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Divergence - Is it Geography?*

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Abstract

This paper tests directly a geography and growth model using regional data for Europe, the US, and Japan during different time periods. We set up a standard geography and growth model with a poverty trap and derive a log-linearized growth equation that corresponds directly to a threshold regression technique in econometrics. In particular, we test whether regions with high population density (centers) grow faster and have a permanently higher per capita income than regions with low population density (peripheries). We find geography driven divergence for US states and European regions after 1980. Population density is superior in explaining divergence to initial income which the most important official EU eligibility criterium for regional aid is built on. Divergence is stronger on smaller regional units (NUTS3) than on larger ones (NUTS2). Thus, the wavelength of agglomeration forces seems to be rather small in Europe. Human capital and R&D are transmission channels of divergence processes. Human capital based poverty trap models are an alternative explanation for regional poverty traps.

JEL Classification: O41, R11, F12
Keywords: threshold estimation, economic geography, regional income convergence, poverty trap, regime shifts, bootstrap

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1 Introduction

This paper revisits the debate on conditional income convergence vs. club convergence of regions within countries in the light of economic geography.[1] Against this background our formost interest is to examine whether (endogenously determined) "peripheral" regions have been catching up or falling behind center regions.

These questions are at the heart of regional economic policies. For example, the main idea behind EU regional policies is one of "harmonious development" with the aim of "reducing disparities between the levels of development of the various regions", as laid out in Article 130a of the Treaty of the European Union. The justification for this is not only political, but also economic, since it is said that "the disequilibria indicate under-utilisation of human potential and an incapacity to take advantage of the economic opportunities that could be beneficial to the Union as a whole". This reflects an understanding of the regional growth process according to which some regions are trapped into lower development levels, out of which they cannot be lifted, when left to market forces alone. However, both the empirical evidence and the robustness of the underlying theoretical model substantiating this view are far from unequivocal.

For instance, a well-known implication of neoclassical growth theory is that per capita income approaches at a decreasing growth rate its long-run steady state level, whereby the latter may differ across countries, regions, or cities depending on a set of structural variables (Solow, 1956). Barro and Sala-i-Martin (1992) found comprehensive cross-section evidence for this hypothesis using country- and regional data of the US, Japan, and Europe. Glaeser, Sheinkman, and Shleifer (1996) argue that population growth should be used instead of income growth in regional growth regressions, because migrants arbitrage away income differences across regions, but not across countries. Based on their concept, they find evidence for population growth convergence of US-cities.

[1] For definitions of unconditional convergence, conditional convergence, and club convergence see Galor (1996).

Nevertheless, there is some theoretical and empirical work that does in principle support the EU commisions view (though without necessarily making a strong case for the effectiveness of EU regional policy). A large body of poverty trap models predict the emergence of convergence clubs: Starting from the same initial conditions and the same structure of the economy, some countries may become rich and others stay poor.[2] Durlauf and Johnson (1995), Quah (1996), Hansen (2000), and Easterly and Levine (2001) provide evidence for club convergence in cross-country datasets. On European regional level, de la Fuente and Vives (1995), Neven and Gouyette (1995), Esteban (2000), Quah (1997a,b), Marcet and Canova (1995), Canova (1999), Boldrin and Canova (2001) and Straubhaar (1999) find a process of convergence until 1980, and a stop of convergence or even an increase in divergence within the EU countries together with further convergence across the EU countries.[3]

One particular type of a poverty trap is a core-periphery pattern of economic activity - i.e. a spatial concentration of economic activity - that emerges in the presence of scale economies, imperfect competition, transport cost, and worker migration (Krugman, 1991, and Krugman and Venables, 1995, Fujita, Krugman and Venables, 1999). A core-periphery pattern may also occur if some regions specialize in R&D activity (Martin and Ottaviano, 1999, 2001), if there are local inputs subject to scale economies (Englmann and Walz, 1995), or if (human) capital accumulation diverges in space (Baldwin, 1998, Baldwin and Forslid, 1999, 2000a, 2000b, Baldwin, Martin, and Ottaviano, 2000, Urban, 2000). There exists empirical evidence for country data that "natural geography" such as access to ports or climate matters for the steady state income level of a country (Gallup, Sachs and Mellinger, 1999). Moreover, there is ample indirect and direct evidence for economic geography models such as most recently Redding and Venables (2001).[4] Spatial econometric studies such as Rey and Montouri (1999) show that income of a US state is dependent on the income of neighbour states.

[2] A survey of poverty trap models is Azariadis (1996).

[3] A recent survey is Puga (2001). More favorable for the convergence hypothesis is de la Fuente (2000). Overman and Puga (2001) point out that a different measure of inequality - the unemployment rate - shows an even more pronounced divergence than GDP.

[4] A survey is Overman, Redding, and Venables (2001).

Junius (1997) shows that the degree of urbanization increases in the take-off stage of industrialization, levels off, and finally decreases as countries grow richer.

Our research objective is different in that we explore, whether there is club convergence of cores and peripheries. We do not ask whether *some* structurally identical regions grow rich, while others stay poor, but whether *center* regions grow rich, while *peripheries* stay poor. For this purpose, we merge a neoclassical growth model with a core-periphery model and derive a reduced form that corresponds to a threshold regression model in econometrics (Hansen, 1996, 1999, 2000). We derive theoretically that centers differ from peripheries by their population density. Then, we estimate endogenously, which regions are centers and which are peripheries, and test, whether centers grow faster than peripheries and remain permanently richer.

We also compare how the use of population density as a threshold variable compares to other potential threshold variables. In choosing which alternative thresholds to use we have been constrained by the availability of data. Of those that were available we have selected the ones which can be interpreted as (part of) the criteria that the EU commission applies when deciding whether a region qualifies for regional policy intervention. Therefore, our exercise may also be seen as a validity test of the official EU criteria. The use of other threshold variables also enables us to test for other club-convergence models.

We find that centers remain permanently richer than peripheries in the US and Europe after 1980, while there is none for Japanese prefectures and European regions before 1980. Moreover, human capital and R&D are transmission channels of divergence. The divergence is stronger on a smaller regional unit (NUTS3) than on a larger regional unit (NUTS2) which suggests a rather short wavelength of agglomeration forces in Europe. Surprisingly, population turns out as superior threshold variable to initial per capia income (which is one of the EU's main eligibility criteria), as far as the European regions after 1980 are concerned. Human capital based poverty trap models find also some empirical evidence.

The rest of the paper is organized as follows: Section 2 sets up a theoretical model and derives a reduced form for estimation; section 3 provides the empirical evidence; Section 4 contains a short summary.

2 The Theoretical Model

We will first set up a neoclassical growth model version of a typical geography model (Krugman, 1980, 1991). There are two regions - home and foreign - and foreign variables are denoted by a star (*). Foreign may be thought of as the "rest of the country". We will only state the equations for the home region. Corresponding equations will hold for foreign. There is one manufacturing sector with monopolistic competition, increasing returns to scale technology, and instantaneous free entry and exit at any discrete period of time t.

Representative consumers save by maximizing their utility function V subject to a dynamic budget constraint and some initial conditions[5]:

$$V = \max_{C_t} \sum_{t=o}^{\infty} d^t E_t[\ln C_t], \tag{1}$$

where d is a discount factor and $E_t[.]$ is the usual expectations operator conditional upon information up to period t. There is exogenous population growth and productivity shock growth unless assumed otherwise. The average growth rates are identical in both regions, but temporary stochastic deviations are allowed for.

The consumption basket C_t is defined as a Dixit-Stiglitz (1977) type CES-subutility function on n_t domestic goods and n_t^* foreign goods:

$$C_t = \left(\sum_{j \epsilon \Theta_t} c_{jt}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1, \tag{2}$$

where Θ_t is the set of all domestic and foreign goods, c_{jt} is the domestic consumer's consumption of the manufacturing good j, where the index j contains all domestic and foreign firms.[6]

[5] The consumer optimization problem including the constraints and initial conditions is stated in appendix 2, equation (29).

[6] In monopolistically competitive markets, every firm produces a different good.

The budget constraint of the representative agent is thus:

$$\sum_{j\epsilon\Theta_t} p_{jt}c_{jt} + S_t \leq Y_t^N, \tag{3}$$

where p_{jt} denote factory gate product prices, S_t is savings, and Y_t^N is nominal income.

Firms differ only by their location.[7] There are fixed cost that give rise to increasing returns to scale on plant level. In particular, α units of an input basket v_t is used to install the production process every day (maintenance work) and β units are used to produce each unit of goods for the domestic and the foreign market x_t:

$$v_t = \alpha + \beta x_t, \tag{4}$$

where the input basket v_t is specified as follows:

$$v_t = A_t k_t^{\varepsilon} l_t^{1-\varepsilon}.$$

The input basket v_t consists of human capital k_t, (raw) labour l_t, and some exogenous i.i.d. productivity shock parameter A_t.[8] We assume immobility of human capital unless it is embodied in raw labour.[9] Initially, human capital per capita is equally distributed. Raw labour may be distributed asymmetrically. To start with, we assume immobility of labour. Then, there will not be a change in the relative distribution of labour except for temporary deviations, since population grows at the same average rate in both regions. We will show in section 2.2 that results will go through under the assumption of migration of (some) labour.

A unit of human capital is created by all varieties of goods. For simplicity, we assume that human capital takes the same CES form as the consumption basket on manufactured goods:[10]

$$I_t = \left(\sum_{j\epsilon\Theta_t} \iota_{jt}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{5}$$

[7] Hence, we can suppress the index j of the firm that produces good j. We distinguish only foreign firms from domestic firms by a star (*).

[8] A deterministic time-trend of the productivity shock variable could easily be added without changing conclusions.

[9] Introduction of physical capital into the model in addition would not affect results, if it is perfectly mobile and ownership is not too unequally distributed. We exclude it, because we do not have a useful measure of it for our regional data.

[10] This way of modelling (human) capital follows closely Baldwin (1998).

where I_t is the human capital investment aggregate used by the firms in the home country and ι_{jt} is demand of the typical domestic firms for human capital goods produced by all domestic and foreign firms j. We also assume a 100 per cent depreciation rate such that next period's human capital stock is equal to this period's investment ($K_{t+1} = I_t$).[11] (Note that $K_t \equiv n_t k_t$). Savings occur in terms of all domestic and foreign goods:

$$S_t = \sum_{j \epsilon \Theta_t} p_{jt} \iota_{jt} = P_t I_t. \tag{6}$$

Finally, there are trade costs of the Samuelson iceberg-type for manufacturing goods, such that only a fraction τ of one produced unit of a good arrives at its foreign destination ($0 < \tau < 1$).

The within-period consumption maximization problem, firms' optimization, and the market clearing conditions are solved following closely Urban (2000). The corresponding ideal CES price index P_t (in home) for manufacturing goods is found to be:

$$P_t = \left(n_t p_t^{1-\sigma} + n_t^* p_t^{ex*(1-\sigma)} \right)^{\frac{1}{1-\sigma}}, \tag{7}$$

where p_t and p_t^{ex*} are the domestic producer prices and export prices of domestic and foreign firms charged to consumers in the home country, respectively. Firms optimize their profits by the mark-up pricing rule:[12]

$$p_t = \left(\frac{\sigma}{\sigma - 1} \right) \bar{c} \beta A_t^{-1} r_t^{\varepsilon} w_t^{1-\varepsilon} \quad \text{and} \quad p_t^{ex} = \tau^{-1} p_t, \tag{8}$$

where r_t is the return to human capital in the home country at time t and w_t is the

[11] It is well-known that specific dynamic optimization problems with logarithmic functional forms can easily be solved without loss of substantive generality, if this depreciation assumption is employed. See, for example, Stokey and Lucas (1989). The loss of generality concerns only the adjustment path. Since we will have to log-linnearize this path anyhow in the empirical specification, the depreciation assumption is not restrictive for our purposes.

[12] See d'Aspremont et. al. (1996) for a discussion of this result. Note also that firms optimize under certainty, because contemporary shocks are known and there is no link in the firm optimization problem to the future.

wage rate in the home country.[13] Factor demand of firms is given by:

$$r_t k_t = \varepsilon n_t p_t, \tag{9}$$
$$w_t l_t = (1-\varepsilon)\, n_t p_t.$$

Foreign consumers fully bear the transport cost. Because of free entry and exit of firms, profits are zero. This condition yields an expression for income of the home country:

$$n_t p_t x_t = K_t r_t + w_t L_t \equiv y_t^N. \tag{10}$$

It follows from the zero profit condition that optimal firm output is constant:

$$x_t = \frac{\alpha(\sigma-1)}{\beta} \equiv 1, \tag{11}$$

where we normalized without loss of generality $\alpha\sigma \equiv 1$ and $\beta \equiv 1-\alpha$. From the above equation and the factor market clearing condition we obtain an equation relating the number of firms to the capital stocks and the technology shock:

$$n_t = A_t K_t^{\varepsilon} L_t^{1-\varepsilon}. \tag{12}$$

Note that economy-wide technology shocks are fully absorbed in fluctuations of firm entry and exit.

Finally, the goods market equilibrium condition for one typical manufacturing firm is secured, if:

$$\frac{p_t^{-\sigma} y_t^N}{n_t p_t^{1-\sigma} + q n_t^* (p_t^*)^{1-\sigma}} - \frac{q\,(p_t)^{-\sigma}\, y_t^N}{q n_t p_t^{1-\sigma} + n_t^* (p_t^*)^{1-\sigma}} = 1, \tag{13}$$

where $q \equiv \tau^{\sigma-1}$ for notational simplicity. Following again the steps in Urban (2000), we summarize the goods market equilibrium conditions in the following equation where

[13] The constant $\bar{c}$ is defined as: $\bar{c} = \varepsilon^{-\varepsilon}(1-\varepsilon)^{\varepsilon-1}$.

we conveniently define the terms of trade $\rho_t \equiv \frac{p_t^*}{p_t}$ and the relative number of firms $N_t \equiv \frac{n_t^*}{n_t}$:

$$N_t = \frac{\rho_t^{\sigma} - q}{\rho_t \left[\rho_t^{-\sigma} - q\right]}. \tag{14}$$

We define for future reference from the equation (14) the correspondence $\rho_t = \rho(N_t)$ and note that relative producer prices depend positively on the relative number of firms. Combining (3), (11), (13), and the depreciation assumption, yields:

$$K_{t+1} = \pi_t n_t - C_t, \tag{15}$$

where we define for convenience $\pi_t \equiv (p_t/P_t)$. Now, we make a guess for a consumption function that optimizes expected utility of consumers around some steady state to be defined later:

$$C_t = d_0 \pi_t n_t, \tag{16}$$

where d_0 is a parameter yet to be determined. We will later confirm this guess to be valid. Inserting (16) and (12) into (15), yields finally:

$$K_{t+1} = (1 - d_0)\,\pi_t A_t K_t^{\varepsilon} L_t^{1-\varepsilon}. \tag{17}$$

This is the difference equation of the home region that summarizes the basic model together with its counterpart for the foreign region under the assumption that the guess (16) is valid.

2.1 Steady-States and Stability

Our final objective is the empirical test of the model (17). First, we have to confirm the guess and to determine the steady states and their corresponding stability properties.

We proceed by taking the logarithm of the ratio of (17) for the foreign region to (17) for the home region and obtain after some manipulations and use of (12) and (14):

$$\ln \widetilde{N}_{t+1} = \varepsilon \ln(1 - d_0^*) - \varepsilon \ln(1 - d_0) + \frac{(1 - 2\sigma)\,\varepsilon}{(1 - \sigma)} \ln \rho_t(N_t) \tag{18}$$

$$+ \varepsilon \ln \widetilde{N}_t + (1 - \varepsilon)\left(\ln L_{t+1}^* - \ln L_{t+1}\right) + \varepsilon \ln A_t^* - \varepsilon \ln A_t,$$

where $\widetilde{N}_t$ is the ratio of foreign to domestic firms in terms of efficiency units[14], $\rho_t(N_t)$ is given by (14) and recall that $E_t(\ln L_t^* - \ln L_t)$ and $E_t(\ln A_t^* - \ln A_t)$ are assumed to be time-invariant constants, while at least L_t^* and L_t may be growing. This difference equation and the exogenous equations of motion of the efficiency parameters are sufficient to describe the behavior of the relative number of firms N_t which corresponds to aggregate regional output, since output of a single firm is a constant (see equation (11)).

Next we determine the steady state equilibria.

Proposition 1: *Assume that population L_t, L_t^* fluctuate randomly around the same deterministic trend and A_t, A_t^* are i.i.d. random variables. Then, the difference equation given by (18) with (14) has either one or three fixed points. If it has three fixed points N^*, N^{**}, N^{***}, with $N^* < N^{**} < N^{***}$,then N^* and N^{***} are stable, while N^{**} is unstable.*

Proof: See appendix 1. **Q.E.D.**

This proposition establishes multiplicity of steady state equilibria for some parameter values and uniqueness of equilibria for some others. While the regime with a unique steady state equilibrium is exactly the case of conditional convergence of a neoclassical growth model, the regime with multiple steady states describes the case of a poverty trap.[15] An explicit condition that distinguishes the two regimes does not exist.[16]

Proposition 2: *If the time preference rates, technology, utility, and average population growth rates are identical across regions and the dynamic system given by (18) with (14) starts with an equal distribution of capital, but an unequal distribution of labour, and the stochastic shocks of A_t, A_t^*, L_t, L_t^* are too small to change the basin of attraction, then the steady state N^{***} is approached, if over the entire time path*

[14] I.e. N_t divided by A_t^*/A_t.

[15] The economic intuition for these results has been given carefully in a very similar model in Urban (2000).

[16] Such an explicit condition can be found if all structural variables and in particular the labour distribution are identical for both regions.

an average labour distribution $\bar{L}^* > \bar{L}$ *holds, the steady state* N^* *is approached, if* $\bar{L}^* < \bar{L}$, *and* $N^{**} = 1$ *is approached, if* $\bar{L}^* = \bar{L}$,where $N^* < N^{**} < N^{***}$ and bars denote steady state values.

Proof: See appendix 2. **Q.E.D.**

Proposition 2 establishes that the initial population will be an important determinant for whether a region becomes a center or a periphery. If structural parameters such as productivity and savings rates are (slightly) dissimilar across regions, then there will still be a threshold value of a relative labour distribution that determines, whether a region becomes a center or a periphery, but the threshold value will not be an equal distribution of labour and will have to be estimated empirically. The appropriate operationalization of the threshold variable is population density, whenever transport costs are uniformly depending on distance.[17]

Finally, we are ready to verify the guess on the consumption function.

Proposition 3: *The linear guess for the consumption function (16) is the optimal solution to the maximization problem of consumers (1) subject to the resource constraint (15) and the pricing equation (14), if* $d_0 = 1 - d\varepsilon$ *is chosen.*

Proof: See appendix 3. **Q.E.D.**

Proposition 3 completes the dynamic analysis of the model for a given distribution of labour. The results so far are similar to Baldwin (1998), Baldwin and Forslid (1999, 2000a, 2000b), Baldwin, Martin, and Ottaviano (2000), but distinguish in that the latter use endogenous growth models which are inconsistent with the empirical results of growth regression analysis of Barro and Sala-i-Martin (1992, 1995). Urban (2000) has provided an exogenous growth model version in continuous time rather than discrete time, without stochastic shocks, and regional asymmetries which are all necessary features for the empirical implementation of the model. Finally, Urban

[17]This follows from Fujita, Krugman, and Venables (1999) and will be discussed in section 2.4 in depth.

(2000) lacks the discussion of a migration process which will be discussed next.

2.2 Initial Migration

Static geography models such as Krugman (1991) imply that a region grows faster as long as there is migration. Migration was a typical phenomenon in the beginning of the age of industrialization. Massive migration from the countryside to the cities was observed and a relatively uniform space became asymmetric, i.e. centers and peripheries were formed. Nowadays, very little migration can be observed, but income divergence may still be driven by an uneven distribution of the population in space which is inherited from the age of industrialization.[18]

The purpose of this section is to show within this geography and growth model that there will be an initial massive migration which will lead to an unequal distribution of population across regions. Then, the center - i.e. the region with more population - starts growing faster by accumulating more human capital. Such a model specification can be regarded more relevant for the typical sample periods which we apply in the empirical part of this paper.[19]

For simplicity, we assume that there are two types of individuals: a fraction l of the first generation is perfectly mobile from the second period of life onwards, while a fraction $(1-l)$ is perfectly immobile.[20] Offsprings of immobile workers are also immobile, while offsprings of mobile workers are also mobile. The average population growth rate of each type is equal.[21] Stochastic temporary shocks of the regional

[18] See Baldwin and Martin (1999a) for a careful empirical comparison of the two globalization waves at the beginning of the industrialization in the 19th century and in the second half of the 20th century. The difference of initial conditions is particularly stressed.

[19] Contemporary migration is rather small over the sample period in the sense that the population density differences are persistent over the sample period. See Fischer and Straubhaar (1999) for the interaction of migration and income growth in Europe.

[20] This assumption guarantees that some workers always remain in the periphery. It also guarantees that migration will occur initially, while the growth process in latter stages is not interfered by migration. The assumption that new-born workers can only move from the second period of life onwards together with the assumption of stochastic population growth allow for temporary stochastic deviations of a regions population from its long run value. This will enable us to use population growth as determinant of income growth. Those assumptions ensure also that the model captures well the stylized fact that migration was much more prevalent in the 19th century than it is now.

[21] Our migration process is modelled only rudimentary, because it is not the main focus of this paper. Instead, we only need to justify, why population of industrialized countries are unequally distributed in space, because the population distribution will determine the separation of growth processes of centers and peripheries. For a more general forward looking migration process with

population growth rate and technology are assumed to be sufficiently small to prevent a center to turn immediately into a periphery. The migration decision is made in the beginning of a time period, before the shocks of this period become public. Human capital is embodied in a worker during the migration period. All productivity shocks are set to 1 in this section for convenience.

Under these assumptions we can show in the next proposition that we obtain a stable asymmetric distribution of the population from the first period onward (except for temporary stochastic deviations caused by differential population growth).

Proposition 4: *Suppose labour is equally distributed in space and the regions are identical in all respects in period 0. In period 1, there is a massive migration towards the center region. From this period onwards* $E\left(L_t^*/L_t\right) = \frac{L^*}{L} = \frac{1+l}{l} > 1$, *where we denote the home region to be the center region by language convention. This distribution of labour is a subgame perfect equilibrium.*

Proof: See appendix 4. **Q.E.D.**

Propostion 4 justifies the existence of an unequal initial distribution of the population. In the proof in the appendix, we apply a subgame perfect equilibrium concept. If all mobile workers have moved to the center, income in the center is larger than in the periphery, since producer prices are larger in the center and consumption price indices are lower. Thus real rental rates and real wages are also larger in the center. If a mobile worker moves then from the center to the periphery at some time period, she can afford less consumption and less human capital accumulation than as if she had stayed in the center. Hence, the equilibrium in the center is stable. As in Baldwin (2001), Krugman (1991b) and Matsuyama (1991), we have multiple equilibria in that it is indeterminate initially which region becomes the center. However, our simplified migration process involves an instantaneous jump to the steady state labour distribution and the problem of expectation driven formation of centers on the transition path vanishes.

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expectation driven equilibria see Baldwin (2001).

2.3 Derivation of Growth Equation and Tests

Next, we derive the reduced form of the growth equation in the presence of multiple equilibria and a threshold. (17) may be rewritten by using (14) as

$$\ln y_{t+1} = \varepsilon \ln(1-a_0) + \varepsilon \ln y_t + \varepsilon \ln\left(\frac{p_t}{P_t}\right) + \varepsilon \ln\left(\frac{L_t}{L_{t+1}}\right) + \ln A_{t+1}, \qquad (19)$$

where y_t is per capita income. Note that the term (p_t/P_t) is non-loglinear. Therefore, this term will have to be evaluated around the steady state. In the steady state it will be

$$\frac{\bar{p}}{\bar{P}} = \left(\bar{K}^{\varepsilon}\bar{L}^{1-\varepsilon} + t\left(\bar{K}^{*}\right)^{\varepsilon}\left(\bar{L}^{*}\right)^{1-\varepsilon}\bar{\rho}^{1-\sigma}\right)^{\frac{1}{\sigma-1}}. \qquad (20)$$

Then, it depends, whether the home region is a center or periphery. If it is a center (denoted by *) it's corresponding steady state value is larger as if it is a periphery (denoted by ***), i.e.

$$\frac{\bar{p}^{*}}{\bar{P}^{*}} > \frac{\bar{p}^{***}}{\bar{P}^{***}}, \qquad (21)$$

because we have shown in proposition 4 that there are more workers in the center and in proposition 1 that there is more capital accumulation in the center.[22] In practise, inequality (21) implies that the steady state income per capita of centers is larger than of peripheries.

Moreover, it has been shown in proposition 2 that the home region becomes a center, if and only if $\bar{L} > \bar{L}^{*}$. Therefore, we employ in our empirical tests the following (generalized) threshold regression equation:

$$\triangle \ln y_{t+1} = \begin{cases} \gamma_{01} + \gamma_{11}\ln y_t + \gamma_{21}\ln\left(\frac{L_t}{L_{t+1}}\right) + \gamma_{31}\ln A_{t+1} & \text{if } \bar{L}/\bar{L}^{*} > \gamma \\ \gamma_{02} + \gamma_{12}\ln y_t + \gamma_{22}\ln\left(\frac{L_t}{L_{t+1}}\right) + \gamma_{32}\ln A_{t+1} & \text{if } \bar{L}/\bar{L}^{*} < \gamma \end{cases}, \qquad (22)$$

where γ_{ij}, $i,j = 0,1,2,3$ are regression coefficients, and γ is a threshold value that splits the sample into two halfs. If all regions were completely symmetric in all variables and parameters except for the state variables, then theory suggests that γ is

[22] The rigorous proof of inequality (21) can be shown with some lines of algebra and is available from the authors upon request.

one. If regions are asymmetric, then γ is not known a priori. The main innovation of the empirical part will be to estimate γ endogenously. This will enable us to estimate which region is a center and which region is a periphery.

The variable technical progress (A_{t+1}) may be taken as unobservable or proxied by a variable such as patent applications. We operationalize the threshold variable $\bar{L}/\bar{L}^*$ as population density. This operationalization follows from a continuous space extension of the core-periphery model of Krugman (1991) which can be found in Fujita, Krugman and Venables (1999). In this model, transport costs are proportional to distance. Then, core-periphery patterns extend to spatial fluctuations and aggregate variables are indexed by "unit" of space. Otherwise, the model results are preserved. We will discuss informally the implications of continuous space below.

We will formulate three hypothesis. The first hypothesis is that there exists a threshold γ such that centers grow different to peripheries. Note that this includes standard growth regressions à la Barro and Sala-i-Martin (1992) as null-hypothesis. While the latter tested neoclassical growth theory against the alternative of an Ak-model, we will test the same null-hypothesis against a model with multiple steady states (poverty trap model).[23]

The second hypothesis is that centers reach a higher steady state income level than peripheries conditional upon identical population growth and technical progress.[24] This will be the case, if

$$-\frac{\gamma_{01}+E[\beta' x]}{\gamma_{11}} > -\frac{\gamma_{02}+E[\beta' x]}{\gamma_{12}}, \tag{23}$$

where $E[\beta' x]$ is the average score of the control variables upon which conditioning takes place. These scores may be different across center and periphery. This hypothesis will

[23]Bernard and Durlauf (1996) have pointed out that regressions testing for the convergence speed larger than zero are "ill-designed to analyze data where some countries are converging and others are not" (p. 167). Note that threshold regressions do exactly that.

[24]If we talk about a theoretical steady state income level, we do not intend to forecast future income. For the latter we would need to exclude structural changes in the future which is implausible over an infinite time-horizon. Instead, we view the theoretical steady state income level as an index number that extrapolates contemporary growth performance into an immaginary time path.

be tested with a non-linear hypothesis test.[25]

Our regional data is limited in the time dimension. Hence, we cannot employ panel-estimations.[26] This limitation may bias the test (23) if regional fixed effects proxy significantly for omitted variables, differ substantially across regions, *and* are at the same time correlated with the convergence speed. Moreover, the test (23) assumes a log-linear growth process.

All these shortcomings can be avoided by simply testing:

$$E[\triangle \ln y_{t+1} \Big| \bar{L}/\bar{L}^* > \gamma] > E[\triangle \ln y_{t+1} \Big| \bar{L}/\bar{L}^* \leq \gamma], \tag{24}$$

which can be done with a standard (two-sided) group mean-difference test. The draw-back of test (24) is that it imposes too strong a condition on divergence. Income differences may be persistent, even if peripheries grow faster than centers but their growth fades out too early. Moreover, no standard control variables are taken into account. Hence, test (24) is a test on unconditional divergence.

The third hypothesis regards the discrimination of different poverty trap models. By the choice of the threshold variable different poverty trap models can be directly compared with the geographical poverty trap model of this paper. For example, many poverty trap models employ initial income as threshold variable (see Azariadis, 1996). Others require human capital to be a threshold variable (Funke and Niebuhr, 2001). In fact, a comparison of the coefficient of determination (R^2) of the respective threshold regressions with identical control variables suffices to discriminate among those theories.

Finally, we can also gain some information on the transmission channel of divergence. Our theory suggests that either migration or human capital accumulation

[25]We can easily accomodate a common constant growth rate of technology by assuming a deterministic common time trend in A_t. As is well-known (see Solow, 1956), this yields a steady state growth rate equal to the exogenous rate of growth of technology. Hence, a steady state income level does not exist anymore. However, there exists a steady state income ratio of center relative to periphery that is given exactly by the left hand side of (23) divided by the right hand side of (23). Thus this test remains valid even in the presence of a common deterministic constant growth rate of technology. The latter claim can be proven with a few lines of algebra which are available from the authors upon request.

[26]Moreover, thereshold regression techniques have only been developed for non-dynamic fixed effect models (Hansen, 1999), while we would need a dynamic panel threshold regression technique.

drive divergence. We can control for effects of endogenous migration by instrumenting population growth by its exogenous components of death and birth rate. We can explore human capital as transmission channel by including it in the regression. If a threshold is significant without human capital as control variable and it renders insignificant with human capital, then human capital is capable of explaining the divergence in per capita growth rates if it is concentrated in centers. Likewise, R&D may serve as another transmission channel of divergence which could be explored in the same way.[27]

2.4 The "Right" Wavelength

We are restricting the theoretical model to two (types of) locations - a center and a periphery. Fujita, Krugman and Venables (1999) have shown in a static-optimizing new economic geography model that this is sufficient to understand the agglomeration forces and convergence forces of the model. There arises, however, one problem in the empirical implementation of a simple core-periphery model. In a continuous space version, many different types of regions may emerge. In fact, a continuous space model can be described as a spatial wave.

This is depicted without further theoretical underpinning somewhat loosely in figure 1, where the picture is strongly inspired by Fujita, Krugman and Venables (1999). There is a different income level and a different amount of workers in each spot in space. Centers and peripheries form as peaks and troughs of a wave.

Regional data are not measured in spots, but as averages on areas. Then, it becomes important which level of regional aggregation those data have. If the region size corresponds with the wavelength of agglomeration forces as in figure 1, then regional data will just show a pattern that is perfectly captured by a simple core-periphery model.

[27] See Martin and Ottaviano (1996) for a geography and growth model with endogenous R&D location decisions.

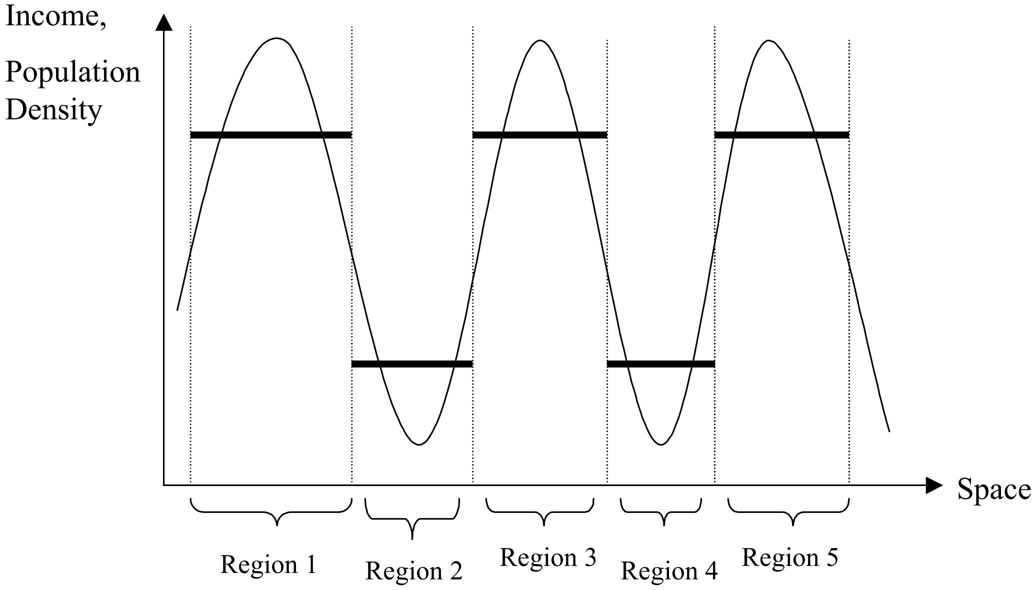

Figure 1: A Parabel to a Continuous Space Model - Perfect Match

The core-periphery pattern may not be recoverable, however, in a second case which is depicted in figure 2.

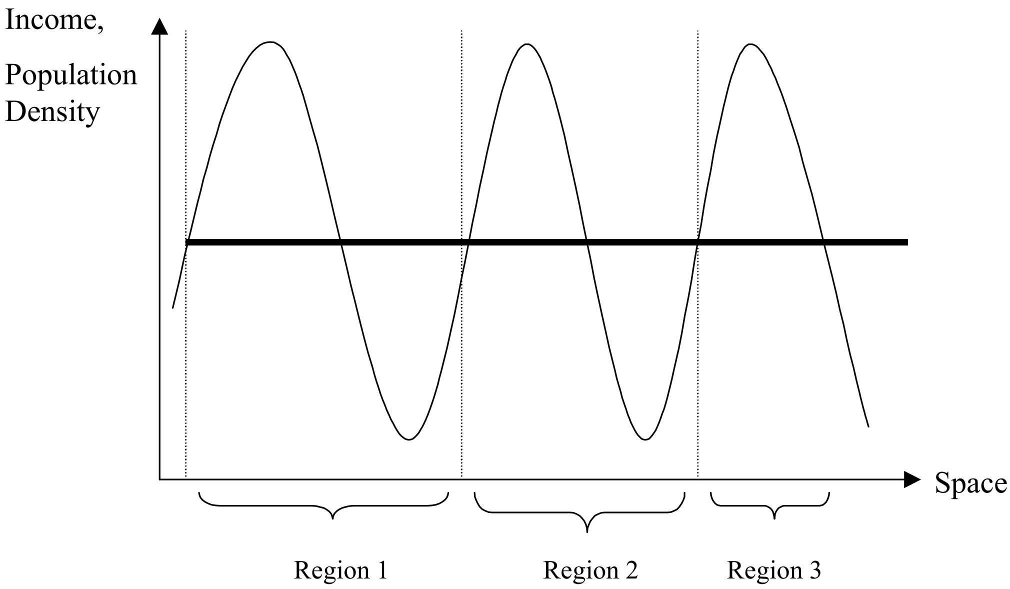

Figure 2: A Parabel to a Continuous Space Model - Regional Units Too Large

In figure 2, regional borders are drawn such that each region contains both peaks and troughs. Regional data on this level of regional aggregation will average out center-periphery differences, although they are present.

Yet, another possibility of a mismatch of legal and economic borders arises which is displayed in figure 3.

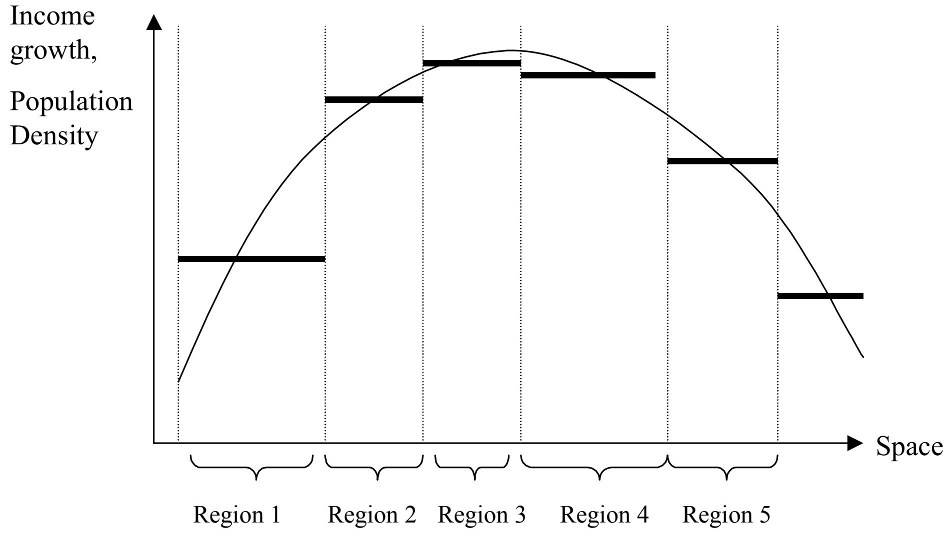

Figure 3: A Parabel to a Continuous Space Model - Regional Units Too Small

Now, a single spatial wave may cover many regional units. Then, threshold regression techniques may identify more than one significant threshold. Moreover, there will be spatial autocorrelation of the error term of the economic growth threshold regression. We will explore the choice of wavelength by applying a Moran-I test of spatial autocorrelation. If the test rejects spatial autocorrelation on a higher level of regional aggregation, but accepts it on a lower level, while there is a stronger sign of divergence on the lower level, then we conclude that the economic wavelength corresponds to areas of a size inbetween the higher and the lower level of aggregation.

Summing up, it will be important in the empirical analysis to use different levels of regional aggregation to explore the empirical wavelength of agglomeration forces. A spatial autocorrelation test may provide additional information.

3 Empirical Analysis

We first repeat the seminal study of Barro and Sala-i-Martin (1992) by applying threshold regression techniques of Hansen (1996, 2000) to their data on US states, European regions, and Japanese Prefectures. Then we use Eurostat data for European regions from 1980 until 1996 both on NUTS2 and NUTS3 level[28].

3.1 Econometric Specification

The growth equation (22) has a correspondence to econometrics. It is a threshold regression model. A threshold regression model estimation involves three steps. First, the optimal sample split threshold γ is estimated. Second, it is tested, whether the optimal sample split is indeed significant. Third, conventional hypothesis tests can be performed.

The optimal sample split is estimated by minimizing mean square errors, i.e.

$$\gamma = \underset{q_i \epsilon Q}{\arg\min}\, e\left(q_i\right)' e\left(q_i\right),$$

where q_i is the value of the threshold variable (population density) of region i, Q is the set of all different values of q_i in the sample, γ is the optimal value of q_i, and $e\left(q_i\right)$ is the vector of OLS residuals of the regression (22) if the sample is splitted in all observations which are larger or smaller than q_i and each sample half is estimated separately. This step enables us to estimate which regions are centers and which are peripheries.

The significance of the sample split could be optained by a conventional structural break test (Chow Test). However, Davies (1977) has argued that this test is invalid in the present context, because it assumes that the sample split γ is known with certainty, while we estimate the optimal sample split γ. A Chow test would not take into account the estimation error of γ and the uncertainty whether the threshold exists under the null-hypothesis. Hansen (1996) suggests a Supremum F-, LM- or Wald-Test which has a non-standard distribution dependent on the sample observa-

[28]Eurostat uses 4 disaggregation levels of regional classifications: NUTS0 corresponds to countries, NUTS1 to states, NUTS2 to a group of communities or cities, NUTS3 to single cities or communities. A description of the data is found in appendix 5.

tions.[29] The critical values can be obtained by a bootstrap.[30] This way, we test the validity of core-periphery growth patterns. Do centers follow a different growth path than peripheries even if we control for exogenous structural differences?

So far, we can evaluate whether centers and peripheries grow differently. Of more interest is, however, the question whether centers become richer than peripheries. Inequality (23) in section 2.3 specifies this hypothesis. Hansen (2000) proves that conventional tests on the regression coefficients as if γ were known with certainty remain valid asymptotically. Therefore, we are able to apply conventional non-linear tests to evaluate this hypothesis. If the threshold is significant but the steady states of center and periphery are not significantly different, then centers grow rich early in time, while peripheries first diverge and converge later[31]. Moreover, an unconditional group mean-difference test is valid for the same reason to test unconditional divergence, i.e. (24).

Hansen (2000) has applied this technique previously to test for poverty traps on country data. Canova (1999) estimates also thresholds for European regions. However, he uses a different technique (Bayesian statistics) and does not test a specific geography model, but a general poverty trap model. We will compare his preferred threshold variable with our estimations. Neven and Gouyette (1995) and Straubhaar and Wolburg (1999) estimate growth regressions of European peripheries. However, they do not estimate which regions are peripheries, but take as peripheries the southern regions or the objective 1 regions as defined by the European commission.

[29] We will employ a Supremum Wald-test if we encounter heteroscedasticity. In this case, we choose the optimal sample split according to the test statistic rather than the mean square error as in Hansen (2000). A software is available from Hansen in GAUSS. However, we employ our own software written in STATA. Our software is more flexible as it allows to limit the sample break to a subsets of variables. This is necessary to include country dummies. Our software has also an option for instrumental variable threshold regression.

[30] Some theoretical upper and lower bounds are available from Andrews (1993). However, Diebold and Chen (1996) demonstrate in a time series Monte Carlo study the superiority of bootstrap methods in particular for small samples and for samples with autocorrelated error terms.

[31] This hypothesis may be found in a geography and endogenous growth model of Baldwin, Martin, and Ottaviano (1998).

3.2 Barro and Sala-i-Martin (1995) Data

We employ data on Japanese prefectures 1955-1990, US states 1900-1990 and European Nuts 1 regions 1950-1990. The data are displayed and described in Barro and Sala-i-Martin (1995). The results are displayed in table 1.

Regressions (1), (2) and (4) repeat a conventional OLS regression as in Barro and Sala-i-Martin (1992)[32] for the purpose of comparison on Japanese prefectures, US states, and European NUTS1 regions from 1950-1990[33], respectively. Accordingly, the GDP growth rate is regressed on initial income and the population growth rate. Additionally, we estimate the threshold of population density that splits the sample best into center and periphery regions and test for the significance of it. Model (3) is the result of threshold regression on US states reporting the different regression coefficients for centers and peripheral regions.

A Supremum-LM test indicates a highly significant sample break for the data on US states. However, there is no sample break for European regions and Japanese prefectures. Hence, only US centers follow a growth path different from peripheries. Furthermore, the Wald test for difference of steady state income levels of centers and peripheries suggests that centers of US states have a higher steady state income level than peripheries at the 1 percent significance level. The US data provide strong evidence that our theoretical model is empirically relevant for the US. Our finding that there is no evidence of growth divergence on NUTS1 level in Europe particularly in the early post-World War period is in line with previous findings.[34] To understand the results for Europe better, we investigate next a different time period.

[32] Barro and Sala-i-Martin (1992) use non-linear least squares estimation, while threshold regression techniques are constrained to OLS estimation. Results are very similar, though.

[33] Data on European regions are differences of the dependent and each independent variable from its country sample mean. This corresponds to a LSDV-estimator of country fixed effects. Hence, we will not be able to recover the regression coefficients of the constant term.

[34] For a survey, see Puga (2001).

Table 1: Threshold Estimation of the Data of Barro and Sala-i-Martin (1995)

Variables	Japanese Prefectures Without Threshold (1)	US States without Threshold (2)	US States with Threshold (3)	European Regions 1950-1980 without Threshold (4)
Constant Center	0.0369*** (0.0022)	0.0243*** (0.0006)	0.0216*** (0.0008)	-
Constant Periphery	-	-	0.0237*** (0.0011)	-
Initial Income Center	-0.0156*** (0.0022)	-0.0172*** (0.0013)	-0.0141*** (0.0011)	-0.0115*** (0.0016)
Initial Income Periphery	-	-	-0.0235*** (0.0020)	-
Population Growth Center	0.1967** (0.0941)	-0.0234 (0.0327)	0.2152*** (0.0710)	0.0021 (0.0753)
Population Growth Periphery	-	-	0.0781** (0.0366)	-
Threshold Estimate	-	-	4.4	-
Threshold 95% Confidence Intervall	-	-	[2.71, 13.88]	-
LM-Test for Threshold	4.84 (0.69)	-	51.04*** (0.00)	5.21 (0.69)
Conditional Steady State Center	2.365	1.413	1.535	-
Conditional Steady State Periphery	-	-	1.0055	-
Wald-Test for Difference of Steady States	-	-	17.49*** (0.00)	-
White-test	0.38	0.31	0.97	0.00***
Adjusted R^2	0.559	0.818	0.912	0.517
Observations	47	48	48	90

Remarks: Standard errors in parenthesis (heteroscedasticity corrected if White test significant);
*** is 99% significant; ** is 95% significant; * is 90% significant;
Modified LM-Test for significance of threshold: Hansen (1996): 1000 bootstrap replications;
Marginal probability in parenthesis;
Confidence intervall of threshold: Hansen (2000);
Wald-Test; H_0: $\gamma_{01}/\gamma_{11}=\gamma_{02}/\gamma_{12}$: probability of H_0 in parenthesis;
White Test for heteroscedasticity: probability of accepting homoscedasticity

3.3 Eurostat Data - NUTS2

3.3.1 Centers and Peripheries

We apply threshold regression to Eurostat data on European regions, NUTS2, during the period from 1980 until 1996 covering 12 EU countries.[35] In particular, we use data on the regional average annual growth rate of GDP per capita in PPP units[36], the

[35]For few regions no data on GDP were available for 1980. Instead, the year 1981 was taken in these cases. For a precise data description see the data appendix which also contains the summary statistics of all variables.

[36]Boldrin and Canova (2001) suggest to use average labour productivity instead of GDP per capita, because labour market participation rates differ widely across regions. However, labour productivity

initial level of GDP per capita in 1980 or 1981, the average annual population growth rate of a region, the average number of patent applications per capita over the period 1989-1996, the share of the population with university degree or equivalent in 1993[37], and the population density (1000 inhabitants per qm^2). GDP data are in nominal PPP units. This means that regional differences in the price development have been taken into account, but there is no correction of the common EU-inflation rate. Our results will not be affected by the lack of this correction.[38]

Before we enter a formal analysis, we describe the spatial distribution of initial income in 1980/1981, of the average annual growth rate, and of population density. Rich regions in 1980/1981 were concentrated in the geographic core of Europe, while the poor regions of Europe were concentrated in the geographic peripheries. Of the 10 richest regions were 5 located in Germany, 2 in Belgium, 1 in France, 1 in the Netherlands, and 1 in Italy. Typically, the richest regions were regions containing major cities such as Brussels, Paris, Hamburg, Frankfurt, etc. In contrast, of the 10 poorest regions in 1980/1981 we observed 5 Greek, 3 Portuguese, and 2 Spanish regions. Comparing the geographic distribution of income with the population density, there is a close match.[39]

The geographic core has a much higher population density than the geographic periphery. Among the regions with highest population density are 3 German, 3 Dutch, a Greek, a Spanish, a French, and a Belgium region. (Often the region containing the countries' capital), while among the 10 regions with the lowest population densities are 4 Greek, 4 Spanish, a Portuguese, and an Italian region. This finding indicates that there must have been at some point in history a divergence in income growth

may not be a good measure of regional performance. Economic integration may increase European-wide competition which may force local firms to increase labour productivity by laying-off workers (especially in the presence of nation-wide labour contracts). As a result, labour productivity converges and unemployment diverges. The latter has been found by Overman and Puga (2001).

[37]There is also a measure of secondary schooling available. However, it proved not to be significant in our regressions.

[38]All constant terms of our regression will have to be reduced by the average annual EU inflation rate. The standard errors are not affected. Nor are the regression coefficients of the other variables or any test statistics. Note also that every regional income study with Eurostat data has faced this problem.

[39]The correlation between GDP per capita in 1980 and population density is 0.38 for NUTS2 regions and 0.48 for NUTS3 regions.

rates of regions with high and low population densities, respectively, or there must have been migration from poorly growing regions to faster growing regions.

In any case, population density looks like a good candidate variable to be included in more formal empirical regional analysis. This correlation tells nothing, so far, about the contemporaneous growth performance of cores and peripheries in Europe. The top growth performers have been Ireland and Luxembourg, and also some Portuguese regions, while among the worst performers are mainly French, but also Greek and Spanish regions.

To investigate more thoroughly, whether population density can explain differences in growth performance, we turn to a formal econometric analysis using threshold regression techniques. Table 2 displays the results for NUTS2 data. We provide the results of cross-section threshold regressions of the GDP growth rate on initial income, the population growth rate, patents, and human capital. Specifications (1)-(3) use OLS threshold regressions, while specifications (4)-(6) apply instrumental variable threshold regressions to take into account a possible endogeneity bias of population growth, because one component of population growth - migration - may respond to GDP growth.[40] Different estimations are made for center regions, i.e. regions with a large population density, and peripheries, i.e. regions with low population densities, where the cut-off level is chosen optimally as described in section 3.1.

Starting with the baseline specification (1), we find that there is a highly significant sample split into centers and peripheries as indicated by a Supremum-Wald test. The threshold value of population density that separates centers and peripheries is a rather high population density of 345 inhabitants per km^2. There are 115 peripheries and 39 centers. The unconditional average growth rate of centers is about 0.05 percentage points lower than in peripheries. But this difference is not statistically significant. In contrast, the theoretical conditional steady state of centers is significantly

[40] The validity of threshold tests is proven for OLS regressions. However, those proofs apply directly to IV-estimation, because the latter are just a transformation of OLS estimators, where the transforms obey exactly the assumptions required for OLS estimations.

larger than the one of peripheries.[41] Moreover, the convergence speed parameter of centers is not significantly different from zero, while it is for peripheries. Hence, we cannot exclude endogenous growth in centers.

Adding succesively the control variables patents and human capital in specifications (2) and (3) of table 2, we find that the threshold is no longer significant while both patent applications and human capital are significant according to standard t-tests. Moreover, the relative conditional steady state of centers and peripheries are no longer significantly different from each other if the control variables patent applications per capita and human capital are introduced. At the same time, the unconditional growth rate of centers and peripheries is becoming larger. Hence, patent application and human capital explain the steady state income differences of centers and peripheries.[42]

In specifications (1)-(3), we find that population growth is positively correlated with GDP p.c. growth in centers, but negatively correlated in peripheries. This hints at endogeneity of population growth. There may be immigration into centers, as they may be expected to become richer in the future. Hence, there may be a positive correlation. In the contrary, there may be emmigration from peripheries, since they are expected to become poorer and the correlation may vanish or even become negative as predicted by the theoretical model. To control for endogeneity of population growth we reestimate the previous specifications with instrumental variable threshold estimations using the exogenous components of population growth, i.e. death and birth growth rates, as instruments. In the baseline specification (4), results are very similar to the OLS specification (1). The threshold remains valid, although it becomes even larger.

[41] The hypothesis is formulated in the theoretical part, equation (23). We report in table 2 an LR-test result, because a corresponding non-linear Wald test proved not invariant to the hypothesis formulation. This deficiency of the non-linear Wald test is well known. Greene (1997), p. 362f, recommends to use an LR- or LM-test instead. We also calculated the LM-test with very similar results to the LR-test without reporting them.

[42] It is important to recall that human capital and patent applications may be endogenous, because human capital is measured in 1993 and patents as average from 1989 until 1996 rather than in 1980. Unfortunately, we do not have appropriate instruments for those variables. Moreover endogeneity of human capital may be caused by forward looking human capital investment decisions. Agents choose a better education in centers, because they know that this attracts more firms which renders human capital investment more profitable and justifies ex post the larger effort into education. For those reasons, human capital has to be used with caution in threshold regressions as control variable.

Only the steady state income difference test is no longer significant. A Hausman test confirms the validity of the chosen instruments. In the specifications (5) and (6) with patents and human capital as control variables the Hausman test indicates that instruments are no longer valid. The estimation results are very similar to the corresponding OLS estimations.

Eventually, we test for spatial autocorrelation. A Moran-I test indicates rather low spatial autocorrelation which is mostly not significant at the 5% significance level.

Table 2: Threshold Estimation of European Regions, NUTS2, Threshold Population Density, 1980/1981-1996

Dependent variable: GDP Growth	OLS/ Country Dummies			IV/ Country Dummies		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant Center	0.065* (0.033)	0.194*** (0.039)	0.206*** (0.082)	.055 (.043)	.185*** (.043)	.196*** (.068)
Constant Periphery	.111*** (0.028)	.236*** (0.045)	0.259*** (0.042)	.111*** (.023)	.228*** (.046)	.256*** (.049)
Initial Income Center	-0.001 (0.004)	-.013*** (0.004)	-.017** (.007)	0.000 (.005)	-.012*** (.008)	-.016** (.008)
Initial Income Periphery	-.005* (0.003)	-.018*** (0.005)	-.022*** (.005)	-.005** (0.003)	-.017*** (.005)	-.022*** (.005)
Population Growth Center	1.46*** (0.285)	0.106 (0.178)	.577 (.365)	2.513*** (0.501)	.215 (.287)	.743 (.554)
Population Growth Periphery	-.191 (.180)	-0.627** (0.295)	-.296 (.187)	-0.195 (0.314)	-.499 (.460)	-.042 (.319)
Patents	-	0.003*** (0.001)	.003** (.001)	-	.003*** (.001)	.002* (0.001)
Human Capital	-	-	.006* (.003)	-	-	.006* (0.003)
Threshold Estimate	0.345	0.061	0.208	0.45	0.094	0.196
Sup-Test for Threshold	30.01*** (0.00)	8.23 (0.45)	10.18 (0.27)	21.83*** (0.00)	5.29 (0.64)	5.21 (0.6)
Unconditional GDP growth center vs periphery	-0.05% (0.65)	0.09% (0.67)	0.27%* (0.06)	-0.15% (0.32)	0.20% (0.24)	0.24%* (0.09)
Relative Steady State Center vs Periphery	3.89** (0.03)	1.11 (0.67)	1.10 (0.75)	∞ (0.26)	1.10 (0.36)	1.10 (0.42)
Wald test for country dummies	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
Hausman test	-	-	-	0.03**	0.64	0.33
Moran-I test	0.13	0.15	0.10	0.19**	0.15	0.07
B.-Pagan test	0.00***	0.21	0.51	-	-	-
Joint R^2	0.63	0.67	0.71	0.60	0.67	0.69
Observations	154	101	86	151	101	86

Remarks: Standard errors in parenthesis (heteroscedasticity consistent if Breusch-Pagan test significant); *** significant at the 99% level; ** significant at the 95% level; * significant at the 90% level; SupTest: SupWald- or SupF-test for significance of threshold: See Hansen (1996), heteroscedasticity correction if Breusch-Pagan test significant, 1000 bootstrap replications, marginal probability in parenthesis; Unconditional GDP growth difference between center and periphery: two-sided test for group-mean difference with group specific variance; Relative steady state income per capita (H_0: $(\gamma_{01}+E(\beta'\mathbf{x}))/\gamma_{11}=(\gamma_{02}+E(\beta'\mathbf{x}))/\gamma_{12}$): Significance level from non-linear LR-test or non-linear Wald test; B.-Pagan-test: Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity; Hausman test for validity of instruments; instruments are the average annual growth rate of birth and of death; Moran-I test for spatial autocorrelation (** indicates significance at 5%-level); Unreported country dummies always included;

So far, we can conclude that population density is an econometrically valid threshold variable and it divides centers and peripheries such that centers get richer than peripheries. The difference is statistically significant, but not robust to instrumental variable estimation. Our results on Europe both before 1980 and after 1980 matches those of de la Fuente and Vives (1995). They find regional convergence in Europe before 1980 and a stop of the convergence process thereafter. We find even some evidence of divergence of centers and peripheries with the refined measurement method of threshold regression using the same data.

3.3.2 Alternative Threshold Variables

Now, we ask whether there may exist a better threshold variable than population density. After all, the threshold variable population density distinguishes poverty traps caused by geography models from other poverty trap models. We tried five alternatives: initial income, the deviation of population density from its country mean, the percentage change of employment in the manufacturing sector, the share of agricultural employment in the population in the year1990[43], and human capital.

The results are displayed in table 3. Initial income is not a significant threshold variable. Moreover, poor regions appear to grow significantly stronger than rich regions. However, the test on the conditional steady state indicates that catch-up of poor regions will not be complete and poor regions will stay permanently poorer than rich regions. Interestingly, the estimated (insignificant) threshold of initial income is at 77% of the EU average GDP per capita income which is astonishingly close to the actual eligibility criterium for regional aid by the EU of 75%. Compared to the population density threshold regressions, initial income as threshold variable does far worth according to the ratio of the two coefficients of determination (relative R^2). In this respect, our study adds a superior threshold variable to the study of Canova (1999).

[43]De la Fuente (2000) suggests that regions with a larger agricultural sector have lower average labour productivity. A move out of agriculture spurs thus also growth.

Table 3: Threshold Estimation of European Regions, NUTS2, Alternative Thresholds, 1980/1981-1996

Dependent variable: Per Capita GDP Growth	Threshold Variable: Initial Income	Deviation of population density from country mean	Decline of Manufac-turing sector	Share of agricultural employment	Human Capital
	(1)	(2)	(3)	(4)	(5)
Constant Center	0.09*** (0.03)	0.06*** (0.02)	.08** (.03)	0.14*** (0.02)	0.08*** (0.03)
Constant Periphery	0.22*** (0.07)	0.13*** (0.03)	.07** (.03)	0.11** (0.05)	0.19*** (0.04)
Initial Income Center	-0.004 (0.003)	-0.001 (0.003)	-.002 (.004)	-0.009*** (0.003)	-0.001 (0.003)
Initial Income Periphery	-0.019** (0.008)	-0.008** (0.004)	-.001 (.003)	-0.006 (0.006)	-0.014*** (.005)
Population Growth Center	0.30 (0.23)	0.44** (0.21)	0.02 (0.31)	-0.02 (0.12)	0.46** (0.20)
Population Growth Periphery	-0.27 (0.25)	-0.07 (0.23)	0.07 (0.14)	1.81*** (0.25)	-0.77*** (0.26)
Threshold Estimate	8.64	-0.044	-.0034	0.008	2.56
Sup-Test for Threshold	13.6 (0.19)	9.25 (0.52)	27.03*** (0.01)	57.31*** (0.00)	48.67*** (0.00)
Unconditional GDP growth difference center vs periphery	-0.50%*** (0.00)	-0.15% (0.25)	0.65%*** (0.00)	0.19% (0.29)	0.27% (0.26)
Relative Steady State Center vs Periphery	2.44*** (0.01)	5.81* (0.09)	0.81 (0.99)	0.87 (0.97)	4.77*** (0.00)
Breusch-Pagan test	0.00***	0.00***	0.00***	0.04**	0.14
R^2	0.58	0.58	0.64	0.62	0.66
Relative R^2	0.92	0.92	1.06	1.01	1.03
Observations	154	154	91	126	100

Remarks: Standard errors in parenthesis; Robust standard errors if Breusch-Pagan test significant;
*** significant at the 99% level; ** significant at the 95% level; * significant at the 90% level;
Sup-Test: SupWald- or SupF-Test for significance of threshold: See Hansen (1996),
1000 bootstrap replications, marginal probability in parenthesis;
LR-Test; H_0: $(\gamma_{01}+E(\beta'\mathbf{x}))/\gamma_{11}=(\gamma_{02}+E(\beta'\mathbf{x}))/\gamma_{12}$; probability of H_0 in parenthesis;
Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity;
Relative R^2 is the ratio of R^2 of the considered threshold regression to the R^2 of a threshold regression with the threshold variable population density and the same observations and control variables;
Unreported country dummies are always included;

We also find that the threshold population density is an absolute measure and not country specific as it would be the case if the deviation of population density from its country mean would perform superior. However, a decline in manufacturing, a high employment share in agriculture, and a low level of human capital are also significant threshold criteria and the corresponding threshold regressions have a superior fit to the one with population density. However, neither the steady state difference test, nor the unconditional divergence test are significant if the agricultural share of employment is used as threshold variable. The threshold variable "decline in manufacturing employment" explains huge significant temporary growth rate differences, but not permanent ones. Only regions with low human capital have a significantly lower steady state level of income.[44] The latter result confirms again that human capital accumulation is an important transmission channel of divergence.

Summing up, we can conclude that among the EU eligibility criteria for regional aid "decline in the employment share of manufacturing" obtains the strongest support in our study if policy measures are temporary. If initial income is believed to be an important eligibility criterium, then the chosen threshold - 75% of EU average income - is astonishingly close to the optimal estimated threshold. Population density and human capital are the only two significant threshold variables that explain persistent long-run differences in GDP p.c. across centers and peripheries. Hence, a refocus of regional economic policy towards increasing the demand of high-skilled labour in peripheries may be advisable. This may be achieved by locating high-skilled public employment such as universities and government agencies in peripheries.

3.4 Eurostat Data - NUTS3

Next, we explore divergence on a smaller level of regional disaggregation (NUTS3). We use data on GDP per capita growth, GDP per capita in 1980, population growth, population density, and numbers of patent applications per inhabitants.[45] The data cover 6 countries: Belgium, France, Germany, Greece, the Netherlands, and Spain. Patent data are mainly missing among greek regions. The distribution of NUTS3 regions is unequal across countries. The bulk of NUTS3 regions is found in Germany (329), while other countries have much larger regional units, e.g. France has 88 regions. In the light of figures (1)-(3), this is not necessarily a problem if the wavelength of agglomeration forces differs across countries. In particular, countries with low population density like France and Spain are expected to have a larger wavelength

[44] Funke and Niebuhr (2001) find for German regions a significant threshold in human capital.

[45] Unfortunately, no data on human capital or the agricultural share of employment was available on NUTS3 level. A precise data description with summary statistics is given in the data appendix.

of agglomeration forces, because cities tend to be further away from each other, and those countries are at the same time divided into larger regional units.

We apply the threshold growth regressions also to these data. The results are displayed in table 4.

Table 4: Threshold Estimation of European Regions, NUTS3, 1980/1981-1996

Dependent variable: GDP Growth	OLS		IV		OLS	
Threshold Variable	Population Density				Initial Income	
Specification No.	(1)	(2)	(3)	(4)	(5)	(6)
Constant Center	0.09*** (0.01)	0.08*** (0.02)	0.05** (.02)	.07*** (.02)	.20 (.12)	.23** (.12)
Constant Periphery	.13*** (0.03)	0.20*** (0.02)	.19*** (.02)	.20*** (.02)	.14*** (.02)	.15*** (.02)
Initial Income Center	-0.004** (0.002)	-0.002 (0.006)	.002 (.002)	-.001 (.002)	-.015 (.01)	-.018 (.013)
Initial Income Periphery	-.009** (0.004)	-0.015*** (0.003)	-.016*** (.002)	-.016** (.002)	-.01*** (.002)	-.010*** (.002)
Population Growth Center	-0.06 (0.08)	0.07 (0.18)	.49 (.35)	.21 (.35)	-.67* (.34)	-.778** (.33)
Population Growth Periphery	-.99*** (0.17)	-0.09 (0.08)	-.30* (.18)	-.16 (.16)	-.12 (.07)	-.11 (.08)
Patents	-	.002*** (0.0005)	-	.002*** (.0005)	-	.002*** (.0006)
Country Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Threshold Estimate	0.041	0.29	0.29	.29	9.22	9.22
SupWald-Test for no Threshold	25.02** (0.02)	18.61* (0.07)	54.06*** (0.00)	37.18*** (0.00)	22.16* (0.06)	21.33* (0.09)
Unconditional GDP growth center vs periphery	0.07% (0.65)	.22%*** (0.00)	.26%*** (0.00)	.27%*** (0.00)	0.12% (0.42)	0.12% (0.40)
Relative GDP per capita steady state center vs periphery	1.63 (0.57)	3.49*** (0.00)	∞*** (0.00)	6.21*** (0.00)	0.89 (0.59)	0.85* (0.09)
Wald-Test for country dummies	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
Hausman-test	-	-	0.00***	0.00***	-	-
Moran-I test	0.25**	0.24**	0.22**	0.23**	0.26**	0.24**
Breusch-Pagan test	0.00**	0.00**	-	-	0.00**	0.00**
Joint R^2	0.2488	0.3067	0.22	0.29	0.2507	0.291
Observations	590	531	547	500	590	531

Remarks: Standard errors in parenthesis (heteroscedasticity consistent if Breusch-Pagan test significant); *** significant at the 99% level; ** significant at the 95% level; * significant at the 90% level; SupTest: SupWald- or SupF-test for significance of threshold: See Hansen (1996), heteroscedasticity correction if Breusch-Pagan test significant, 1000 bootstrap replications, marginal probability in parenthesis; Unconditional GDP growth difference between center and periphery: two-sided test for group-mean difference with group specific variance; Relative steady state income per capita (H_0: $(\gamma_{01}+E(\beta'\mathbf{x}))/\gamma_{11}=(\gamma_{02}+E(\beta'\mathbf{x}))/\gamma_{12}$): Significance level from non-linear LR-test or non-linear Wald test; B.-Pagan-test: Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity; Hausman test for validity of instruments; instruments are the average annual growth rate of birth and of death; Moran-I test for spatial autocorrelation (** indicates significance at 5%-level); Unreported country dummies are always included;

Table 4 contains threshold regressions with the dependent variable GDP growth per capita and the independent variables initial income, population growth and patent applications per inhabitant. Specification (1) and (2) are the OLS threshold regressions with the threshold variable population density; specifications (3) and (4) apply instrumental variable threshold regressions[46], and specifications (5) and (6) use initial income as threshold variable instead of population density for the purpose of comparison.

Again, the threshold estimates are significant over all specifications. However, in the baseline specification (1) without patent applications as control variable centers do neither grow faster nor are permanently richer in the steady state. Note also that the threshold is rather low. However, adding patents as control variable in specification (2) yields a much larger threshold value and both the steady state difference test and the unconditional divergence test are highly significant. Centers now tend to grow faster by about 0.22 percentage points. This would amount to an annual income difference of 719 Euro between centers and peripheries in 1996 if the income level was identical across center and periphery in 1980 at the EU average income level.

Next, we control for endogeneity of population growth by using the instruments birth and death growth rates. Those instruments are valid according to a Hausman test. Now, the threshold of specification (1) jumps to the one of specification (2) even without patents and both the unconditional growth rate difference test and the theoretical steady state difference test are significant. Moreover, the convergence speed coefficient cannot be rejected to be zero in centers which implies that there may be endogenous growth in centers, but not in peripheries. The coefficient of population growth changes sign and becomes positive, but stays insignificant which suggests some mild degree of endogeneity of migration also on NUTS3 data. Patent applications are again a highly significant and robust control variable across all specifications.

The alternative threshold variable initial income is significant, but there is neither a significant difference of the unconditional growth rate of poor and rich regions, nor remains there a permanent income gap of poor and rich regions. Rather leap-frogging occurs at the 10 % significance level in the specification with patent applications. Moreover, threshold regressions with the threshold variable initial income

[46]These estimations do not correct for heteroscedasticity. However, this is very unlikely to affect our results.

have a lower R^2 than those with the threshold variable population density. We conclude that population density is a superior candidate to explain growth divergence in Europe after 1980.

Next, there is stronger spatial autocorrelation on NUTS3 data than on NUTS2 data according to the Moran-I test. We refer for the explanation to section 2.4: spatial autocorrelation of the error term on NUTS3- and weaker evidence of divergence on NUTS2-data may indicate that some centers and peripheries fall together in some NUTS2 regions, while several NUTS3 regions together may form a single center. In other words, the wavelength of agglomeration forces is suspected to be somewhere in between the regional disaggregation levels NUTS2 and NUTS3. Also the fact that the threshold estimates on NUTS2- and NUTS3-data are fairly close suggests that both data sets capture the same agglomeration forces.

The jump in the threshold from specification (1) to specifications (2)-(3) suggests the existence of several thresholds. Therefore, we test next the hypothesis of one against two thresholds.[47] We do find a second significant threshold both for specifications (1) and (2) of table 4 which explains the puzzling result in specification (1). There are no more than two significant thresholds. We present the results for the finally preferred specification with two thresholds and patent applications as control variable in table 5.

The two thresholds are close to each other at 290 and 210 inhabitants per km^2. The two low-population density groups are quite similar in terms of their relative average unconditional growth performance. In fact, the middle group is quite small (54 regions) and heterogenous in its GDP p.c. growth rates. Importantly, both the unconditional divergence and the steady state income difference test are significant between the highest population density and the middle population density group. The unconditional divergence test is not significant with respect to the low population

[47]Hansen (1996) derives the convergence results upon which the bootstrap procedure of the threshold test is built for only one threshold. Hansen (2000) points out that it is unknown whether his testing procedure applies to several thresholds, but applies them nevertheless to this case. He suggests a step-wise procedure. A first threshold is taken as given when a second threshold is searched for, etc. We follow his algorithm.

density group.

Table 5: Threshold Estimation of European Regions, NUTS3, Multiple Splits in Preferred Specification, 1980/1981-1996

Dependent variable: Per Capita GDP Growth	Threshold: Population Density		
	High population density >0.29	Medium population density: 0.29-0.21	Low population density: <0.21
Constant	.08*** (0.02)	0.33*** (0.03)	.16*** (0.02)
Initial Income	-0.002 (0.002)	-0.03*** (0.004)	-0.011*** (0.002)
Population Growth	-0.07 (0.18)	-0.24 (0.30)	-0.09 (0.08)
Patents	0.002*** (0.001)		
H_0: no threshold H_a: 1 threshold	18.61* (0.07)		
H_0: 1 threshold H_a: 2 thresholds	19.59* (0.06)		
H_0: 2 thresholds H_a: 3 thresholds	16.37 (0.11)		
Unconditional GDP p.c. growth difference Center vs Periphery	-	0.24%*** (0.00)	0.18% (0.30)
Relative Steady State GDP p.c. Center vs Periphery	-	3.62*** (0.00)	2.79*** (0.00)
Moran I	0.25**		
Breusch-Pagan test	0.00***		
R^2	0.33		
Observations	531		

Remarks: Standard errors in parenthesis (heteroscedasticity consistent if Breusch-Pagan test significant); *** significant at the 99% level; ** significant at the 95% level; * significant at the 90% level; SupTest: SupWald- or SupF-test for significance of threshold: See Hansen (1996), heteroscedasticity correction if Breusch-Pagan test significant, 1000 bootstrap replications, marginal probability in parenthesis; Unconditional GDP growth difference between center (defined as group with highest population density) and periphery: two-sided test for group-mean difference with group specific variance; Relative steady state income per capita (H_0: $(\gamma_{01}+E(\beta'\mathbf{x}))/\gamma_{11}=(\gamma_{02}+E(\beta'\mathbf{x}))/\gamma_{12}$): Significance level from non-linear LR-test or non-linear Wald test; B.-Pagan-test: Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity; Hausman test for validity of instruments; instruments are the average annual growth rate of birth and of death; Moran-I test for spatial autocorrelation (** indicates significance at 5%-level obtained from percentiles of a bootstrap);

Hence, we can conclude that divergence in growth processes between centers and peripheries is established on NUTS3 level, while evidence on NUTS2 level is somewhat weaker. The wavelength of agglomeration forces seems to be thus quite small in Europe, while it appeared quite large in the US. In contrast, we do not find evidence of divergence for Japanese prefectures. These results are consistent with our theoretical model. Note that countries with low population density face higher transport costs. Then, our theoretical model predicts that countries with high transportation costs, i.e. low overall population density, like the US may be in the divergence regime of the model, while countries with low transport costs because of high population density like Japan are in the convergence regime. Europe which has an intermediate population density may show some weaker tendency of divergence. An alternative explanation could be the activeness of regional economic policy which is very pronounced in Japan[48], less pronounced in Europe and little active in the US. However, we do not investigate into the impact of regional economic policy in this paper.

4 Conclusion

We asked the question whether regional income divergence exists and is caused by agglomeration forces as opposed to other divergence forces such as those assumed implicitly by the EU regional economic policy.

We merge an economic geography model with a neoclassical growth model and derive from the model that centers distinguish from peripheries in the sense of theory by a larger population density. Also, theory predicts that centers become permanently richer than peripheries.

We derive from the theoretical model a reduced form which can be directly tested using threshold regression techniques. We apply this technique to data on US states, Japanese prefectures and European regions. We check robustness by varying the sample period 1950-1980 versus 1980-1996, the regional disaggregation level (NUTS1, NUTS2 and NUTS3) for European regions and the use of different control variables and different threshold variables.

First, we find that US states with a high population density tend to grow significantly faster than regions with low population density. Japanese prefectures do not grow in dependence of their population density. In Europe, there is some significant income divergence between centers and peripheries since 1980 on NUTS2 level. The difference is stronger on NUTS3 level. An average person that decided to live in a center rather than a periphery in 1980 would have had an annual income gain

[48]We thank Prof. Hashimoto for pointing this out to us.

of on average 719 Euros in 1996. Part of this income gain is explained by the choice of higher education, while living in centers.

Of the EU regional economic policy eligibility criteria decline of the manufacturing sector of a region may call for temporary policies. Surprisingly, our threshold variable population density fares superior to initial income which is one of the main eligibility criteria for regional aid of the EU commision. If regional economic policy is effective, then we recommend to focus on measures that redirect demand for high-skilled labour towards peripheries. For example, universities or government agencies may be relocated towards peripheries.

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Appendix

Appendix 1: Proof of Proposition 1.

(a) In the following we denote fixed points by bars. We define the steady state conditions from equations (14) and the deterministic counterpart of (18), where we take into account that the variable pairs L_t and L_t^* and A_t and A_t^* grow by assumption each at the same rates, although labour may be unequally distributed in the steady state:

$$f\left(\bar{N},\bar{\rho}\right) = \bar{N} - \left(\frac{1-d_0^*}{1-d_0}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{L^*}{L}\right) \bar{\rho}^{\left(\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)} = 0 \tag{25}$$
$$g\left(\bar{N},\bar{\rho}\right) = \bar{N} - \frac{\bar{\rho}^{\sigma}-t}{\bar{\rho}\left(\bar{\rho}^{-\sigma}-t\right)} = 0$$

First, we show that there exists at least one steady state equilibrium. (i) If $\bar{N}=0$, then $\bar{\rho}\Big|_{f(\bar{N},\bar{\rho})=0}=0$ and $\bar{\rho}\Big|_{g(\bar{N},\bar{\rho})=0}=t^{\frac{1}{\sigma}}>0$. (ii) If $\bar{N}=\infty$, then $\bar{\rho}\Big|_{f(\bar{N},\bar{\rho})=0}=\infty$ and $\bar{\rho}\Big|_{g(\bar{N},\bar{\rho})=0}=t^{-\frac{1}{\sigma}}<\infty$. Then, there must exist at least one steady state solution by the intermediate value theorem, because the functions of (25) are continuous.

Next, we show that there are at most three steady state equilibria. To see this, we equalize $f\left(\bar{N},\bar{\rho}\right)=g\left(\bar{N},\bar{\rho}\right)$ and obtain:

$$\bar{\rho}^{\sigma}-t = \left(\frac{a^*}{a}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{L^*}{L}\right) \left(\bar{\rho}^{\left(1-\sigma+\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)} - t\bar{\rho}^{\left(1+\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)}\right). \tag{26}$$

The equation (26) can be transformed into a polynomial of degree 3, which has at most three solutions by Descartes' rule of sign.

Finally, we discuss stability. The condition for stability of any steady state $\bar{N}$, $\bar{\rho}$ is by definition and (18):

$$\varepsilon + \frac{\varepsilon\left(2\sigma-1\right)}{\left(\sigma-1\right)} \frac{d\ln\bar{\rho}}{d\ln\bar{N}}\Bigg|_{g\left(\bar{N},\bar{\rho}\right)=0} < 1 \tag{27}$$

After a small transformation, we obtain:

$$\frac{d\ln\bar{\rho}}{d\ln\bar{N}}\Bigg|_{g\left(\bar{N},\bar{\rho}\right)=0} < \frac{\left(1-\varepsilon\right)\left(\sigma-1\right)}{\varepsilon\left(2\sigma-1\right)} = \frac{d\ln\bar{\rho}}{d\ln\bar{N}}\Bigg|_{f\left(\bar{N},\bar{\rho}\right)=0}. \tag{28}$$

The reverse inequality of (28), i.e. $\left(d\ln\bar{\rho}/d\ln\bar{N}\right)\Big|_{g(\bar{N},\bar{\rho})=0} > \left(d\ln\bar{\rho}/d\ln\bar{N}\right)\Big|_{f(\bar{N},\bar{\rho})=0}$, is a necessary condition for the existence of three equilibria by the intermediate value theorem and (i) and (ii). Hence, the steady state equilibrium must be stable, if it is unique. If there exist three steady state equilibria $\bar{N}^*$, $\bar{N}^{**}$, and $\bar{N}^{***}$, $\bar{N}^*<\bar{N}^{**}<\bar{N}^{***}$, then the equilibria $\bar{N}^*$ and $\bar{N}^{***}$ must be stable and $\bar{N}^{**}$ unstable by the intermediate value theorem, (i) and (ii), and the above inequality. **Q.E.D.**

Appendix 2: Proof of Proposition 2. If $L_0^*=L_0+\omega$, $\omega>0$ and $K_0^*=K_0$. Then, $n_t^*>n_t$ for all t by forward induction of (17) and using (14). Hence, $\bar{N}>1$, $\bar{\rho}>1$. Vice versa, if $L_0^*+\omega=L_0$, $\omega>0$ and $K_0^*=K_0$. Then, $n_t^*<n_t$ for all t by forward

induction of (17) and using (14). Hence, $\bar{N} < 1$, $\bar{\rho} < 1$. Finally, if $L_0^* = L_0$ and $K_0^* = K_0$. Then, $n_t^* = n_t$ for all t by forward induction of (17) and using (14). Hence, $\bar{N} = 1$, $\bar{\rho} = 1$. **Q.E.D.**

Appendix 3: Proof of Proposition 3.[49]

Now, the Consumer optimization problem can be stated as:

$$\max_{\{C_t\}} \sum_{t=o}^{\infty} d^t E_t \left[\ln C_t\right] \tag{29}$$

s.t.:

$$\begin{aligned} K_{t+1} &= \pi_t n_t - C_t, \\ L_t &= t * a_0 + \nu_t, \\ L_t^* &= t * a_0 + \nu_t^*, \end{aligned}$$

together with (12), the familiar boundary conditions and initial conditions for the capital stocks and the initial values of the population and technology shocks. Recall that the deterministic population growth trend $t * a_0$ is identical in both regions, while there may be i.i.d. random fluctuations v_t, v_t^* around it. The first order conditions can be found to be:

$$\frac{1}{C_t} = dE_t \lambda_{t+1}, \tag{30}$$

$$\lambda_t = d\varepsilon \pi_t n_t K_t^{-1} E_t \lambda_{t+1}, \tag{31}$$

where λ_t is the Lagrange-multiplier associated with the constraint in (29). It must be shown that the first order conditions (30)-(31) are fulfilled for the guess (16).

Combining (30) and (31), taking logarithm, and solving for $\ln \lambda_t$ yields:

$$\ln \lambda_t = -\ln C_t + \ln \varepsilon + \ln \pi_t + \ln n_t - \ln K_t. \tag{32}$$

The logarithm is taken from (31) and equation (32) is inserted:

$$-\ln d - \ln C_t = \ln E_t \left[\frac{\varepsilon \pi_{t+1} n_{t+1}}{C_{t+1} K_{t+1}}\right]. \tag{33}$$

The guess (16) for C_t is forwarded one period and plugged into the right hand side of (33) to yield:

$$\begin{aligned} \ln E_t \left[\frac{\varepsilon \pi_{t+1} n_{t+1}}{C_{t+1} K_{t+1}}\right] &= \ln E_t \left[\frac{\varepsilon}{d_0 K_{t+1}}\right] \\ &= \ln \varepsilon - d_0 - \ln (1 - d_0) - \ln \pi_t - \ln n_t, \end{aligned} \tag{34}$$

where the second line is obtained by inserting the constraint in (29). The guess (16) is inserted into the left hand side of (33) and equalized to (34):

$$\ln d + \ln \varepsilon = \ln (1 - d_0). \tag{35}$$

Since the parameter d_0 is chosen to be $d_0 = 1 - d\varepsilon$, the guess (16) fulfills the first order conditions (30) and (31). **Q.E.D.**

[49]The proof follows closely Chow (1997).

Appendix 4: Proof of Proposition 4.

Let the home region be the center. We need first an auxiliary result. We note from (15), (16), and proposition 3 that in the steady state

$$\bar{K} = d\frac{\varepsilon\bar{\rho}\bar{n}}{\bar{P}} = d\frac{\bar{r}\bar{K}}{\bar{P}}, \tag{36}$$

where the second equality follows from (9). Hence, the real returns to human capital are equalized across regions in the steady state, i.e.

$$\frac{\bar{r}}{\bar{P}} = \frac{\bar{r}^*}{\bar{P}^*}. \tag{37}$$

Second, notice that $(K_t^*/K_t) \to 0$ implies that $N_t \to 0$, since L_t^*/L_t is bound between 0 and infinity by the assumption of immobility of some workers. But if $(K_t^*/K_t) \to 0$, then $(r_t^*/r_t) \to \infty$, because human capital is infinitely scarce in the foreign region. However, $(P_t^*/P_t) = \rho_t^{\frac{2\sigma-1}{\sigma-1}} < \infty$, as $N_t \to 0$, where the inequality can easily be checked with (14). Then must hold that

$$\frac{r_t/r_t^*}{P_t/P_t^*} \longrightarrow \infty, \text{ as } N_t \to 0. \tag{38}$$

¿From the continuity property of real returns to human capital, (37), (38), and the steady state ranking $N^* < N^{**} < N^{***}$, follows that

$$\frac{r_t/r_t^*}{P_t/P_t^*} > 1, \text{ if } N^* < N_t < N^{**} \text{ or } N_t > N^{***} \tag{39}$$

and the reverse inequality else.

Now, we are ready for the main proof. There is no migration at a distribution of labour $(L^*/L) = l/(1+l) < 1$, if there is no incentive for any inhabitant of the center i to move to the periphery in any time period t_0, i.e.

$$E_t\left[\sum_{t=t_o}^{\infty} d^t \ln\left(C_{it}/C_{it}^*\right)\right] > 0, \tag{40}$$

must hold, where

$$\begin{aligned} C_{it} &= d_0\frac{w_t + r_tK_{it}}{P_t} = d_0\frac{p_tn_t}{P_tL_t}, \\ C_{it}^* &= d_0\frac{w_t^* + r_t^*K_{it}^*}{P_t^*}, \\ K_{it+1} &= (1-d_0)\frac{p_tn_t}{P_tL_t}, \\ K_{it+1}^* &= (1-d_0)\frac{w_t^* + r_t^*K_{it}^*}{P_t^*} \end{aligned} \tag{41}$$

and

$$K_{it_0} = K_{it_0}^*, \tag{42}$$

because we assumed that human capital is embodied in migrants. It suffices to show that in period t_0 a worker who moves from the center to the periphery has both less consumption and less human capital accumulation than a worker who remains in the center, i.e.

$$E_t\{\ln\left(C_{it_0}/C^*_{it_0}\right)\} > 0, \tag{43}$$

and

$$E_t\left(K_{it_0+1}/K^*_{it_0+1}\right) > 0. \tag{44}$$

The inequality (43) can be rewritten with the help of (9) and (41) as:

$$E_t\left\{\ln\left(\frac{r_{t_0}/P_{t_0}}{r^*_{t_0}/P^*_{t_0}}\right) - \ln\left(\frac{K^*_{it_0}}{K_{t_0}}\right)\right\} > 0, \tag{45}$$

which is true, since the first term in the curley brackets is larger than 1 by (39), as long as the population growth shocks are not too large to switch the steady state from N^* to N^{***}, and the second term is zero by assumption (42). But from (41) and (45) follows immediately that

$$E_t\left(\ln C_{it_0}\right) = E_t \ln\left[\frac{d_0}{1-d_0}\left(K_{it_0+1}\right)\right] > E_t(\ln C^*_{it_0}) = E_t \ln\left[\frac{d_0}{1-d_0}\left(K^*_{it_0+1}\right)\right].$$

and thus (44) holds by Jensen's inequality.

There is a fraction of $l/2$ mobile workers in the periphery who move to the center in period 1. The worker distribution of the center relative to the periphery is thus $(1+l)/l$. This distribution does not change anymore, since there are only immobile offsprings left in the periphery and the mobile offsprings in the center have no incentive to move to the periphery. Thus, the population in center and periphery grow both at the same average rate and the relative distribution remains constant except for temporary population growth shocks. **Q.E.D.**

Appendix 5: Data Description

(a) Eurostat NUTS2 Data

The data for the European regions are taken from the CD-Rom version of the Eurostat Regio Database (2001). Eurostat provides data by 4 different regional classifications of regions, using their Nomenclature of Territorial Units for Statistics (NUTS): NUTS 0 generally corresponds to countries, NUTS 1 to states, NUTS 2 to a group of communities or cities, and Nuts 3 to single cities or communities. Eurostat (1995) also calls NUTS 2 regions "Basic Regions", and describes these as the appropriate level for analysing regional-national problems. Therefore, we use the data classified according to NUTS 2.

More specifically, NUTS 2 regions correspond to national administrative units in Austria (Bundesländer), Belgium (Provinces), Finland (Suuralueet), Germany (Regierungsbezirke), Greece (Development Regions), Italy (Regioni), Netherlands (Provincies), Portugal (Commissaoes de Coordenacao Regional), and Sweden (Riksområden). NUTS 2 regions also correspond to national administrative units, but with exceptions, in France (Régions, plus the four departments d'Outre Mer), and Spain (Communidades Autónomas, plus Ceuta y Melilla). Three member states are classified as a single NUTS 2 region: Denmark, Ireland and Luxembourg. In the UK, groups of Counties have been introduced as an intermediate (NUTS 2) level between NUTS 2 (Standard regions) and NUTS 3 (a combination of Counties and Local Authority Regions) units.

Our data used in the regressions covers the period 1980 to 1996. In the 2001 CD Rom there is also data for the subsequent years, but they are prepared following a new

European System of Accounts (ESA95) which replaces the old one (ESA79), on which our data is based and lacks comparability.

This choice of period restricts the list of countries from which regional data could be used to Belgium, Denmark, France, (Western) Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain. Within these countries we exclude all islands except Sicilia (Italy), which is only separated from Calabria (Italy) by the 3300 metres-wide Strait of Messina.

We also had to exclude Berlin, since from 1990 onwards East- and West-Berlin appears as only one region in the dataset. Three regions of the Netherlands (Flevoland, Overijssel, Gelderland) did not have data for GDP per capita in 1980 or 1981 and had to be excluded as well. Finally, Groningen was the richest European region in 1980 with by far the worst growth performance, because North Sea oil activities were attributed somewhat artificially to this region. Therefore we follow Neven and Gouyette (1995) and exclude this region, too.

This reduces the total of 210 NUTS 2 region available in Eurostat (2001) to 154 regions of which there are 11 in Belgium, 30 in West-Germany, 1 region Denmark, 15 regions in Spain, 21 regions in France, 10 regions in Greece, 1 region Ireland, 19 regions in Italy, 1 region Luxembourg, 9 regions in the Netherlands, 5 regions in Portugal, and 27 in the UK. We have obtained the observations for the UK from an older version of the Regiostat CD using an older NUTS2 classification. The UK NUTS2 regions were re-classified recently and no data are available except for the most recent years for the new classification. Similarly, the old classification is used for Ireland. The observation for London in 1981 is missing on the Eurostat CD and is replaced by information of the hardcopy version of the Eurostat "Annual Yearbook of Regional Statistics". When constructing country dummies, one country dummy is formed for Ireland and Luxembourg who both had similarly exceptional growth performances thanks to their tax policies. Denmark is considered as a German region, as it has a similar growth performance as German regions.

Table A1 provides an overview of the variables used.

Table A1: NUTS2 Summary Statistics

Variable	Observations	Mean	Standard Deviation	Min	Max
GDP growth p.c.	154	0.0595	0.007	0.040	0.089
Population growth	154	0.003	0.003	-0.007	0.013
Initial Income	154	8.80	0.26	8.08	9.49
Population density	154	0.357	0.713	0.02	6.22
Patent applications	101	-3.32	1.63	-6.90	-0.69
Share of agricultural employment	126	0.028	0.25	0.001	0.142
Percentage change in share of manufacturing employment	91	-0.01	0.01	-0.04	0.03
Human capital	100	2.80	0.32	1.79	3.47

The variables are defined as follows:

GDP growth: Average growth rate of GDP per capita in Purchasing Power Standards (PPS) between 1980 and 1996 (in log). For a few regions there is no GDP data for 1980, so that instead 1981 data is used. GDP data is not deflated. The EU-12 (excl. Greece, UK, Sweden) GDP deflator of OECD Economic Indicators for the period 1980 to 1996 is 5.2%.

Population growth: Average population growth rate between 1980 and 1996 (in log);

Initial income: GDP per capita in PPS as of 1980 (in log); In few cases initial income was not available in 1980, but in 1981 instead.

Population density: Population (in 1000s) per km2;

Patents: Patent applications per million inhabitants (in log);

Share of agricultural employment: People employed in agriculture, fisheries, mining and forestry as a share in total population in 1990 (in log). 1990 was chosen since this substantially increased the number of observations compared to 1980.

Human capital: People aged 25-59 with "high" educational attainment (ISCED 5,6,7) as a share of population aged 25-59 (in log) in 1993;

Decline of manufacturing employment: Share of manufacturing employment in population of 1990 minus share of manufacturing employment in population in 1980;

Area: Area of the region in km^2;

We construct the instrumental variables by decomposing population growth into its components birth rate, death rate, and net immigration over the period 1980/1981-1996. Then, we annualize the contributions of the death rate and birth rate to the population growth rate and use the resulting variables as instruments.

(b) Eurostat NUTS3 Data

Eurostat-NUTS3 data cover 1980-1996 and 1982-1996 for the regions of the Netherlands. Of the 1082 NUTS3 regions, we have observations only on 592 regions which stem from 6 countries: Belgium, France, Germany, Greece, the Netherlands, and Spain. We have excluded islands as for NUTS2 regions (except for the Greek islands) and we have lost the observations on East Germany and West-Berlin. The definitions of the variables is given as for NUTS2 regions above. Table A2 summarizes the observations by country and table A3 gives a summary statistics for all variables.

Table A2: NUTS3 Variables

Country	NUTS3-REgions	Observations without patents	Observations with Patents
Belgium	43	43	41
France	94	88	88
Germany	444	329	325
Greece	51	51	10
Netherlands	40	32	32
Spain	51	49	37

Table A3: NUTS3 Summary Statistics

Variable	Observations	Mean	Standard Deviation	Min	Max
gdpgrow	592	.0537413	.0101874	.0138308	.0859327
initinc	592	8.797134	.3441952	7.857442	10.14747
popgrow	592	.0046021	.0047403	-.0131378	.020131
patents	533	-2.471947	1.183849	-6.232776	.1918546
popdense	592	.4713863	1.139194	.0095169	20.89848

(c) Barro and Sala-i-Martin Data

The other data used in order to compare our results directly to previous research is the same as used and published in Barro and Sala-i-Martin (1995), i.e. for Japanese Prefectures 1955-1990, US states 1900-1990 and European regions for the period 1950 to 1990. The data is described at length in their book.