capital migration beyond the superordinate economy's borders equals zero, so that

$$\sum_{i=1}^{N}\left(s_h Q_{i,t} - dH_{i,t}\right) = \mu_{h,t}\sum_{i=1}^{N}\dot{H}_{i,t} \tag{7}$$

and consequently

$$\mu_{h,t} = \frac{\sum_{i=1}^{N} q_{i,t}}{\sum_{i=1}^{N}\left(q_{i,t}\prod_{i\neq j}^{N}\left(\frac{v_{h,i,t}}{v_{h,j,t}}\right)^{\lambda w_{ij}}\right)} > 0 \tag{8}$$

From eqs. (6) and (8) it can be seen that $\mu_{k,t}$ and $\mu_{h,t}$ will always be greater than zero, since all terms and hence both the nominator and the denominator must be positive.

2.4. The Cobb-Douglas Case

Output per unit of effective labour with a Cobb-Douglas production function equals

$$q_{i,t} = k_{i,t}^{a} h_{i,t}^{b} \tag{9}$$

from which it follows that

$$\dot{k}_{i,t} = s_k \mu_{k,t} k_{i,t}^{a} h_{i,t}^{b} \prod_{i\neq j}^{N}\left(\frac{k_{i,t}^{a-1}h_{i,t}^{b}}{k_{j,t}^{a-1}h_{j,t}^{b}}\right)^{\lambda w_{ij}} - \eta k_{i,t} \tag{10}$$

where $\eta = n + g + d$ to save space.

Human capital is usually defined as 'the total contribution of workers of different skill levels to production' (Romer 2005, pp. 134). Therefore, H is to be distinguished from raw labour L as it represents acquired skills. Accordingly, two types of workers exist: Those who supply only raw labour, and those who additionally supply the skills which are considered to be human capital as defined above. The latter are supposed to earn a higher wage which consists of a compensation for raw labour plus a premium for their human capital supply. Thus the difference between workers who supply human capital and workers who don't equals the profits of foregone human capital investments, i.e. its marginal product. Put differently, although human capital represents a form of capital, its revenues are part of wages.

In terms of national accounts, the share of income earned by the owners of physical capital in equilibrium takes the following form:

$$V_{K,i,t} = K_{i,t}\frac{\partial Q_{i,t}}{\partial K_{i,t}} \tag{11}$$

where V symbolises a factor's total compensation, with the first subscript referring to the respective factor. In the Cobb-Douglas case, eq. (11) simply equals $aQ_{i,t}$. It follows that the share of income that is found on the payrolls is the sum of compensations for raw labour plus human capital

$$V_{L,i,t} + V_{H,i,t} = L_{i,t}\frac{\partial Q_{i,t}}{\partial L_{i,t}} + H_{i,t}\frac{\partial Q_{i,t}}{\partial H_{i,t}} \tag{12}$$

which in the Cobb-Douglas case consequently equals $(1-a)Q_{i,t}$.

Assume that $x_{i,t}$ measures the share of workers who represent one unit of human capital in i at t. Under this scenario, those workers who qualify as human capital receive a premium in addition to marginal product of labour which equals the marginal product of the human capital they supply. In contrast, those workers who do not qualify as human capital just receive compensation for raw labour. In the Cobb-Douglas case we thus have

$$V_{L,i,t} = Q_{i,t}\left(1-x_{i,t}\right)\left(1-a-b\right) \tag{13}$$

$$V_{H,i,t} = Q_{i,t}\left(x_{i,t}\left(1-a-b\right)+b\right) \tag{14}$$

To save space, let $c = 1-a-b$ and, for simplicity, consider $x_{i,t} = h_{i,t}$. Then the total compensation for one unit of human capital equals $v_{h,i,t} = q_{i,t}(h_{i,t}c+b)$, and hence

$$\dot{h}_{i,t} = s_h \mu_{h,t} k_{i,t}^a h_{i,t}^b \prod_{i \neq j}^{N} \left(\frac{q_{i,t}(b+ch_{i,t})}{q_{j,t}(b+ch_{j,t})}\right)^{\lambda w_{ij}} - \eta h_{i,t} \tag{15}$$

3. DYNAMICS

3.1. Economic Growth

The total differential of the production function with respect to time equals

$$\frac{dq_{i,t}}{dt} = \frac{\partial q_{i,t}}{\partial k_{i,t}}\frac{dk_{i,t}}{dt} + \frac{\partial q_{i,t}}{\partial h_{i,t}}\frac{dh_{i,t}}{dt} \tag{16}$$

By setting $\mu_{k,t} = \mu_{h,t} = 1$ for simplicity, output growth at t may be expressed as

$$\frac{\dot{q}_{i,t}}{q_{i,t}} = as_k\left(\frac{q_{i,t}}{k_{i,t}}\right)^{1+\phi_i} \prod_{i \neq j}^{N}\left(\frac{k_{j,t}}{q_{j,t}}\right)^{\lambda w_{ij}} + bs_h\frac{q_{i,t}v_{h,i,t}^{\phi_i}}{h_{i,t}} \prod_{i \neq j}^{N}\left(\frac{1}{v_{h,j,t}}\right)^{\lambda w_{ij}} - \eta(a+b) \tag{17}$$

where $\phi_i = \lambda \sum_{i=1}^{N} w_{ij}$. Note that this variable becomes higher, the more the neighbours i has and the closer it lies to them. Hence the more centrally located a region, the greater the effects of other regions' attributes will be. To avoid extreme fluctuations or the explosion of the model, the integration of i within the system is constrained so that $\phi_i < 1 \forall i$.

It follows that for any $j \neq j'$

$$\frac{\partial(\dot{q}_{i,t}/q_{i,t})}{\partial h_{j,t}} = -b\lambda w_{ij} \frac{q_{i,t}}{h_{j,t}} \times \left(\begin{array}{l} as_k \dfrac{q_{i,t}^{\phi_i} k_{j,t}^{\lambda w_{ij}} h_{j,t}^{b}}{k_{i,t}^{1+\phi_i} \left(k_{j,t}^{a} + h_{j,t}^{b}\right)^{1+\lambda w_{ij}}} \prod_{j' \neq i}^{N} \left(\dfrac{k_{j',t}}{q_{j',t}}\right)^{\lambda w_{ij'}} + \\ s_h \dfrac{b^2 + c(1+b)h_{j,t}}{h_{i,t}\left(b + ch_{j,t}\right) v_{h,j,t}^{\lambda w_{ij}}} \prod_{j' \neq i}^{N} \left(\dfrac{1}{v_{h,j',t}}\right)^{\lambda w_{ij'}} \end{array} \right) \tag{18}$$

which is unambiguously negative since all variables must be positive. Therefore, an increase in human capital endowment in neighbouring regions has a decreasing effect on output growth of region i. This is because the latter becomes less attractive for both types of capital. Equation (18) also shows that this effect is stronger, the stronger the connectivity between the two regions is, i.e. the higher w_{ij}.

The effect of a change in the human capital stock within i has a contrasting effect:

$$\frac{\partial(\dot{q}_{i,t}/q_{i,t})}{\partial h_{i,t}} = b \frac{q_{i,t}}{h_{i,t}^2} \times \left(\begin{array}{l} as_k \left(1+\phi_i\right) \dfrac{q_{i,t}^{\phi_i}}{k_{i,t}^{1+\phi_i} h_{i,t}} \prod_{i \neq j}^{N} \left(\dfrac{k_{j,t}}{q_{j,t}}\right)^{\lambda w_{ij}} + \\ s_h \dfrac{v_{h,i,t}^{\phi_i}\left(\left(1+b\right)\left(c\phi_i h_{i,t} - 1\right) + b^2\left(1+\phi_i\right) + ch_{i,t}\right)}{b + ch_{i,t}} \prod_{i \neq j}^{N} \left(\dfrac{1}{v_{h,j,t}}\right)^{\lambda w_{ij}} \end{array} \right) \tag{19}$$

The first term in brackets is unambiguously positive, the second term is positive if $h_{i,t} > \left(1 + b - b^2(1-\phi_i)\right) / \left(c\left(1 + \phi_i\left(1+b\right)\right)\right)$, which, with plausible values for the parameters, takes on values around one. Considering the positive value of the first term, it is very unlikely yet principally possible for regions with very low human capital endowments that eq. (19) becomes negative. Therefore, the equation shows how under normal circumstances an increase in a region's own human capital stock benefits its further development: A large stock of human capital will attract further human as well as physical capital, and an increase in i's human capital stock will also increase i's output growth. However, the actual magnitude of this effect depends on the interplay of the stocks of factors in the various regions plus the connectivities of i.

Considering i's current output level, an increase may have a positive or negative effect on growth:

$$\frac{\partial(\dot{q}_{i,t}/q_{i,t})}{\partial q_{i,t}} = (1+\phi_i)\times$$
$$\left(-s_k(1-a)\left(\frac{h_{i,t}^{b(1+\phi_i)}}{q_{i,t}^{1+(1-a)\phi_i}}\right)^{\frac{1}{a}} \prod_{j'\neq i}^{N}\left(\frac{k_{j,t}}{q_{j,t}}\right)^{\lambda w_{ij}} + bs_h \frac{v_{h,i,t}^{\phi_i}}{h_{i,t}} \prod_{j'\neq i}^{N}\left(\frac{1}{v_{h,j,t}}\right)^{\lambda w_{ij}} \right) \tag{20}$$

On the one hand, i benefits from its increased attractiveness on foreign factors. On the other hand, an increase above steady state must decrease i's output as a matter of depreciation. However, plausible parameters imply that $1-a>b$, thus a tendency for negative levels of eq. (20) exists.[2]

An output-increase in a particular region j affects i's growth depending on the relative sizes of factors in both regions, with the total effect remaining ambiguous:

$$\frac{\partial(\dot{q}_{i,t}/q_{i,t})}{\partial q_{j,t}} = \frac{\lambda w_{ij}}{b}\frac{q_{i,t}}{q_{j,t}}\times$$
$$\left(\begin{array}{l} a(1-b)s_k\left(\frac{h_{i,t}^{a(1+\phi_i)}}{q_{i,t}^{1+(1-b)\phi_i}}\left(\frac{q_{j,t}^{1-b}}{h_{j,t}^{a}}\right)^{\lambda w_{ij}}\right)^{\frac{1}{b}} \prod_{\substack{j'\neq i\\ j'\neq j}}^{N}\left(\frac{q_{j',t}^{1-b}}{h_{j',t}^{a}}\right)^{\frac{\lambda w_{ij'}}{b}} - \\ b^2 s_h \frac{v_{h,i,t}^{\phi_i}}{h_{i,t}v_{h,j,t}^{\lambda w_{ij}}} \prod_{\substack{j'\neq i\\ j'\neq j}}^{N}\left(\frac{1}{v_{h,j',t}}\right)^{\lambda w_{ij'}} \end{array} \right) \tag{21}$$

The interpretation is analogous to eq. (20), but this time the tendency for positive levels exists, as $1-b>b^2$.

To summarise, an increase of human capital endowments in neighbouring regions will reduce economic growth of region i, while an increase within its own borders will increase growth. The effect of output in region i or its neighbours depends on the interplay of human capital, physical capital and neighbourship. Therefore, it is possible that regions with low initial output levels will not converge to the mean if its connectivities are unfavourable and if its human capital endowment is low compared to its neighbours. Furthermore, the impacts of neighbouring regions are stronger, the more centrally located a region is, i.e. the more neighbours it has.

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[2] Note that a negative impact of initial output would resemble β-convergence, although the interpretation in this paper is different.

3.2. Steady states

Equilibrium is defined a state of the system in which there are no further changes with respect to the capital stocks per unit of effective labour, i.e. it must be that $\dot{k}_i^* = \dot{h}_i^* = 0\ \forall i$, with the stars indicating equilibrium levels. Because physical capital relocations depend on relative marginal productivity, the condition $\dot{k}_i^* = 0\ \forall i$ implies that in equilibrium $\partial q_i^* / \partial k_i^* = \partial q_j^* / \partial k_j^*\ \forall i, j$. It follows that in equilibrium, the nominator and denominator of eq. (6) are identical, and therefore $\mu_k^* = 1$.

In contrast, for human capital the equilibrium condition $\dot{h}_i^* = 0\ \forall i$ allows for $v_{h,i}^* \neq v_{h,j}^*$ which is due to the incentive to migrate based on wages. This means that a particular level of human capital can be upheld even under permanent emigration, as human capital is simultaneously reproduced while depreciating. In other words, in order to keep a relatively high level of human capital a region must permanently attract human capital from neighbouring regions if both terms on the right hand side of eq. (15) are to have identical values. Simultaneously, a region with a relatively low human capital level permanently produces and loses human capital to its neighbours, but needs less gross investments to uphold its relatively low equilibrium level.

By solving both eqs. (10) and (15) for η, it follows that in equilibrium

$$s_h \mu_h^* \frac{q_i^{*1+\phi_i} (h_i^* c + b)^{\phi_i}}{h_i^*} \prod_{i \neq j}^{N} \left(\frac{1}{k_j^{*a} h_j^{*b} (h_j c + b)} \right)^{\lambda w_{ij}} = s_k \left(\frac{h_i^{*b}}{q_i^{*1-a}} \right)^{\frac{1}{a}} \tag{22}$$

Solving this equation for q_i yields steady state output as

$$q_i^* = \left(\left(\frac{s_k}{s_h \mu_h^*} \right)^{a} \frac{h_i^{*a+b}}{(b + c h_i^*)^{a\phi_i}} \prod_{i \neq j}^{N} \left(q_j^* (b + c h_j^*) \right)^{a \lambda w_{ij}} \right)^{\frac{1}{1+a\phi_i}} \tag{23}$$

A special case arises if each connectivity $w_{ij} = w_{ij'} \forall w_{ij} > 0$ and simultaneously $\phi_i = \phi_j \forall i, j$ or, expressed verbally, if each of a particular region's connectivities is considered as equally important and if, in addition, each region is as centrally located as any other region.[3] In this case, cancelling and restructuring of eq. (23) leads to:

$$\frac{k_i^*}{h_i^*} = \frac{s_k}{s_h \mu_h^*} \prod_{i \neq j}^{N} \frac{v_j^{*\frac{\phi}{\omega(i)}}}{v_i^{*\phi}} \forall w_{i,j} > 0 \tag{24}$$

[3] Note that this case corresponds to a row-standardised spatial weight matrix based on binary connectivities.

where $\phi = \lambda \sum_{i=1}^{N} w_{ij} \forall i$ and $\omega(i)$ equals i's number of non-zero connectivities (i.e. the number of regions which are considered as neighbours to i). Note that $\prod_{i \neq j}^{N} v_j^{*\phi/\omega(i)} / v_i^{*\phi} \approx 1$, from which it follows that the neighbours' impact on long run levels almost disappears, hence they will be almost identical. Furthermore, from almost identical output levels across all regions it follows from eq. (8) that $\mu_h^* \approx 1$. But if this is the case, then eq. (24) collapses to $k_i^* / h_i^* \approx s_k / s_h$ and each region converges to the same steady state levels which are identical to the ones in Sardadvar (2012).

Therefore, from eq. (23) a number of the model's key conclusions can be drawn.

- Firstly, each region's eventual levels of factors depend on their neighbours' values. The higher the individual neighbours' steady state levels are, the higher is i's steady state output level. From this it follows that all regions approach individual levels of factor endowments and output in the long run.
- Secondly, equilibrium is dependent on the parameter of integration λ, the connectivities w_{ij}, and the values of s_k, s_h, a and b. Therefore, the system evolves towards an equilibrium that is determined by these factors. Considering that λ, s_k and s_h result from political decision-making, equilibrium can be influenced and changed.
- Thirdly, equilibrium also depends on starting levels as displayed by the inclusion of h_i^* on the right hand side of eq. (23).
- Fourthly, from eqs. (18) to (21) it follows that development in the medium run may be quite turbulent, depending on connectivities, the degree of integration and initial factor endowments. Until equilibrium is eventually reached, regions may surpass each other with respect to output, possibly displaying trends of β- and σ-convergence and -divergence subsequently or even simultaneously.
- Fifthly, if all connectivities are equally important and each region is as central as any other region, then all regions converge to the same steady state level.

In addition, steady state output of i is an increasing function of h_i^*:

$$\frac{\partial q_i^*}{\partial h_i^*} = \frac{h_i^*\left(ac\left(1-\phi_i\right)+b\right)+b\left(a+b\right)}{1+a\phi_i} \times \left(\left(\frac{s_k}{s_h \mu_h^*}\right)^a \frac{1}{h_i^{*1-a(1-\phi_i)-b}(b+ch_i^*)^{1+2a\phi_i}} \prod_{i \neq j}^{N} \left(q_j^*(b+ch_j^*)\right)^{a\lambda w_{ij}}\right)^{\frac{1}{1+a\phi_i}} \tag{25}$$

which is unambiguously positive. In contrast to the effect on medium run growth, the steady state of i is positively influenced by h_j^*:

$$\frac{\partial q_i^*}{\partial h_j^*} = \frac{a\lambda w_{ij}}{1+a\phi_i}\left(q_j^*\left(c\left(1+b\right)+\frac{b}{h_j^*}\right)\right)\times$$
$$\left(\left(\frac{s_k}{s_h\mu_h^*}\right)^a \frac{h_i^{a+b}}{\left(b+ch_i^*\right)^{a\phi_i}} \frac{1}{\left(q_j\left(b+ch_j^*\right)\right)^{1+a\left(\phi_i-\lambda w_{ij}\right)}} \prod_{i\neq j'}^{N}\left(q_{j'}^*(b+ch_{j'}^*)\right)^{a\lambda w_{ij'}}\right)^{\frac{1}{1+a\phi_i}} \tag{26}$$

Finally, q_i^* is positively influenced by q_j^*

$$\frac{\partial q_i^*}{\partial q_j^*} = \frac{a\lambda w_{ij}}{1+a\phi_i}\times$$
$$\left(\left(\frac{s_k}{s_h\mu_h^*}\right)^a \frac{h_i^{*a+b}}{(b+ch_i^*)^{a\phi_i}} \frac{(b+ch_j^*)^{a\lambda w_{ij}}}{q_j^{*1+a\left(\phi_i-\lambda w_{ij}\right)}} \prod_{i\neq j'}^{N}\left(q_{j'}^*(b+ch_{j'}^*)\right)^{a\lambda w_{ij'}}\right)^{\frac{1}{1+a\phi_i}} \tag{27}$$

From eqs. (25), (26) and (27) it follows that steady state levels are expected to be *similar* across neighbouring regions. This positive influence of the neighbours' steady state output despite its negative effect on economic growth is due to feedback effects which emerge in the long run. In the medium run, high human capital endowments attract investments and hence a region may grow at its neighbours' expense. At some point, however, marginal productivity becomes so low that the region's neighbours start to benefit. Therefore, in the long run all regions converge to their individual steady state output levels, which are more similar among neighbouring regions.

3.3. Simulation Results

In order to illustrate the model, in this section three simulations are run. The first scenario shows how the model behaves if the initial factor endowments are arbitrarily given. The second scenario considers identical initial endowments among regions, but at some point an exogenous shock leads to a small increase of human capital endowment in one particular region, leading to a collapse of the old equilibrium. In the third scenario, one region starts out with much more human capital than the others, where due to its initial advantage the respective region remains the most productive region in the long run despite the occurrence of σ-convergence in the medium run.

Consider those variables which are identical across regions to equal $a = 0.3$, $b = 0.2$, $\eta = 0.08$, $s_k = 0.25$, $s_h = 0.15$, and $\lambda = 0.1$. The superordinate economy consists of 12 regions A, B, …, L, whose borders are displayed by the accompanying spatial weights matrix:

$$\mathbf{W} = \begin{pmatrix} 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix} \tag{28}$$

For the first simulation, the initial factor endowments are arbitrarily given, with the corresponding vectors of the values of $k_{i,0}$ and $h_{i,0}$ equalling:

$$\mathbf{k}_0^{'} = \begin{pmatrix} 10 & 9 & 5 & 8 & 9 & 7.5 & 8.5 & 7 & 8 & 7.5 & 5 & 4 \end{pmatrix}$$

$$\mathbf{h}_0^{'} = \begin{pmatrix} 7 & 6 & 5 & 4.5 & 5.5 & 4 & 5 & 3.5 & 5 & 4 & 3 & 1.5 \end{pmatrix}$$

As can be seen from Figure 5, disparities regarding output reduce during the first 60 periods. Although overall σ-convergence applies during these first 60 periods, a closer look also reveals that some regions do not converge to the mean but rather diverge: E and I move upwards, while D moves downwards. From $t = 61$ onwards, variance increases. Put differently, the observation of σ-convergence during the first 60 periods is deceptive for two reasons: Firstly, some regions diverge during this period despite global convergence. Secondly, others are caught in a downward spiral, i.e. their continuous shrinking (in efficiency units) leads to a decreasing variance in the first 60 periods, while others rise, which leads to σ-divergence in the medium run.

Figure 5. First simulation of the model, 200 periods

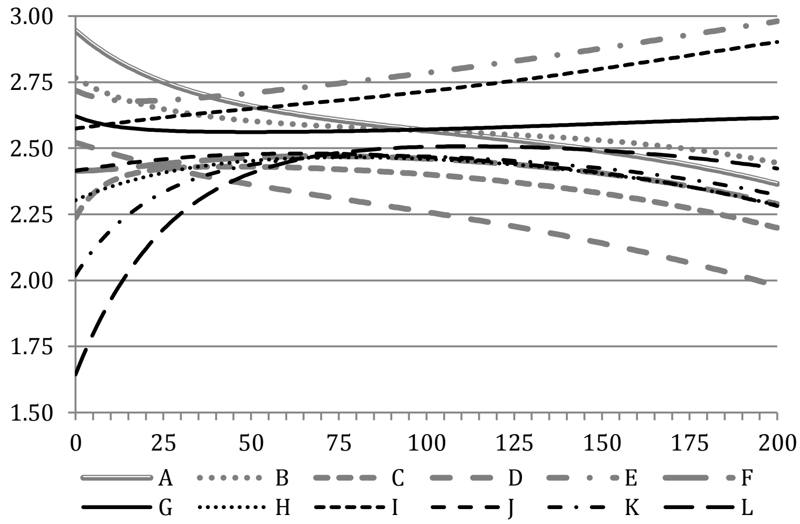
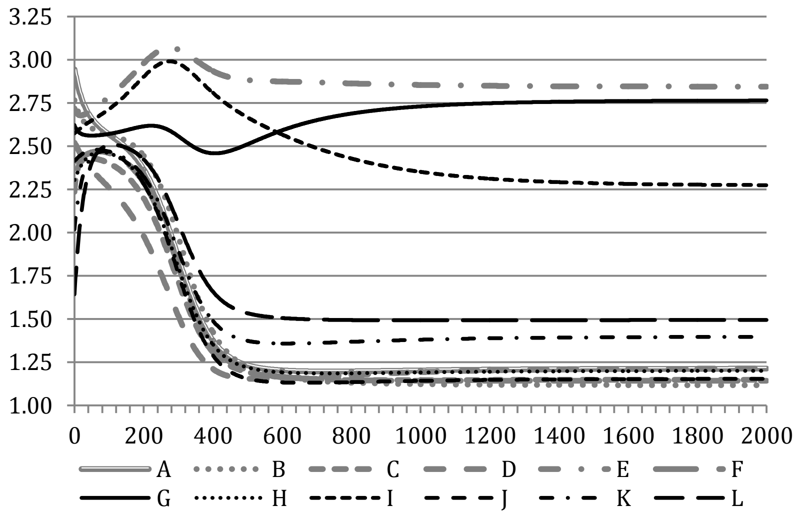


Figure 6 displays the development for the same scenario over 2,000 periods. It can be seen that after many position changes and periods of σ-convergence as well as σ-divergence, all regions eventually converge to their individual balanced growth paths. Three regions are found clearly above the mean, while the others are below, some of which display similar output levels. Therefore, in the long run, growth rates converge, but output levels differ substantially. In addition, during certain periods some groups of regions may converge, while others diverge. This issue of simultaneous convergence and divergence may, as in Figures 5 and 6, depend on the current output level, an issue which has recently been taken up by Monastiriotis (2014). However, occurrences of convergence of some regions do not lead to convergence clubs of the same regions, as they may overpass each other in the long run.

Figure 6. First simulation of the model, 2,000 periods



In the second simulation, displayed in Figure 7, all regions start out with identical initial factor endowments of $k_0 = 5$ and $h_{i,0} = 3$. With factor endowments and hence output and wages being identical in each region, there is no incentive for factor relocations, and each region converges to the levels that would prevail in the case of closed economies.[4] However, this is an unstable equilibrium: At $t = 200$, region B exogenously receives 0.1 extra units of h, which has a devastating effect to the system. This small deviation initiates large factor relocations, from which region B benefits the most. At $t = 876$, region B has accumulated a human capital stock of $h_{B,876} = 11.29$, which is four times higher than the mean $\bar{h}_{876} = 2.82$. Five periods later, B's output level has reached its maximum $q_{B,881} = 3.27$. After that, B's level shrinks slightly but remains way above the other regions.

[4] The corresponding steady states are identical to the ones in the model by Mankiw et al. (1992).

Figure 7. Second simulation of the model, 2,000 periods

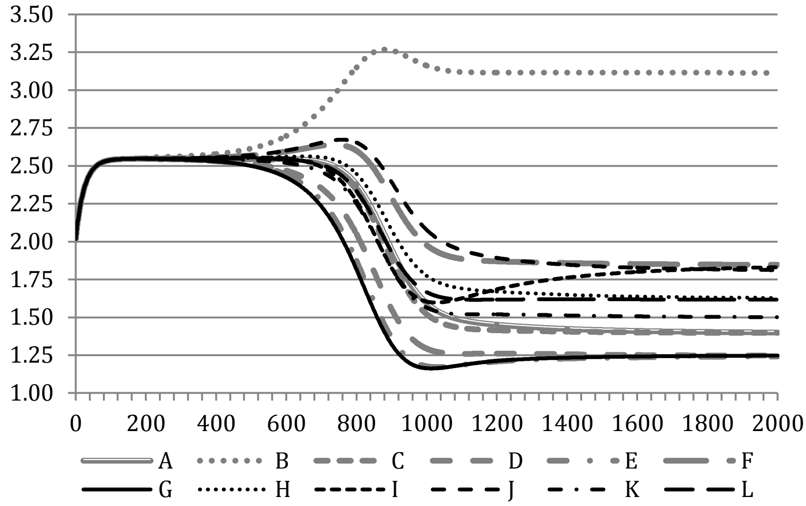


Figure 8. Third simulation of the model, 2,000 periods

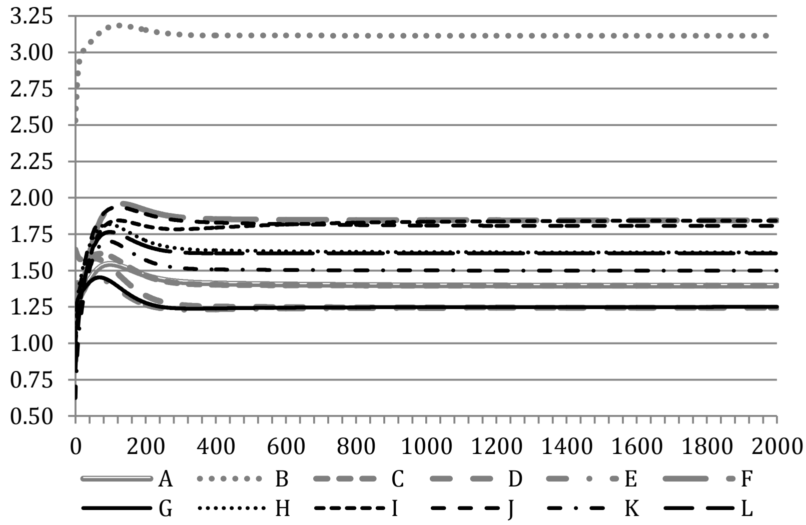


Figure 8 illustrates a third simulation, representing a scenario in which region B starts out with more human capital than the sum of all other regions, while other values are relatively small and similar across the regions:

$$\mathbf{k}_0' = \begin{pmatrix} 2 & 3 & 4 & 1.5 & 0.5 & 3 & 2 & 1 & 1 & 0.75 & 0.25 & 0.5 \end{pmatrix}$$
$$\mathbf{h}_0' = \begin{pmatrix} 1 & 20 & 1.5 & 2 & 1.5 & 0.5 & 1 & 1.5 & 1 & 1 & 0.75 & 1 \end{pmatrix}$$

In this case, B's human capital level immediately starts to fall due to depreciation. However, the high human capital level attracts physical capital investments, and its output increases until B has reached its highest level with $q_{B,124}$ = 3.18. 15 periods later, B's physical capital endowment has reached its peak with $q_{B,139}$ = 9.97. Although both decline slightly afterwards, B remains the most productive region by far and in that sense the system's core. In Figure 8, it is also interesting to note that during the first 50 periods of high growth rates, variance decreases, i.e. times of prosperity coincide with σ-convergence.

4. EMPIRICS

4.1. Spatial Econometric Specifications, Regions and Data

LeSage (2014) distinguishes between local and global spillover specifications, where local spillovers refer to interaction effects between pairs of spatial units. From this perspective, effects on growth as in eqs. (18) to (21) capture *local* effects. Furthermore, from eqs. (18) to (21) it follows that human capital within region i has a positive effect on i's economic growth, while human capital levels in regions which are neighbours to i have a negative effect. Regarding output levels, it follows that the effect of the current output level in region i on its neighbours depends on how far away these levels are from steady states, in addition to the interplay with other factors. In order to test these medium run predictions, a specification is needed which includes spatial effects of the explanatory variables:

$$\left(\mathbf{q_T}-\mathbf{q_0}\right)/T = \alpha\boldsymbol{\iota} + \beta_1\mathbf{q_0} + \gamma_1\mathbf{h_0} + \beta_2\mathbf{W}\mathbf{q_0} + \gamma_2\mathbf{W}\mathbf{h_0} + \mathbf{u} \tag{29}$$

where $\mathbf{q}$ and $\mathbf{h}$ are $N\times 1$ vectors which contain the natural logarithms of output and human capital levels per labour unit, respectively, with 0 symbolising the observation period's initial year and T representing the number of years. $\mathbf{W}$ is an $N\times N$ matrix that captures connectivities between all regions via its elements w_{ij}, and $\boldsymbol{\iota}$ is an $N\times 1$ vector of ones. $\mathbf{u}$ is an $N\times 1$ vector of residuals.

A regression specification as in eq. (29) is referred to in the spatial econometrics literature (e.g. LeSage and Fischer 2008, LeSage and Pace 2009) as a spatial lag of X model (SLXM). It contains a home region's as well as its neighbours' characteristics. From eqs. (18) and (19) it is expected that $\gamma_1 > 0$ and $\gamma_2 < 0$, while eqs. (20) and (21) display how β_1 depends on the state of the system while it is expected that $\beta_2 > 0$ as discussed above. Furthermore, if the system experiences no recession then α should be positive as it captures global economic growth. A restricted regression of eq. (29) which tests for $\beta_1 = -\beta_2$ and $\gamma_1 = -\gamma_2$ takes the form

$$\left(\mathbf{q_T}-\mathbf{q_0}\right)/T = \alpha\boldsymbol{\iota} + \beta\left(\mathbf{q_0}-\mathbf{W}\mathbf{q_0}\right) + \gamma\left(\mathbf{h_0}-\mathbf{W}\mathbf{h_0}\right) + \mathbf{u} \tag{30}$$

where the coefficients β and γ reveal whether within-region effects and neighbouring effects outweigh each other.

With the theoretical model assuming the same quality of institutions and equal access to technology within the European Union, respective differences may diminish over time but are probably still present. Furthermore, relative similarities regarding these and other differences may be spatially lagged and be captured by spatial autocorrelation of the residuals as measured by Moran's I (see Goodchild 1986), which takes on values between -1 and 1:

$$I = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}\left(u_i - \bar{u}\right)\left(u_j - \bar{u}\right)}{\sum_{i=1}^{N}\left(u_i - \bar{u}\right)^2} \tag{31}$$

Concerning the model's long run predictions, from eq. (23) it follows that region i's steady state output level is dependent on the respective levels in neighbouring regions as well as human capital levels in i and its neighbouring regions. In the sense of LeSage (2014) in this case *global* spillovers apply, as they refer to a scenario where changes in one spatial unit set in motion a sequence of adjustments in (potentially) all spatial units such that a new long run steady state equilibrium arises. From eqs. (25), (26) and (27) it is expected that all of these effects are positive. Therefore, the econometric specification where the dependent variable is output *level* has the form

$$\mathbf{q_t} = \rho\mathbf{W}\mathbf{q_t} + \alpha\boldsymbol{\iota} + \mu_1\mathbf{h_t} + \mu_2\mathbf{W}\mathbf{h_t} + \mathbf{u} \tag{32}$$

An econometric specification as in eq. (32) is referred to in the literature as a spatial Durbin model (SDM) (e.g. LeSage and Fischer 2008, LeSage and Pace 2009). In contrast to the SLXM, the SDM's coefficients are not identical to the partial derivatives of the dependent variable. Rather, a change in the explanatory variable for a single region can potentially affect the dependent variable in all other regions. This can be seen by expressing eq. (32) as:

$$\mathbf{q_t} = \left(\mathbf{I_N} - \rho\mathbf{W}\right)^{-1}\left(\mu_1\mathbf{I_N} + \mu_2\mathbf{W}\right)\mathbf{h_t} + \left(\mathbf{I_N} - \rho\mathbf{W}\right)^{-1}\alpha\boldsymbol{\iota} + \left(\mathbf{I_N} - \rho\mathbf{W}\right)^{-1}\mathbf{u}$$

where $\mathbf{I_N}$ represents an $N \times N$ identity matrix. As shown by LeSage and Pace (2009), the derivative of $q_{i,t}$ with respect to $h_{j,t}$ is potentially non-zero and determined by the element in row i, column j of the matrix $\left(\mu_1\mathbf{I_N} + \mu_2\mathbf{W}\right)$. From this it follows that a change in the explanatory variable for a single region can potentially affect the dependent variable in all other regions (LeSage and Pace 2009, pp. 35).

The interpretation of the parameters therefore differs from linear regressions and becomes more complicated. The present paper follows LeSage and Pace (2009) in estimating direct, indirect and total impacts in order to draw inference from the regression results. Firstly, the average direct impacts capture the effect of a change in $h_{i,t}$ on $q_{i,t}$ and includes feedback influences that arise from the fact that $\left(\mathbf{I_N} - \rho\mathbf{W}\right)^{-1} = \mathbf{I_N} + \rho\mathbf{W} + \rho^2\mathbf{W}^2 + \rho^3\mathbf{W}^3 + \ldots$, i.e. impacts passing through neighbouring regions and back to region i. This effect corresponds to eq. (25), where a positive value implies a positive impact of an increase in i's human capital stock on i 's equilibrium output level. Secondly, the average indirect impacts capture the effect of a change in $h_{j,t}$ by the same amount across all regions on $q_{i,t}$ and thus capture the impact of an increase in human capital within the neighbours of region i on the latter. This effect corresponds to the sum for all regions $j \neq i$ in eq. (26), i.e. $\sum_{i \neq j}^{N} \partial q_i^* \Big/ \partial h_j^*$, where a positive value implies a positive effect of an increase in the human capital stocks of i 's neighbours on i 's equilibrium output. Thirdly, the average total impacts capture the effect of a change of h_t in the j th region over all $q_{i,t}$, i.e. direct plus indirect effects. A positive value implies that an increase of human capital stocks in the whole systems increases total equilibrium output.

The model is tested for 250 European Union's regions on the NUTS2[5] level for the years 2000-2013, based on ESA10.[6] Although actual population sizes are not identical, they are comparable as most NUTS2 regions' population sizes lie between the official population thresholds of 800,000 and 3,000,000 (European Parliament and Council of the European Union 2003, Article 3) Output per labour unit is measured by GRP at current market prices in euros per inhabitant.[7] Human capital is estimated by the percentage of inhabitants with tertiary education to the number of gainfully active persons. The source of all data is Eurostat.

Distances between regions are taken by car travel times between NUTS2 regions as calculated by Schürmann and Talaat (2000). Results in this paper are based on the concept of two regions as being considered as neighbours if the distance between them lies below a *critical cut-off* value, with

$$\begin{cases} w_{ij}^* = 0 \text{ if } i = j \\ w_{ij}^* = 1 \text{ if } \delta_{ij} \leq \delta^* \\ w_{ij}^* = 0 \text{ if } \delta_{ij} > \delta^* \end{cases}$$

where δ_{ij} equals the distance between two regions i and j in time units and δ^* is a pre-defined critical cut-off distance. If a region happens to have no neighbour for whom $\delta_{ij} \leq \delta^*$ applies, then the closest region is considered to be

[5] The study covers the European territory of the EU on the NUTS2 level. Due to lack of data, the classification used in this study deviates from the official classification as of December 2011 in the following cases: Croatia, Cyprus, Estonia, Latvia, Lithuania, Luxemburg, and Malta are not included; the NUTS2 regions Brandenburg-Nordost and Brandenburg-Südwest as well as the NUTS2 regions of Denmark and Slovenia have been merged to one region, respectively. By focussing on Europe, the study excludes the French regions Guadeloupe, Martinique, Guyana and Réunion, the Portuguese regions Região Autónoma dos Açores and Região Autónoma da Madeira, and the Spanish regions Ciudad Autónoma de Ceuta, Ciudad Autónoma de Melilla and Canarias.

[6] In cases of missing data on the NUTS2 level, growth rates for the respective periods of the superordinate NUTS1 regions are assumed for their corresponding NUTS2 regions.

[7] It does no harm to rely on nominal values as relative growth rates are studied (see Sardadvar (2011, Chapter 9) for a discussion).

the sole neighbour. The i th row and j th column of $\mathbf{W}$ consists of the element $w_{ij} = \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}^{*}$, i.e. the spatial weights matrix is standardised so that both the average row and the average column sums equal one.

Note that the spatial weights matrix as specified here is neither row- nor column-standardised. Rather, regions which happen to lie more centrally located display higher row sums as compared to peripheral regions. This way, one of the basic characteristics of the capital accumulation functions – centrally located regions being more exposed to influences of other regions – is reflected by the empirical specification.

For instance, if δ^{*} = 3 h, then the applied travel time distances correspond to 1,738 neighbourhoods within all 250 regions. Standardisation in this case leads to each non-zero element of $\mathbf{W}$ equalling 0.1438, which is also necessarily equal to the row sums of those regions which have only one neighbour assigned to. Regions with exactly two neighbours have row sums of 0.2877, regions with three neighbours have row sums of 0.4315 and so on.[8] In the case of δ^{*} = 4 h, $\mathbf{W}$ has 2,973 non-zero elements, equalling 0.0841 each.[9] From this it also follows that a greater cut-off distance reduces the impact of individual regions classified as neighbours. In contrast, the average total impact a region is exposed to remains unchanged, as the average row-sum across all regions equals one as discussed above.

4.2. Results

Before estimating the regressions, it may be helpful calculating the variances of the natural logarithms of GRP per capita, i.e. testing for what is referred to in the literature as σ-convergence (see Sala-i-Martin 1996). Figure 9 displays the observation area's corresponding values for each year. It is striking to see that until the outbreak of the recession in 2008, the variance shows a clear downward trend. Since then, it stagnates.

The regression estimations which correspond to eq. (29) are displayed in Tables 1 and 2 for δ^{*} = 3 h and δ^{*} = 4 h, respectively. The results are given for the whole observation period 2000-2013, for the period before the outbreak of the recession 2000-2008, and for the period afterwards 2008-2013. Additional results for δ^{*} = 2 h and δ^{*} = 5 h can be found in Tables 5 and 6 in the Appendix.

It can be seen that the results for 2000-2013 clearly support the model's predictions: Within one region, initial output, β_1, is negative, while human capital, γ_1, is positive, with the respective values for neighbouring regions, β_2 and γ_2,

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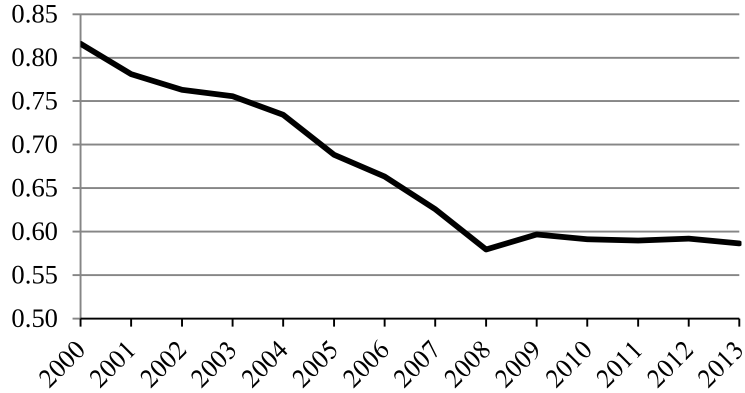
[8] The regions with most neighbours in the case of $\delta^{*} = 3$ h is Düsseldorf (NUTS code: DEA1) with 26 neighbours and a row sum of 3.7399, closely followed by North Brabant (NL41) and Limburg (NL42) with 25 neighbours each and corresponding row sums of 3.5961.

[9] With $\delta^{*} = 4$ h Düsseldorf remains the most central region with 40 neighbours and a row sum of 3.3636, this time closely followed by Cologne (DEA2) and Münster (DEA5) with 39 neighbours each and corresponding row sums of 3.2795.

displaying contrasting signs. Spatial autocorrelation of the residuals is positive and significant in both cases, but the values are remarkably low, especially for 2000-2013 with $\delta^* = 4$ h. The restricted regression corresponds to eq. (30) and displays a total negative impact of initial output, β, and a total positive impact of initial human capital, γ. However, the likelihood ratio test rejects the restricted regression.

Figure 9. Variance of the natural logarithms of GRP per inhabitant, 2000-2013



When looking at the results for 2000-2008 and 2008-2013, it can be seen that the value of β_1 is about three times as large before as after the crises. This might be interpreted as a decrease in the speed of convergence, as a negative value of β_1 is usually interpreted as evidence for β-convergence as defined by Sala-i-Martin (1996). However, as displayed in Fig. 9, σ-convergence during the same period does not apply. It is also interesting to note that for 2008-2013 statistical explanation power is lowest, the spatial autocorrelation of the residuals is highest and the likelihood ratio test does not reject the restricted version.

Therefore, although a negative value of β_1 implies a corresponding effect of high initial output on growth, it does not necessarily imply convergence of GRP levels. As shown by the model, a region rich in physical capital is able to remain attractive to new investments as well as human capital suppliers by simultaneously displaying high human capital levels. This interpretation is supported by the unambiguously positive effects of human capital endowments within one region, as displayed by γ_1, and output in neighbouring regions, as displayed by β_2. The strong negative impact of human capital in neighbouring regions, γ_2, confirms eq. (18) and has also been found in a number of empirical studies (among them Olejnik 2008, Ramos et al. 2010, Fischer et al. 2010, Resende et al. 2013). Taken together, the estimations underline that a negative impact of initial output on growth is not necessarily an evidence for convergence, as it is more than outweighed by human capital endowments within one region as well as in neighbouring regions.

Table 1: SLXM estimations with 3 hours travel time as threshold distance

	without dummy			including NMS dummy		
	2000-2013	**2000-2008**	**2008-2013**	**2000-2013**	**2000-2008**	**2008-2013**
α	0.275 (0.000)	0.431 (0.000)	-0.014 (0.609)	0.188 (0.000)	0.367 (0.000)	-0.122 (0.015)
β_1	-0.031 (0.000)	-0.045 (0.000)	-0.015 (0.000)	-0.022 (0.000)	-0.038 (0.000)	-0.003 (0.489)
γ_1	0.019 (0.000)	0.018 (0.001)	0.021 (0.000)	0.016 (0.000)	0.016 (0.002)	0.020 (0.000)
β_2	0.012 (0.000)	0.015 (0.000)	0.020 (0.000)	0.010 (0.000)	0.014 (0.000)	0.019 (0.000)
γ_2	-0.039 (0.000)	-0.049 (0.000)	-0.025 (0.000)	-0.033 (0.000)	-0.044 (0.000)	-0.024 (0.000)
NMS	—	—	—	0.019 (0.011)	0.014 (0.256)	0.019 (0.003)
σ^2	0.012	0.018	0.019	0.012	0.018	0.019
R^2	0.750	0.772	0.110	0.771	0.777	0.153
LIK	752.31	652.35	633.89	764.09	655.19	640.58
AIC	-1,492.61	-1,292.69	-1,255.78	-1,514.18	-1,296.37	-1,267.17
F-stat	187.3 (0.000)	212.2 (0.000)	8.714 (0.000)	168.8 (0.000)	174.0 (0.000)	10.01 (0.000)
M's I	0.141 (0.000)	0.187 (0.000)	0.290 (0.000)	0.155 (0.000)	0.194 (0.000)	0.313 (0.000)
			restricted regression			
α	0.031 (0.000)	0.048 (0.000)	0.002 (0.161)	0.021 (0.000)	0.033 (0.000)	0.001 (0.674)
β	-0.005 (0.002)	-0.004 (0.114)	-0.015 (0.000)	-0.003 (0.000)	-0.002 (0.200)	-0.012 (0.002)
γ	0.0189 (0.001)	0.018 (0.040)	0.019 (0.000)	0.012 (0.000)	0.007 (0.097)	0.015 (0.003)
NMS	—	—	—	0.048 (0.000)	0.072 (0.000)	0.007 (0.042)
LR-t	319.71 (0.000)	339.23 (0.000)	1.46 (0.482)	69.67 (0.000)	103.92 (0.000)	11.48 (0.003)

Notes: The estimations have been carried out with *R* using the *spdep* and *sandwich* packages. *p*-values of the heteroscedasticity-consistent standard errors are given in parentheses for the regression coefficients. σ^2 is the residual variance, R^2 refers to adjusted values. *LIK* and *AIC* are the maximised log-likelihood and the Akaike information criterion, respectively. *F-stats* refers to the *F*-statistic with the *p*-values given in parentheses. *M's I* is the Moran's *I* of the residuals, where the *p*-values are based on 10,000 sampled raw parameter estimates. *LR-t* is the χ^2 value of the likelihood ratio test, with the *p*-value for rejecting the restricted regression given in parentheses.

Table 2: SLXM estimations with 4 hours travel time as threshold distance

	without dummy			including NMS dummy		
	2000-2013	**2000-2008**	**2008-2013**	**2000-2013**	**2000-2008**	**2008-2013**
α	0.275 (0.000)	0.428 (0.000)	-0.006 (0.817)	0.195 (0.000)	0.370 (0.000)	-0.116 (0.018)
β_1	-0.032 (0.000)	-0.046 (0.000)	-0.015 (0.000)	-0.024 (0.000)	-0.040 (0.000)	-0.004 (0.420)
γ_1	0.022 (0.000)	0.022 (0.000)	0.020 (0.000)	0.019 (0.000)	0.020 (0.001)	0.020 (0.000)
β_2	0.015 (0.000)	0.018 (0.000)	0.020 (0.000)	0.013 (0.000)	0.017 (0.000)	0.018 (0.000)
γ_2	-0.047 (0.000)	-0.059 (0.000)	-0.025 (0.000)	-0.041 (0.000)	-0.055 (0.000)	-0.023 (0.001)
NMS	—	—	—	0.018 (0.015)	0.013 (0.306)	0.019 (0.002)
σ^2	0.012	0.017	0.019	0.011	0.017	0.019
R^2	0.768	0.785	0.131	0.786	0.788	0.175
LIK	761.77	659.36	636.82	772.70	661.82	643.90
AIC	-1,511.54	-1,306.71	-1,261.63	-1,531.39	-1,309.65	-1,273.81
F-stat	206.8 (0.000)	227.9 (0.000)	10.37 (0.000)	184.3 (0.000)	186.2 (0.000)	11.59 (0.000)
M's I	0.073 (0.005)	0.113 (0.001)	0.233 (0.000)	0.077 (0.004)	0.120 (0.001)	0.236 (0.000)
			restricted regression			
α	0.031 (0.000)	0.048 (0.000)	0.002 (0.234)	0.021 (0.000)	0.033 (0.000)	0.000 (0.891)
β	-0.006 (0.001)	-0.004 (0.084)	-0.015 (0.000)	-0.004 (0.000)	-0.002 (0.154)	-0.011 (0.003)
γ	0.020 (0.000)	0.020 (0.023)	0.019 (0.000)	0.013 (0.000)	0.009 (0.068)	0.014 (0.005)
NMS	—	—	—	0.048 (0.000)	0.071 (0.000)	0.008 (0.016)
LR-t	336.49 (0.000)	348.14 (0.000)	0.77 (0.679)	84.69 (0.000)	114.13 (0.000)	10.01 (0.007)

Notes: See Table 1.

Table 3: SDM estimations with 3 hours travel time as threshold distance

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
α	0.767	-0.050	0.085	0.026	-0.059	0.108	0.114	0.385	0.641	0.623	0.605	0.583	0.510	0.582
	(0.000)	(0.872)	(0.788)	(0.935)	(0.858)	(0.747)	(0.748)	(0.286)	(0.095)	(0.104)	(0.116)	(0.127)	(0.199)	(0.146)
μ_1	0.647	0.629	0.656	0.676	0.706	0.762	0.729	0.752	0.794	0.807	0.847	0.889	0.901	0.909
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
μ_1	-0.458	-0.462	-0.502	-0.527	-0.543	-0.611	-0.560	-0.600	-0.655	-0.686	-0.722	-0.773	-0.762	-0.783
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Direct	0.713	0.691	0.701	0.726	0.763	0.802	0.771	0.775	0.797	0.804	0.842	0.878	0.896	0.900
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Indirect	0.663	0.643	0.477	0.510	0.588	0.374	0.418	0.209	0.013	-0.021	-0.056	-0.101	-0.031	-0.092
	(0.019)	(0.030)	(0.118)	(0.127)	(0.063)	(0.211)	(0.167)	(0.435)	(0.960)	(0.941)	(0.834)	(0.727)	(0.913)	(0.752)
Total	1.376	1.335	1.178	1.235	1.351	1.176	1.189	0.983	0.810	0.783	0.785	0.777	0.865	0.808
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.005)	(0.016)	(0.011)	(0.019)	(0.008)	(0.016)
ρ	0.862	0.874	0.871	0.880	0.878	0.870	0.856	0.843	0.827	0.842	0.841	0.850	0.839	0.842
	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
σ^2	0.077	0.066	0.064	0.056	0.054	0.052	0.053	0.053	0.055	0.054	0.052	0.049	0.050	0.048
LIK	-71.97	-54.99	-50.25	-35.33	-28.85	-22.86	-23.27	-22.77	-23.40	-24.35	-20.03	-13.11	-14.72	-10.43
BP	11.914	8.947	7.291	4.501	3.471	1.769	1.648	1.789	3.544	4.616	3.636	2.414	2.718	0.362
	(0.003)	(0.011)	(0.026)	(0.105)	(0.176)	(0.413)	(0.439)	(0.409)	(0.170)	(0.162)	(0.162)	(0.299)	(0.257)	(0.835)
Wald	1887.6	2286.8	2164.9	2536.0	2446.1	2145.7	1741.5	1434.4	1165.2	1407.5	1403.1	1580.6	1358.6	1413.3
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: The estimations have been carried out with *R* using the *spdep* package. *p*-values of the regression coefficients are given in parentheses. σ^2 is the residual variance, *LIK* refers to the value of the maximised log-likelihood value. 'Direct', 'indirect' and 'total' refer to the impacts of an increase of the spatially lagged variable as discussed by LeSage and Pace (2009), with the corresponding *p*-values in parentheses being based on 1,000 sampled raw parameter estimates. *BP* refers to the spatially adjusted version of the Breusch-Pagan test for heteroskedasticity, using studentised values (see Anselin 1988), *Wald* is the square of the asymptotic standard error.

Table 4: SDM estimations with 4 hours travel time as threshold distance

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
α	0.534	-0.304	-0.185	-0.200	-0.269	-0.041	-0.103	0.126	0.387	0.420	0.335	0.356	0.312	0.417
	(0.002)	(0.352)	(0.576)	(0.549)	(0.443)	(0.908)	(0.785)	(0.743)	(0.343)	(0.298)	(0.407)	(0.378)	(0.461)	(0.333)
μ_1	0.601	0.579	0.599	0.628	0.662	0.718	0.676	0.688	0.737	0.759	0.789	0.840	0.848	0.860
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
μ_1	-0.416	-0.411	-0.445	-0.479	-0.501	-0.579	-0.516	-0.535	-0.600	-0.652	-0.670	-0.731	-0.719	-0.747
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Direct	0.667	0.646	0.656	0.682	0.723	0.755	0.720	0.723	0.751	0.765	0.796	0.842	0.857	0.860
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Indirect	0.983	1.020	0.858	0.837	0.888	0.572	0.668	0.467	0.198	0.089	0.117	0.047	0.103	0.031
	(0.010)	(0.012)	(0.047)	(0.061)	(0.045)	(0.186)	(0.096)	(0.208)	(0.564)	(0.815)	(0.768)	(0.907)	(0.788)	(0.939)
Total	1.650	1.666	1.514	1.519	1.611	1.327	1.389	1.190	0.950	0.854	0.912	0.889	0.960	0.891
	(0.000)	(0.000)	(0.001)	(0.002)	(0.001)	(0.005)	(0.002)	(0.003)	(0.012)	(0.035)	(0.035)	(0.043)	(0.023)	(0.042)
ρ	0.887	0.899	0.898	0.904	0.901	0.895	0.885	0.868	0.854	0.874	0.872	0.878	0.867	0.868
	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
σ^2	0.078	0.067	0.064	0.058	0.055	0.053	0.053	0.055	0.056	0.054	0.053	0.051	0.052	0.051
LIK	-67.06	-48.22	-42.38	-31.49	-24.67	-18.65	-17.95	-21.01	-21.02	-19.23	-16.64	-11.25	-13.77	-10.85
BP	9.783	5.807	4.182	2.622	2.074	1.008	0.617	0.633	1.002	2.450	2.317	2.083	2.990	1.291
	(0.008)	(0.055)	(0.124)	(0.270)	(0.355)	(0.604)	(0.734)	(0.729)	(0.606)	(0.294)	(0.314)	(0.353)	(0.224)	(0.525)
Wald	2010.8	2520.0	2493.5	2782.2	2645.2	2323.2	1936.7	1455.4	1178.8	1578.2	1546.3	1698.6	1418.5	1437.2
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: See Table 3.

In order to control for a catching-up of the formerly centrally planned economies – which may be due to technology and/or a convergence to their own steady states as discussed in the Introduction – the estimations are run again by inclusion of a dummy control variable for those regions that accessed the EU in 2004 or 2007 ('new member states', NMS). The results can be found in the corresponding columns in Tables 1 and 2. It can be seen that while the NMS coefficients as such have positive signs, the values of β_1 decrease. Furthermore and perhaps most strikingly, β_1 becomes statistically non-significant for 2008-2013. In contrast, γ_2 remains negative and highly significant in each case. It should also be mentioned that the NMS coefficients are statistically not significant at the ten per cent level for 2000-2008 in the unrestricted specification, while the inclusion of the NMS dummy leads to a rejection of the restricted specification in each case.

The SDM specification estimations which correspond to eq. (32) are displayed in Tables 3 and 4 for $\delta^* = 3\text{ h}$ and $\delta^* = 4\text{ h}$, respectively. As with the SLXM estimations, additional results for $\delta^* = 2\text{ h}$ and $\delta^* = 5\text{ h}$ can be found in Tables 7 and 8 in the Appendix. Results are given for each year of the observation period. α, μ_1, μ_2 and ρ are the coefficients for the intercept, human capital in i, human capital in i's neighbours as well as output in i's neighbours, respectively. 'Direct', 'indirect' and 'total' are the respective impacts of human capital as discussed in the previous section.

The direct impacts are positive for each year in each case, i.e. an increase in the human capital stock within one region has a positive effect on output levels. Total impacts are – as expected – also positive, but they decrease over time. Indirect impacts are initially positive, but around 2007/2008 they start to decrease in values with their *p*-values increasing at the same time. This development continues until the end of the observation period.

An intercept is included in the regressions for control reasons but is non-significant for each year starting with 2001. Output in neighbouring regions, ρ, has a positive effect on i's output. Therefore, all of these results confirm the predictions of eqs. (25), (26) and (27) except for the vanishing indirect impacts of human capital. In general, the results in Tables 3 and 4 are very similar although explanatory power is slightly higher for $\delta^* = 4\text{ h}$.

One particular aspect of the theoretical model relates to vertical integration (as captured by λ) as well as horizontal integration (as captured by the w_{ij} terms). As illustrated by simulation results, if variables change, then the system inevitably moves towards a new steady state. What is hence of particular interest when examining the SDM estimations is their development over time. Although steady states are a theoretical concept and cannot be measured in the real world, changes in the variables' impacts hint at equilibrium level changes. In this respect, the SDM estimations display that the influence of human capital in neighbouring regions on output level loses its statistical significance somewhere around 2006. Furthermore, the total impact of human capital on output levels starts to decrease in 2005. What is remarkable about these developments is that they begin clearly before the outbreak of the crises.

On the one hand, it is difficult to distinguish medium run effects as caused by the acts of vertical integration such as the introduction of the euro in 1999, horizontal integration such as the accession of the new member states in 2004 and 2007, the consequences of the crises that broke out in 2007/2008, and the recovery of transition-induced recession in the NMS that started around 1995. On the other hand, the present paper's regression estimations hint at decisive changes occurring before the current crises, hence the immediate halt of the convergence process as displayed in Figure 9 should be interpreted in this context. Taking everything together, the results indicate that the system of the European Union's regions moves towards a new equilibrium as a consequence of its recent integration processes.

5. CONCLUSIONS AND OUTLOOK

Only a handful of neoclassical growth models have so far studied interdependencies of regional economies by simultaneously considering the effects of space and time. In addition, neoclassical growth models have usually little to tell about the roles of historical coincidence, alternation of convergence and divergence trends, persisting core-periphery patterns, and human capital migration. Models of economic geography have been successful in explaining these phenomena in an environment with increasing returns to scale, of which the most influential model is Krugman's (1991a, 1991b) core-periphery model. However, this as well as its succeeding models are most often restricted to two regions, and growth is not modelled as such. The main objective of this paper was to incorporate the effects of factor relocations into a neoclassical growth model which is able to explain alternating convergence and divergence trends as well as persisting core-periphery patterns in a scenario with free factor movement, where the regional economies under consideration have access to the same technology and are big enough to display constant returns to scale.

The theoretical model assumes that human capital migration decisions depend on expected wages for human capital suppliers, while physical capital relocations depend on expected profits. Both types of movement are spatially bounded, and more centrally located regions are subject to greater dependence on circumstances in other regions. The model explains why regions with high initial levels of human capital are attractive for both human capital suppliers as well as investment flows. Furthermore, in the long run, the levels of wages for human capital suppliers are region-specific and consequently, the physical capital levels approach differing levels, too. Each region's steady state level is positively dependent on its neighbours' levels as well as on its own initial levels.

Simulation results illustrate that in the medium run, convergence and divergence may alternate until each region has reached its own steady state growth path. In the long run, therefore, disparities prevail, with similar levels across regions which are spatially close. It should also be stressed that during transition periods some groups of regions may converge, while others diverge.

A further aspect of the model relates to the indeterminateness of the eventual equilibrium, as exogenous events and shocks inevitably alter the relationships between the economies. For instance, if a region – for whatever reason – is confronted with a sudden change in the endowments in one or more factors, its relative position to other regions will change. Since all regions are connected to each other, this will have an effect on future factor movements and steady state equilibrium. The latter aspect is of particular importance when studying the developments within the European Union, which is characterised by continuously changing framework conditions while expanding its territory. For this reason, the empirical part of the paper tests for economic growth as well as output levels for the observation period 2000-2013, a time which is characterised by the EU's eastern enlargements on the one hand, and the outbreak of the financial and euro crises on the other hand.

Spatial lag of X as well as spatial Durbin error model specifications for 250 regions are applied to confront the model with European data. The study area comprises the regions of the European Union on the NUTS2 level, the observation periods is split into 2000-2008, 2000-2008 and 2008-2013. The results confirm both the model's predictions regarding human capital, with positive effects within one region's borders, and negative effects in neighbouring regions. In contrast, initial output in neighbouring regions has a positive effect. Perhaps most importantly, the effect of initial output levels within regions is negative until 2008, but becomes statistically non-significant for the period 2008-2013. An accompanying display of the evolution of variance of output levels confirms this trend reversal.

Spatial Durbin model specifications are applied for each year during the observation period 2000-2013. As predicted by the model, the results show that neighbouring regions are expected to have similar levels. Furthermore, human capital endowments both within a region and in neighbouring regions have positive impacts, although the latter disappear somewhere around 2006. These results indicate the system of the European Union's regions may move towards a new equilibrium in the wake of its own integration processes.

The empirical record of interregional disparities within Europe over the past 120 years is one of persistent disparities, with strong spatial autocorrelation. The same economies which were highly developed back then are the most advanced today, and most of them are neighbours to each other. Within these economies, those which lie geographically closer to the economic core-regions are also more advanced. There is little evidence that the interlude during which some European economies were centrally planned had any effect on long run growth. Rather, it seems as if the years of high growth rates that followed the transition-induced recession are just a temporary phenomenon.

Only very few national economies have managed to catch up to the highest developed economies so far. It is remarkable that Asian economies such as Japan or the Republic of Korea were considerably regulated and closed during their catching-up processes, and with respect to investment and migration flows to a large extent still are. Within the European Union, the crises have hit the cohesion countries hardest, and the gap has widened again. For instance, Germany attracts immigrants from other member states, who are relatively highly qualified (Gathmann et al. 2014). Hence, peripheral countries and regions are losing human capital to the core, which may alleviate the burden of unemployment in the short-run, but hinder development in the long run.

Taking on a long run perspective, European economic history since industrialisation provides little evidence of long run convergence. Rather, historical coincidence and neighbourhood relations shape the spatial distribution of productivity and wealth down to the present day. This paper's theoretical model has incorporated these issues by showing how investment flows and the migration of skilled workers have the potential to stabilise or deepen existing disparities. Temporary convergence of some regions or the whole system may occur as the system moves towards a new equilibrium in the wake of parameter changes or external shocks.

The empirical section underlines the importance of human capital endowments and spatial locations. Furthermore, it is shown that the convergence process has come to a halt at around 2008. In this context, the present paper hypothesises that this trend reversal is only partly due to the current crises. Rather, more attention should be paid to changing interregional relations and dynamics in the wake of the European Union's own integration processes, as these are expected to have severe impacts on interregional growth rates and the persistence of disparities in the long run.

APPENDIX

Table 5: SLXM estimations with 2 hours travel time as threshold distance

	without dummy			including NMS dummy		
	2000-2013	**2000-2008**	**2008-2013**	**2000-2013**	**2000-2008**	**2008-2013**
α	0.270 (0.000)	0.432 (0.000)	-0.027 (0.340)	0.169 (0.000)	0.355 (0.000)	-0.139 (0.007)
β_1	-0.029 (0.000)	-0.044 (0.000)	-0.011 (0.003)	-0.018 (0.000)	-0.035 (0.000)	0.001 (0.839)
γ_1	0.013 (0.000)	0.011 (0.016)	0.018 (0.002)	0.011 (0.000)	0.010 (0.028)	0.016 (0.004)
β_2	0.008 (0.000)	0.012 (0.000)	0.013 (0.020)	0.006 (0.000)	0.011 (0.000)	0.010 (0.071)
γ_2	-0.024 (0.000)	-0.036 (0.000)	-0.016 (0.022)	-0.020 (0.000)	-0.033 (0.000)	-0.013 (0.075)
NMS	—	—	—	0.023 (0.002)	0.018 (0.147)	0.020 (0.003)
σ^2	0.013	0.018	0.020	0.012	0.018	0.019
R^2	0.717	0.761	0.052	0.749	0.768	0.098
LIK	736.88	646.12	625.99	752.76	650.38	632.75
AIC	-1,461.76	-1,280.23	-1,239.98	-1,491.53	-1,286.76	-1,251.51
F-stat	158.4 (0.000)	198.9 (0.000)	4.429 (0.002)	149.9 (0.000)	165.6 (0.000)	6.438 (0.000)
M's I	0.346 (0.000)	0.344 (0.000)	0.389 (0.000)	0.364 (0.000)	0.347 (0.000)	0.418 (0.000)
			restricted regression			
α	0.032 (0.000)	0.049 (0.000)	0.003 (0.044)	0.021 (0.000)	0.033 (0.000)	0.001 (0.414)
β	-0.004 (0.006)	-0.004 (0.139)	-0.012 (0.001)	-0.003 (0.001)	-0.002 (0.210)	-0.009 (0.029)
γ	0.015 (0.003)	0.015 (0.064)	0.015 (0.001)	0.009 (0.001)	0.006 (0.139)	0.011 (0.035)
NMS	—	—	—	0.048 (0.000)	0.073 (0.000)	0.006 (0.047)
LR-t	295.71 (0.000)	337.13 (0.000)	0.99 (0.609)	52.02 (0.000)	101.33 (0.000)	11.47 (0.003)

Notes: See Table 1.

Table 6: SLXM estimations with 5 hours travel time as threshold distance

	without dummy			including NMS dummy		
	2000-2013	**2000-2008**	**2008-2013**	**2000-2013**	**2000-2008**	**2008-2013**
α	0.275 (0.000)	0.425 (0.000)	-0.001 (0.974)	0.199 (0.000)	0.367 (0.000)	-0.108 (0.031)
β_1	-0.033 (0.000)	-0.046 (0.000)	-0.016 (0.000)	-0.024 (0.000)	-0.040 (0.000)	-0.005 (0.310)
γ_1	0.022 (0.000)	0.022 (0.000)	0.020 (0.000)	0.020 (0.000)	0.020 (0.001)	0.019 (0.000)
β_2	0.015 (0.000)	0.020 (0.000)	0.020 (0.000)	0.015 (0.000)	0.018 (0.000)	0.019 (0.000)
γ_2	-0.052 (0.000)	-0.065 (0.000)	-0.025 (0.000)	-0.047 (0.000)	-0.060 (0.000)	-0.024 (0.001)
NMS	—	—	—	0.017 (0.017)	0.013 (0.305)	0.019 (0.003)
σ^2	0.011	0.017	0.019	0.011	0.017	0.018
R^2	0.781	0.788	0.159	0.798	0.791	0.201
LIK	768.99	661.18	640.87	779.47	663.66	647.83
AIC	-1,525.99	-1,310.36	-1,269.74	-1,544.93	-1,313.32	-1,281.65
F-stat	222.8 (0.000)	232.2 (0.000)	12.73 (0.000)	197.2 (0.000)	189.7 (0.000)	13.52 (0.000)
M's I	0.053 (0.011)	0.097 (0.000)	0.179 (0.000)	0.054 (0.006)	0.106 (0.000)	0.166 (0.000)
			restricted regression			
α	0.032 (0.000)	0.0481 (0.000)	0.001 (0.289)	0.021 (0.000)	0.033 (0.000)	0.000 (0.995)
β	-0.006 (0.001)	-0.004 (0.089)	-0.015 (0.000)	-0.004 (0.000)	-0.002 (0.181)	-0.012 (0.001)
γ	0.021 (0.000)	0.020 (0.023)	0.019 (0.000)	0.013 (0.000)	0.009 (0.080)	0.014 (0.003)
NMS	—	—	—	0.048 (0.000)	0.071 (0.000)	0.008 (0.012)
LR-t	352.65 (0.000)	352.66 (0.000)	0.66 (0.719)	97.77 (0.000)	117.44 (0.000)	8.97 (0.011)

Notes: See Table 1.

Table 7: SDM estimations with 2 hours travel time as threshold distance

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
α	1.179	-0.056	0.002	-0.064	-0.208	-0.066	0.014	0.300	0.590	0.563	0.546	0.486	0.350	0.459
	(0.000)	(0.863)	(0.995)	(0.839)	(0.529)	(0.844)	(0.969)	(0.400)	(0.117)	(0.138)	(0.153)	(0.196)	(0.371)	(0.251)
μ_1	0.656	0.655	0.689	0.714	0.751	0.799	0.781	0.798	0.827	0.839	0.871	0.898	0.916	0.917
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
μ_1	-0.383	-0.416	-0.452	-0.482	-0.495	-0.549	-0.524	-0.552	-0.593	-0.621	-0.652	-0.687	-0.672	-0.693
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Direct	0.751	0.747	0.772	0.801	0.847	0.875	0.855	0.844	0.849	0.855	0.883	0.910	0.940	0.930
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Indirect	0.575	0.556	0.507	0.520	0.575	0.438	0.433	0.268	0.126	0.098	0.080	0.073	0.144	0.074
	(0.002)	(0.004)	(0.006)	(0.010)	(0.003)	(0.019)	(0.023)	(0.128)	(0.431)	(0.569)	(0.644)	(0.684)	(0.408)	(0.680)
Total	1.327	1.303	1.279	1.320	1.421	1.313	1.288	1.112	0.976	0.952	0.962	0.983	1.084	1.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ρ	0.793	0.818	0.813	0.824	0.819	0.811	0.798	0.778	0.759	0.771	0.773	0.785	0.773	0.776
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
σ^2	0.090	0.073	0.070	0.061	0.058	0.055	0.056	0.057	0.058	0.059	0.057	0.053	0.054	0.053
LIK	-94.30	-73.47	-67.33	-52.44	-44.17	-37.28	-35.54	-34.50	-34.17	-38.53	-33.73	-26.85	-27.95	-25.65
BP	14.510	11.347	10.721	7.595	6.846	4.526	5.258	5.032	6.190	8.101	7.572	4.955	6.252	1.941
	(0.001)	(0.003)	(0.005)	(0.022)	(0.033)	(0.104)	(0.072)	(0.081)	(0.045)	(0.017)	(0.023)	(0.084)	(0.044)	(0.379)
Wald	1449.7	1948.2	1844.1	2114.8	1998.0	1790.4	1518.7	1217.1	989.4	1121.0	1147.1	1308.4	1141.2	1185.0
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: See Table 3.

Table 8: SDM estimations with 5 hours travel time as threshold distance

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
α	0.417	-0.481	-0.385	-0.383	-0.489	-0.287	-0.393	-0.182	0.049	0.216	0.197	0.189	0.121	0.239
	(0.020)	(0.173)	(0.275)	(0.290)	(0.197)	(0.456)	(0.327)	(0.651)	(0.907)	(0.609)	(0.641)	(0.653)	(0.784)	(0.602)
μ_1	0.553	0.539	0.559	0.588	0.618	0.651	0.605	0.603	0.642	0.699	0.735	0.781	0.786	0.789
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
μ_1	-0.359	-0.357	-0.389	-0.427	-0.441	-0.494	-0.421	-0.427	-0.484	-0.589	-0.621	-0.673	-0.654	-0.670
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Direct	0.621	0.608	0.618	0.650	0.684	0.701	0.662	0.646	0.671	0.717	0.750	0.793	0.803	0.799
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Indirect	1.260	1.354	1.209	1.210	1.303	0.967	1.126	0.816	0.560	0.301	0.258	0.227	0.341	0.230
	(0.013)	(0.014)	(0.023)	(0.034)	(0.022)	(0.075)	(0.026)	(0.074)	(0.196)	(0.555)	(0.582)	(0.653)	(0.467)	(0.642)
Total	1.881	1.962	1.827	1.860	1.986	1.669	1.788	1.462	1.232	1.018	1.008	1.020	1.144	1.029
	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)	(0.004)	(0.001)	(0.003)	(0.007)	(0.058)	(0.042)	(0.057)	(0.022)	(0.049)
ρ	0.896	0.907	0.906	0.912	0.911	0.905	0.895	0.881	0.872	0.891	0.890	0.895	0.883	0.880
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
σ^2	0.084	0.071	0.067	0.062	0.059	0.056	0.056	0.058	0.058	0.056	0.055	0.053	0.055	0.056
	(0.000)													
LIK	-69.68	-50.14	-42.25	-34.20	-26.59	-20.86	-18.92	-21.18	-19.78	-19.02	-16.04	-11.39	-16.37	-18.19
BP	15.394	9.832	8.308	5.667	4.640	7.582	7.221	8.178	7.280	8.637	8.124	10.156	8.320	7.205
	(0.000)	(0.007)	(0.016)	(0.059)	(0.098)	(0.023)	(0.027)	(0.017)	(0.026)	(0.013)	(0.017)	(0.006)	(0.016)	(0.027)
Wald	1918.2	2378.7	2362.3	2684.0	2600.9	2293.0	1877.7	1440.7	1218.2	1694.0	1677.6	1839.7	1459.3	1397.3
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: See Table 3.

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CROISSANCE ÉCONOMIQUE RÉGIONALE ET ÉTATS STATIONNAIRES AVEC DES FACTEURS DE PRODUCTION MOBILES : MODÈLE THÉORIQUE ET APPLICATION À L'EUROPE

Résumé - *L'article présente un modèle théorique spatial de croissance permettant d'étudier l'effet de la mobilité du capital physique et humain sur la croissance des économies ouvertes. Les résultats analytiques et les simulations montrent la manière dont le développement d'une économie est influencé par ses voisins, comment à moyen terme des processus de convergence et de divergence peuvent s'enchaîner et comment la migration interrégionale due aux différences de salaires entraîne un maintien des disparités à long terme. Sur le plan empirique, un modèle économétrique spatial est appliqué aux régions européennes (niveau NUTS2) sur la période 2000-2013. Les estimations soulignent le rôle de la localisation du capital humain et de son évolution.*

Mots-clés - THÉORIE DE LA CROISSANCE NÉOCLASSIQUE, CAPITAL HUMAIN, MIGRATION INTERRÉGIONALE, INTÉGRATION EUROPÉENNE, CONVERGENCE, DIVERGENCE