HWWA HAMBURG

DISCUSSION PAPER

Divergence - Is it Geography?

Thomas Straubhaar, Marc Suhrcke, Dieter Urban

HWWA DISCUSSION PAPER

181

Hamburgisches Welt-Wirtschafts-Archiv (HWWA)
Hamburg Institute of International Economics
2002
ISSN 1616-4814

The HWWA is a member of:

- Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)
- Arbeitsgemeinschaft deutscher wirtschaftswissenschaftlicher Forschungsinstitute (ARGE)
- Association d’Instituts Européens de Conjoncture Economique (AIECE)

Divergence - Is it Geography?

Thomas Straubhaar
Marc Suhrcke
Dieter Urban

The authors thank Elvisa Cokoja Torlak for her research assistance. Many helpful comments came from Matthias Ross and workshop participants of a workshop on "Economic geography and regional growth" at HWWA, Hamburg, the ERWIT conference 2001 at LSE, and seminars at University of Hamburg and University of Lueneburg.

This discussion paper is part of the HWWA's research programme "European Integration and Spatial Development".

HWWA DISCUSSION PAPER

Edited by the Department
EUROPEAN INTEGRATION
Head: Dr. Konrad Lammers

Hamburgisches Welt-Wirtschafts-Archiv (HWWA)
Hamburg Institute of International Economics
Öffentlichkeitsarbeit
Neuer Jungfernstieg 21 - 20347 Hamburg
Telefon: +49-40 428 34 355
Telefax: +49-40 428 34 451
E-mail: hwwa@hwwa.de
Internet: http://www.hwwa.de/

Thomas Straubhaar
HWWA Hamburg Institute of International Economics
Telefon: +49 40 428 34 350/351
Telefax: +49 40 428 34 451
E-mail: Straubhaar@hwwa.de

Marc Suhrcke
UNICEF Innocenti Research Centre
Piazza SS. Annunziata 12, 50122 Florenz, Italy
Tel +39 055 2033 345
Fax +39 055 244817
msuhrcke@unicef.org

Dieter Urban
London School of Economics
Centre for Economic Performance
Houghton Street, London WC2A 2AE, U.K.
E-mail: D.M.Urban@lse.ac.uk

Contents

ABSTRACT		VII
1	INTRODUCTION	1
2	THE THEORETICAL MODEL	3
2.1	Steady-States and Stability	6
2.2	Initial Migration	9
2.3	Derivation of Growth Equation and Tests	12
2.4	Endogeneity and Conditional Steady State	14
2.5	The Spatial Wavelength	16
3	EMPIRICAL ANALYSIS	18
3.1	Econometric Specification	19
3.2	Barro and Sala-i-Martin (1995) Data	21
3.3	Eurostat Data – NUTS2	22
3.3.1	Centers and Peripheries	22
3.3.2	Alternative Threshold Variables	27
3.4	Eurostat Data – NUTS3	30
4	CONCLUSION	34
REFERENCES		36
APPENDIX		39
Appendix 1:	Derivation of Growth Equation and Dynamical System	39
Appendix 2:	Proof of Proposition 1	40
Appendix 3:	Proof of Proposition 4	41
Appendix 4:	Derivation of consumption function	43
Appendix 5:	Data Description	44

List of Tables

Table 1:	Threshold Estimation on the Data of Barro and Sala-i-Martin (1995)	22
Table 2:	Threshold Estimation of European Regions, NUTS2, Threshold Population Density, 1980/1981-1996	25
Table 3:	Differences Across Centers and Peripheries	26
Table 4:	Threshold Estimation of European Regions, NUTS2, Alternative Thresholds, 1980/1981-1996	28
Table 5:	Threshold Estimation of European Regions, NUTS3, 1980/1981-1996	31
Table 6:	Threshold Estimation of European Regions, NUTS3, Multiple Splits in Preferred Specification, 1980/1981-1996	34
Table A1:	Provides an overview of the variables used	45
Table A2:	NUTS3 Variables	46
Table A3:	NUTS3 Summary Statistics	46

List of Figures

Figure 1:	A Parabel to a Continous Space Model – Perfect Match	17
Figure 2:	A Parabel to a Continous Space Model – Regional Units Too Large	17
Figure 3:	A Parabel to a Continous Space Model – Regional Units Too Small	18

Abstract

This paper tests a geography and growth model using regional data for Europe, the US, and Japan. 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 compared 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). Human capital and R&D are likely candidates for transmission channels of divergence processes.

Keywords: threshold estimation, new economic geography, regional income, growth, poverty trap, regime shifts, bootstrap

JEL classification: O41, R11, F12

March 14, 2002

Divergence - Is it Geography?*

By

Thomas STRAUBHAAR (HWWA and CEPR),

Marc SUHRCKE (UNICEF and HWWA),

Dieter URBAN (LSE)

Abstract

This paper tests a geography and growth model using regional data for Europe, the US, and Japan. 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 higher per capita income in the long-run 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 is used as eligibility criterium for regional aid by the EU commission. Divergence is stronger on smaller regional units (NUTS3) than on larger ones (NUTS2). Human capital and R&D are likely candidates for transmission channels of divergence processes.

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

Mailing Address of corresponding author: Dieter M. Urban, Centre for Economic Performance, London School of Economics, Houghton Street, London WC2A 2AE, U.K.; Tel.: ++44 207 955 6967; Fax.: ++44 207 955 7595; E-mail: D.M.Urban@lse.ac.uk.

*The authors thank Elvisa Cokoja Torlak for her research assistance. Many helpful comments came from Matthias Ross and workshop participants of a workshop on "Economic geography and regional growth" at HWWA, Hamburg, the ERWIT conference 2001 at LSE, and seminars at University of Hamburg and University of Lueneburg.

1 Introduction

This paper revisits the debate on conditional income convergence vs. club convergence of regions within countries in the light of New 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.

This question is 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. Moreover, by defining the criteria according to which regional aid is provided the EU Commission reveals also which types of regions it believes to become stuck in a poverty trap. Foremost, regions with less than 75% of EU average income are eligible. But also regions with industrial adjustment problems, huge structural unemployment problems, and regions specialized in agriculture are targeted.

This policy view has some backing in theoretical poverty trap models which are in contrast to neoclassical growth theory.[2] One particular type of a poverty trap is a core-periphery model of economic activity - i.e. a spatial concentration of economic activity - that emerges in the presence of scale economies, imperfect competition, and

[1] We use the terms divergence in per capita income or club convergence interchangeably if there exist two regions that are characterized by a stochastic dynamical system with identical parameters and the difference of output per capita of the two regions does not converge in probability to an unimodal distribution with mean zero. For definitions of unconditional convergence, conditional convergence, and club convergence see Galor (1996). For two formal definitions of convergence as catch-up or long run forecast in a stochastic setting see Bernard and Durlauf (1996).

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

transport cost.[3] Income divergence is driven by agglomeration forces rather than other complementarities.

Empirically, there is evidence of regional income divergence though not necessarily related to center-periphery disparities.[4] Moreover, there is ample indirect and direct evidence for economic geography models such as most recently Redding and Venables (2001),[5] although it does not provide evidence of income growth divergence driven by agglomeration forces. Spatial econometric studies such as Rey and Montouri (1999) show that income of a US state is dependent on the income of neighbour states, but it remains only loosely related to new economic geography models.

Our research objective is different in that we explore, whether there is club convergence of centers 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 are richer in the long-run.

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

[3] Those models distinguish by the state variables that drive divergence. Interregional or intersectoral worker mobility is one possibility (Krugman, 1991, and Krugman and Venables, 1995, Fujita, Krugman and Venables, 1999), regional specialization in R&D activity (Martin and Ottaviano, 1999, 2001) is another. Also, local inputs may be subject to scale economies (Englmann and Walz, 1995), or (human) capital accumulation diverges in space (Baldwin, 1998, Baldwin and Forslid, 1999, 2000a, 2000b, Baldwin, Martin, and Ottaviano, 2000, Urban, 2000).

[4] See for example on cross-country data Durlauf and Johnson (1995), Quah (1996), Hansen (2000), and Easterly and Levine (2001). 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. 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.

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

available we have selected the ones which can be seen as (part of) the criteria that the EU commission applies when deciding whether a region qualifies for regional policy intervention. Therefore, our exercise may be seen as a validity test of the official EU criteria. The use of other threshold variables also enables us to discriminate against other club-convergence models.

We find that centers are expected to be richer in the long-run than peripheries in the US and Europe after 1980, whereas there is no significant center-periphery difference for Japanese prefectures and European regions before 1980. Moreover, human capital and R&D are likely transmission channels of divergence. The evidence on divergence is stronger on smaller regional units (NUTS3) than on larger regional units (NUTS2) which suggests a rather short wavelength of agglomeration forces in Europe. Surprisingly, population density turns out to be a superior threshold variable compared to initial per capita income (which is used for 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

The purpose of this section is to obtain a reduced form from a theoretical geography and growth model that guides our empirical research: the choice of the econometric method, the variables, and the discrimination of geography and growth driven poverty traps from alternative poverty trap models. At the same time we require this model to fulfill some stylised facts and to contain a Solow growth model as a special case in an alternative hypothesis. Fulfilling these requirements comes at a price, though. We will have to employ a number of specific simplifying assumptions that are ultimately justified by the confrontation of the model with data. Henceforth, we make little effort to provide a general theory, but stick rather to a specific model.

There are two regions - home and foreign - and foreign variables are denoted by a star (*).[6] 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 maximize their utility function V subject to a dynamic budget constraint and some initial conditions:

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

where d is a region independent discount factor and $E_t[.]$ is the usual expectations operator conditional upon past information including period t. The stochastic elements are population growth and productivity shocks which we are more specific about below.

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 goods.[7]

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 savings, and Y_t^N nominal income.

[6] Foreign may be thought of as the "rest of the country".

[7] In monopolistically competitive markets, every good is produced by a different firm.

Firms differ only by their location.[8] 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, ε the region independent income share of capital, and A_t denotes total factor productivity which is assumed to be a stochastic deviation from a deterministic time trend.

More specifically, we assume on the stochastic shocks that $A_t = g^A \cdot t \cdot e_t^A$, where g^A is an exogenous technology growth parameter common to both regions and e_t^A is a region specific i.i.d. random shock with mean one. Likewise, regional population L_t fluctuates around a time trend g^L that is common to both regions, i.e. $L_t = g^L \cdot L_1 \cdot t \cdot e_t^L$, where L_1 is some initial level of population that is endogenized in section 2.2 and may vary across regions and e_t^L is some region-specific i.i.d population growth shock with mean one. For simplicity, there is zero correlation of any stochastic shocks.[9]

We assume immobility of human capital unless it is embodied in raw labour.[10] 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.

[8] 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 (*).

[9] This assumption abstracts from the findings of Funke, Hall, and Ruhwedel (1999) that industry specific shocks are dominant and regional shocks are thus autocorrelated if regions are specialized. We will take this into account in the empirical part by testing for spatial autocorrelation.

[10] 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.

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:[11]

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

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 ($K_{t+1} = I_t$).[12] (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 ($0 < \tau < 1$).

2.1 Steady-States and Stability

Before we can solve the model, we need some further notation. First, we define GDP per capita of a region as $y_t = \sum_{j=1}^{n} x_j p_{j0} = xn$, with some fixed base year price p_{i0} which can be fixed to 1 without loss of generality because all firms within a region are identical. Then we can define the relative GDP per capita as $Y_t = y_t^* / y_t$. Now we can summarize its dynamics in a single non-linear difference equation (equation of motion) which is derived in appendix 1:

$$\ln Y_{t+1} = c_0 + c_1 \ln \rho(Y_t) + \varepsilon \ln Y_t + \phi_t, \tag{7}$$

[11] This way of modelling (human) capital follows closely Baldwin (1999).

[12] 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.

where

$$\begin{aligned} c_0 &\equiv \varepsilon \ln L_1^* - \varepsilon \ln L_1 \gtrless 0, \\ c_1 &= (1-2\sigma)\,\varepsilon / (1-\sigma) > 0, \\ \phi_t &\equiv \varepsilon \ln e_t^{L*} - \varepsilon \ln e_t^{L} + \varepsilon \ln e_{t+1}^{A*} - \varepsilon \ln e_{t+1}^{A}. \end{aligned}$$

c_0 and c_1 are constants in terms of model parameters and ϕ_t is a stochastic term that consists of uncorrelated i.i.d random shocks with mean zero and is therefore i.i.d. with mean zero itself. $\rho(Y_t)$ is the relative producer price (terms of trade) which is given implicitly by a transformation of the goods market equilibrium condition as[13]:

$$Y_t \left(\frac{e_t^{L*} L_1^*}{e_t^{L} L_1} \right) = \frac{(\rho_t^{\sigma} - q)}{\rho_t \left[\rho_t^{-\sigma} - q \right]}. \tag{8}$$

The left hand side of (8) is nothing else but the ratio of regional GDP, while the right hand side can be shown to be an increasing function in the relative producer price. In other words, the relative producer prices rise if the relative home-market size rises. There is a bias of demand for locally produced goods, because goods from outside the region require a transport cost mark-up. Hence, demand for local goods is the stronger the larger is the home market. At the same time, supply of a single good is given independently of the home market size.[14] Thus a rise in demand rises relative producer prices. It is this home-market effect that distinguishes this model from a standard neoclassical growth model and eventually yields multiple equilibria.[15] The latter is derived in the following proposition.

Proposition 1: Steady State Equilibria and Stability

Assume that regional populations L_t, L_t^* and total factor productivities A_t, A_t^* fluctuate randomly each around the same deterministic trend and are uncorrelated i.i.d. random variables. Then, the difference equation given by (7) and (8) has either one or three fixed points. If it has three fixed points Y^*, Y^{**}, Y^{***}, with $Y^* < Y^{**} < Y^{***}$, then Y^* and Y^{***} are stable, while Y^{**} is unstable.

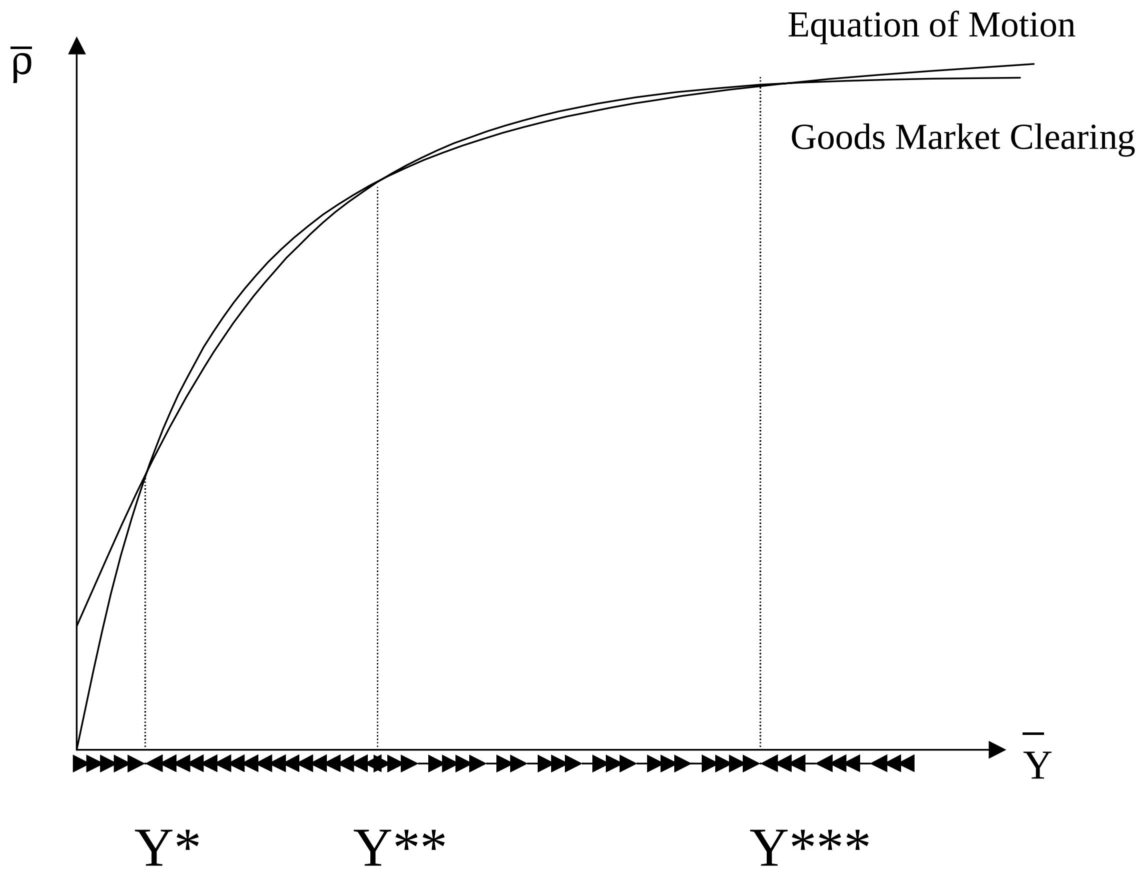
[13] The derivation is found in appendix 1, equation (22).

[14] See equation (19) in appendix 1.

[15] Urban (2001) has shown in a neoclassical two-country model with CRS technology, perfect competition and Armington condition that the opposite relation between terms of trade and income holds which yields always a unique stable steady state equilibrium.

Proof: See appendix 2. **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.[16] A general explicit condition that distinguishes the two regimes of multiple or unique steady state equilibria does not exist.[17] Henceforth, we will assume for the theory sections that the regime with multiple equilibria applies.



Steady State Equilibria and Stability in the Poverty Trap Regime

We can demonstrate the bifurcation regime in the above proposition by depicting the two equations (7) and (8) in the $\bar{\rho} - \bar{Y}$ diagramme above, where bars denote

[16]A parameter constellation that actually yields multiple equilibria is $d_0 = d_0^*$, $L_0 = L_0^*$, $\varepsilon = 0.75$, $\sigma = 2$, $\tau < 0.6$.

[17]If we assume that both regions are identical except for temporary shocks and differences in endogenous variables, then we can find a bifurcation condition that is identical to the one found in Urban (2000). The regime with multiple equilibria will occur if trade cost are large.

steady state values (e.g. $Y_t = Y_{t+1} = \bar{Y}$). The goods market equilibrium condition and the equation of motion are both increasing in $\bar{\rho} - \bar{Y}$ space. Multiplicity of equilibria emerges because the terms of trade rise with increasing relative GDP in a region and with increasing terms of trade there is an increase in wealth, a larger accumulation of human capital and eventually an increase of GDP in a region. This circular process drives the divergence of per capita income which is based on the divergence of human capital accumulation. Human capital accumulation diverges, because the return to human capital formation is endogenously larger, wherever there is a larger home market. Hence, location is an important endogenous determinant of economic growth in this model.

The results so far are similar to Baldwin (1999), 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 (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 distribution of population in 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]

[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.

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 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 one 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 2: *Suppose labour is equally distributed in space and the regions are identical in all respects in period 0 except for a stochastic shock favoring the foreign region such that* $e_0^L < e_0^{L*}$ and/or $e_0^A < e_0^{A*}$. *Moreover, suppose that the regime with*

[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 average. 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 expectation driven equilibria see Baldwin (2001).

multiple equilibria applies. In period 1, there is a massive migration towards the foreign region. From this period onwards $E\left(L_t^*/L_t\right) = \frac{2+l}{2-l} \equiv \frac{L_1^*}{L_1} > 1$. *This distribution of labour is a subgame perfect equilibrium.*

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

Propostion 2 explains why there may have been massive urbanization, i.e. migration from the peripheries to the centers in the past. 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 returns to human capital 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 chooses less human capital accumulation than as if she had stayed in the center. Hence, the center-periphery equilibrium 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.

Putting the two propositions together, we can think of the following thought experiment. Let's start with two regions which are equal in all respects in a regime with a unique equilibrium. Then, the structure of the economy changes and multiple equilibria arise. A temporary stochastic shock suffices to form expectations of one region having a permanently higher per capita GDP than the other (proposition 1). Then, massive migration of all footlose workers takes place to the former region forming a center and a periphery (proposition 2). This aggravates agglomeration forces even further and centers start actually growing faster than peripheries, because the larger home market of centers allows for a larger return to human capital accumulation (proposition 1).

Summing up, the growth performance of regions with high population density (centers) will be different from the ones with low population density (peripheries). Moreover, centers will have a permanently higher GDP per capita than peripheries even if they started with identical initial conditions.

2.3 Derivation of Growth Equation and Tests

Next, we derive the reduced form for estimation of the growth equation in the presence of multiple equilibria and a threshold:[22]

$$\ln y_{t+1} = \varepsilon \ln(\varepsilon d) + \varepsilon \ln y_t + \varepsilon \ln \pi_t + \varepsilon \ln\left(\frac{L_t}{L_{t+1}}\right) + \ln A_{t+1}. \qquad (9)$$

Note that the term $\ln \pi_t \equiv p_t/P_t$ is non-loglinear in y_t. Therefore, this term will have to be evaluated around the steady state. Importantly, this term differs dependent on a region being center or periphery. However then, seperate equations of (9) apply to either center or periphery. Therefore, we employ in our empirical tests the following (generalized) threshold regression equation:

$$\triangle \ln y_{t+1} = \begin{cases} \gamma_{01} + \gamma_{11} \ln y_t + \gamma_{21} \ln\left(\frac{L_t}{L_{t+1}}\right) + \gamma_{31} \ln A_{t+1} & \text{if } L_1/L_1^* > \gamma \\ \gamma_{02} + \gamma_{12} \ln y_t + \gamma_{22} \ln\left(\frac{L_t}{L_{t+1}}\right) + \gamma_{32} \ln A_{t+1} & \text{if } L_1/L_1^* < \gamma \end{cases}, \qquad (10)$$

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 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. The threshold variable L_1/L_1^* will be measured as population density as suggested by the theoretical model. Population density would still be the appropriate measure if we generalized the model to continuous space

[22] This equation is obtained from taking the logarithm of equation (27) in appendix 1.

and assumed uniform transport costs over distance. This will be briefly discussed in section 2.5.

Two caveats have to be made on the interpretation of a significant threshold in threshold regression equation (10). First, instead of multiple equilibria the threshold may simply be due to different unobserved parameters in centers and peripheries such as the income share of capital ε. Second, a threshold may be significant without existance of a poverty trap if the true functional form of the growth regression is not log-linear.

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 have a permanently higher steady state GDP per capita than peripheries conditional upon identical population growth and technical progress.[24] This will be the case, if

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

where $E[\beta' x]$ is the average score of the control variables upon which conditioning takes place. These scores may be different across centers and peripheries. This hypothesis will be tested with a non-linear hypothesis test.

Our regional data is limited in the time dimension. Hence, we cannot employ panel-estimations.[25] This limitation may bias the test of (11) if regional fixed effects

[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 cure exactly this problem of growth regressions.

[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.

[25] De la Fuente (1998) showed for Spanish regions that panel estimates of the convergence speed are upward biased, because business cycle effects interact with the long run growth behaviour. There are

proxy significantly for omitted variables, differ substantially across regions, *and* are at the same time correlated with the convergence speed. Moreover, the test (11) assumes a log-linear growth process for which we cannot test, since we cannot investigate the time path of GDP p.c. growth for each region.

All these shortcomings can be avoided by simply testing:

$$E[\triangle \ln y_{t+1} \,|L_1/L_1^* > \gamma] > E[\triangle \ln y_{t+1} \,|L_1/L_1^* \leq \gamma], \tag{12}$$

which can be done with a standard (two-sided) group mean-difference test. The drawback of test (12) 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 quickly. Moreover, no standard control variables are taken into account. Hence, test (12) 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.

2.4 Endogeneity and Conditional Steady State

An important problem of empirical growth research is the treatment of endogeneity problems. Population growth appears as independent variable in (10). Yet, population growth consists of the birth rate, the death rate and the net-migration rate and the latter may well be endogenous with respect to GDP growth. Workers may immigrate

two crude methods of correction for business cycle effects suggested which yield both panel estimates of the convergence speed close to the cross-section estimates.

Another reason for not using panel estimation techniques is that 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.

where econmic growth is largest. We can, however, easily control for this problem by using the death- and birth rate as instruments for population growth in an IV-threshold regression.

More involved is the endogeneity of another variable: human capital. We just provide a sketch of the problem. Suppose our theoretical model is true. Then it is straightforward to show that human capital follows a similar threshold process as income, i.e.

$$\ln k_{t+1} = \begin{cases} \alpha_{01} + \alpha_{11} \ln k_t & \text{if } L_1/L_1^* > \gamma \\ \alpha_{02} + \alpha_{12} \ln k_t & \text{if } L_1/L_1^* < \gamma \end{cases}, \tag{13}$$

where we simplified notation by suppressing control variables and α_{ij} are coefficients. Suppose that a researcher would estimate the following regression without threshold:

$$\ln y_{t+1} = \beta_0 + \beta_1 \ln y_t + \beta_2 \ln k_{t+1} + u_t, \tag{14}$$

where (as in our data set) human capital k_{t+1} is only available in the end of the period rather than in the beginning.[26] However, there is a simple link through the production function between human capital and income, i.e. $\ln y_t = \delta_1 \ln k_t$. Inserting this equation together with (13) in (14) yields a surprising result:

$$\ln y_{t+1} = \begin{cases} \gamma_{01} + \gamma_{11} \ln y_t + u_t & \text{if } \bar{L}/\bar{L}^* > \gamma \\ \gamma_{02} + \gamma_{12} \ln y_t + u_t & \text{if } \bar{L}/\bar{L}^* < \gamma \end{cases},$$

with $\gamma_{01} = \beta_0 + \delta_1\alpha_{01}$, $\gamma_{02} = \beta_0 + \delta_1\alpha_{02}$, $\gamma_{11} = \beta_1 + \alpha_{11}/\delta_1$, and $\gamma_{12} = \beta_1 + \alpha_{12}/\delta_1$. By including an endogenous variable which drives the divergence process as control variable into a standard growth regression, the threshold is hided behind this endogenous variable. In fact, a formal test would reject a threshold even though it exists. The reason why centers may grow faster than peripheries is exactly, because more human capital is accumulated in centers than in peripheries. However, more human capital is accumulated in centers, because centers provide more favourable investment conditions (e.g. a larger variety of goods to consume in the future).

This is only one possible interpretation. It may also be the case that a standard growth regression like (14) is correctly specified and a threshold truely does not

[26] The inclusion of human capital as proxy variable would still be justified, if initial and final human capital are closely correlated.

exist. For example, this is the case if more human capital is accumulated in centers if workers in centers just have a higher time preference rate and invest more into human capital. In this case, human capital is exogenous with respect to economic growth. Unfortunately, we cannot empirically discriminate with our data the two possibilities, because we do not have data to estimate (13) directly. Hence, we will conclude that human capital is a likely candidate of a transmission channel of divergence if a significant threshold renders insignificant by the inclusion of the human capital variable. Likewise, R&D may serve as another transmission channel of divergence which could be explored in the same way.[27]

2.5 The Spatial 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 migration-driven New Economic Geography model that this generalizes in a straightforward way to continuous space. In fact, a spatial wave on a circle line is formed such that regions whith high population density have a higher per capita income. Importantly, such a spatial wave implies an infinite number of different types of regions, rather than just two like in our model. Therefore, it is important to reflect informally on its likely consequences, although a formal analysis of a continuous space version of our growth model is beyond the scope of this paper. We hypothesize on a continuous space version of our model that regions with high population density grow faster and population density is clustered in spatial waves in analogy to Fujita, Krugman and Venables (1999).

Yet, regional data are not measured in spots on a continuous line, 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.

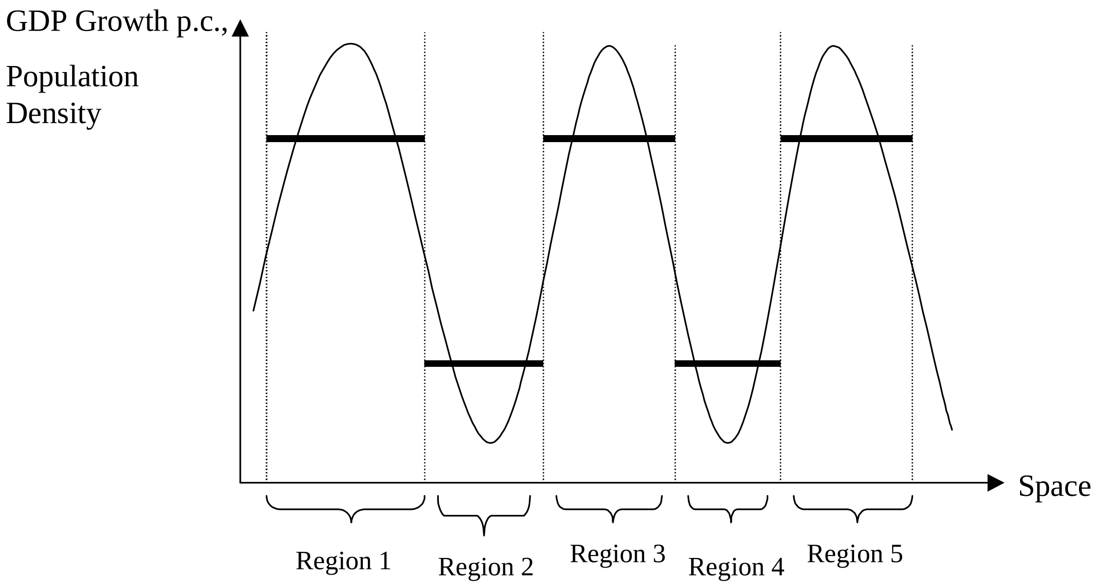


Figure 1: A Parabel to a Continuous Space Model - Perfect Match

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

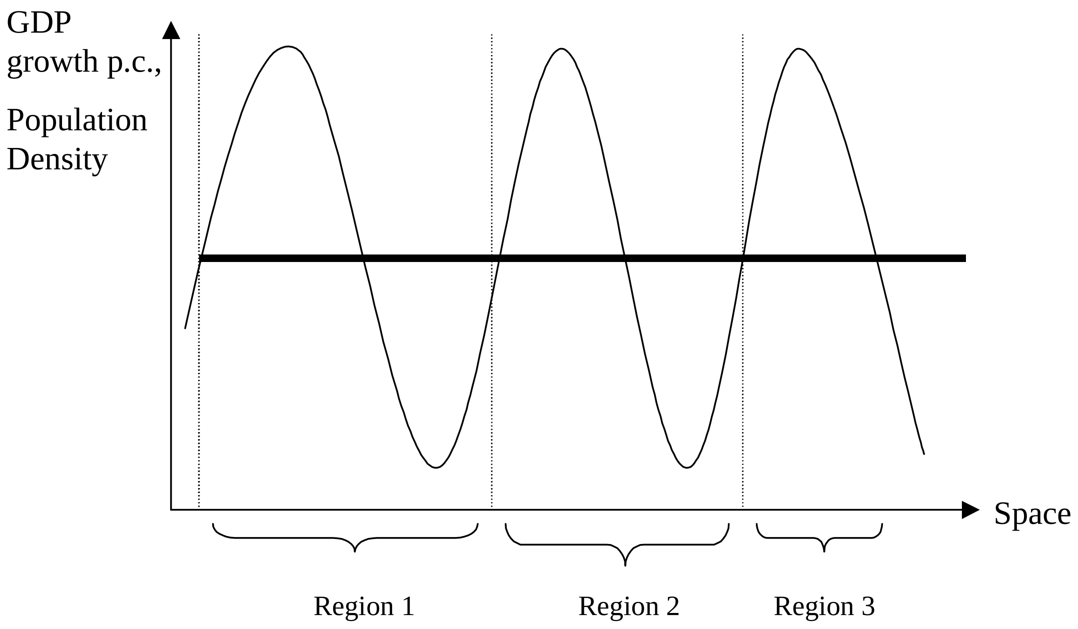


Figure 2: A Parabel to a Continuous Space Model - Regional Units Too Large

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 is possible (see figure 3).

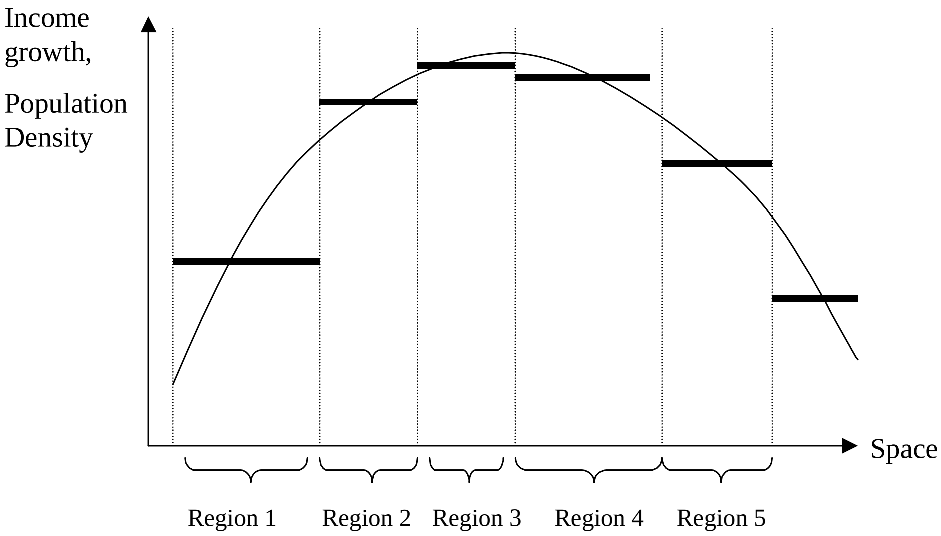


Figure 3: A Parabel to a Continuous Space Model - Regional Units Too Small

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 to see what results they would have obtained if they had used this more general estimation technique. Then, we use Eurostat data for European regions from 1980 until 1996 both on NUTS2 and NUTS3 level[28] to thoroughly explore whether there are divergence trends related to geography models in the recent regional development of Europe.

3.1 Econometric Specification

The growth equation (10) has a correspondence to econometrics: 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.

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

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 (10) 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 obtained from 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

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

which has a non-standard distribution dependent on the sample observations.[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 (11) 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. (12).

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 subset of variables. This is necessary to include country dummies, since matrix singularity problems would arise in the estimations otherwise. 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.

The regressions in column 2, 3 and 5 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. Column 4 reports the result of a threshold regression on US states.

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 regions in Europe particularly in the early post-World War period is in line with previous findings.[34]For the US states, the findings of convergence of Barro and Sala-i-Martin (1992) are not statistically valid, because an implicit restriction on coefficient heterogeneity is violated. We conclude that threshold regression technique may be relevant for regional economic growth analysis.

[32] Barro and Sala-i-Martin (1992) use non-linear least squares estimation, while threshold regression techniques are constrained to linear 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 on the Data of Barro and Sala-i-Martin (1995)

Dependent Variable: GDP per capita growth	Japanese Prefectures Without Threshold	US States without Threshold	US States with Threshold	European Regions 1950-1980 without Threshold
Constant Center	0.0369*** (0.0022)	0.08*** (0.004)	0.06*** (0.01)	-
Constant Periphery	-	-	0.09*** (0.01)	-
Initial Income Center	-0.0156*** (0.0022)	-0.007*** (0.001)	-0.006*** (0.001)	-0.0115*** (0.0016)
Initial Income Periphery	-	-	-0.010*** (0.001)	-
Population Growth Center	0.1967** (0.0941)	-0.02 (0.03)	0.22*** (0.06)	0.0021 (0.0753)
Population Growth Periphery	-	-	0.08** (0.04)	-
Threshold Estimate	-	-	4.4	-
Sup-Test for Threshold	4.84 (0.69)	-	16.54*** (0.00)	5.21 (0.69)
Unconditional GDP growth center vs. periphery	-	-	0.44%*** (0.00)	-
Relative Steady State Center vs. Periphery	-	-	1.10*** (0.00)	-
White-test	0.38	0.64	0.00***	0.00***
Adjusted R^2	0.56	0.82	0.91	0.52
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;
Sup-Test for Threshold: Modified F-Test or LM-Test for significance of threshold see Hansen (1996); 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;
White Test for heteroscedasticity: probability of accepting homoscedasticity;

3.3 Eurostat Data - NUTS2

3.3.1 Centers and Peripheries

To understand better why we obtained significant thresholds for some datasets and not for others, 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

[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.

PPP units[36], the 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 country 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

[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 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.

that there must have been at some point in history a divergence in income growth rates of regions with high and low population densities, respectively, or there must have been migration from poorly growing regions to faster growing regions.

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. In any case, population density looks like a good candidate variable to be included in more formal empirical regional analysis.

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.

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

Dependent variable: GDP Growth	OLS Threshold Estimation			IV Threshold Estimation		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant Center	0.07* (0.03)	0.19*** (0.04)	0.21*** (0.08)	0.05 (0.05)	0.19*** (0.05)	0.20*** (0.07)
Constant Periphery	0.11*** (0.03)	0.24*** (0.05)	0.26*** (0.04)	0.11*** (0.03)	0.23*** (0.05)	0.26*** (0.05)
Initial Income Center	-0.001 (0.004)	-0.013*** (0.004)	-0.017** (0.007)	0.000 (0.006)	-0.012** (0.005)	-0.016** (0.008)
Initial Income Periphery	-0.005* (0.003)	-0.018*** (0.005)	-0.022*** (0.005)	-0.005* (0.003)	-0.017*** (0.005)	-0.022*** (0.005)
Population Growth Center	1.46*** (0.29)	0.11 (0.18)	0.58 (0.37)	2.58*** (0.61)	0.22 (0.22)	0.74 (0.55)
Population Growth Periphery	-0.19 (0.18)	-0.63** (0.30)	-0.30 (0.19)	-0.20 (0.26)	-0.50 (0.40)	-0.04 (0.32)
Patents	-	0.003*** (0.001)	0.003** (0.001)	-	0.003*** (0.001)	0.002* (0.001)
Human Capital	-	-	0.006* (0.003)	-	-	0.006* (0.003)
Threshold Estimate	0.35	0.06	0.21	0.45	0.09	0.20
Sup-Test for Threshold	30.01*** (0.00)	8.23 (0.45)	10.18 (0.27)	23.61*** (0.00)	8.35 (0.43)	5.21 (0.6)
Unconditional GDP growth center vs periphery	-0.05% (0.65)	0.09% (0.67)	0.27%* (0.06)	-0.15% (0.30)	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)	∞ (0.27)	1.10 (0.32)	1.10 (0.42)
Wald test for country dummies	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
Hausman test	-	-	-	0.07*	0.84	0.33
Moran-I test	0.13	0.15	0.10	0.19**	0.15	0.07
Breusch-Pagan test	0.00***	0.21	0.51	0.00***	0.00***	0.68
Joint R^2	0.63	0.67	0.71	0.59	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; Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity; Hausman test for significance of instruments; instruments are the birth- and death rate; Moran-I test for spatial autocorrelation (** indicates significance at 5%-level according to the percentile distribution of 1000 bootstraps); Unreported country dummies always included;

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

[41] The hypothesis is formulated in the theoretical part, equation (11). 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.

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.

This is thus the case that we discussed theoretically in section 2.4. It may be the case that human capital accumulation and R&D drive the divergence process. In this case, the threshold test statistic may be insignificant, although the threshold exists. We can only check for this hypothesis imperfectly by noting the differences of average human capital and patent applications across all centers and peripheries, respectively.

Table 3: Differences Across Centers and Peripheries

	Center	Periphery	Mean difference Test (probability of equal mean)
Human Capital	3.07	2.73	0.00***
Patent Applications	0.16	0.03	0.00***

Remark: *** significant at 1 percent level; Threshold estimate from specification (1), table 2, applied.

It can be seen from table 3 above that there are significantly more human capital and significantly more patent applications in centers than in peripheries. Any differences in the growth performance of centers and peripheries may thus be explained by the differences in human capital and patent applications. Thus human capital accumulation and R&D are likely candidates of a transmission process of divergence.

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, although growth theory implies a negative relation. 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 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. 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.

So far, we can conclude that population density is a significant threshold variable and it divides centers and peripheries such that centers get richer than peripheries in the baseline specification. 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 weak 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 year 1990[42], and human capital.

[42] 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 4: 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;

The results are displayed in table 4. 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).

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.[43] The latter result suggests again that human capital accumulation may be a 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.

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

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.[44] 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 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.

A more severe shortcoming of our data is that we are unable to take into account commuting which is likely to be signifcantly large on NUTS3 data. Geography models suggest that net commuting takes place from peripheries into nearby centers. This may upward bias our GDP per capita measure in centers relative to peripheries, but not necessarily have an impact on growth rates (if the share of commuting workers did not increase over time). Hence, we will tend to underestimate the convergence speed in centers and overestimate it in peripheries. Still, the significance of commuting itself shows the relevance of agglomeration forces and economic geography which we want to show in this paper.

Next, we apply the threshold growth regression techniques to the NUTS3 data. The results are displayed in table 5 which 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)

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

and (2) are the OLS threshold regressions with the threshold variable population density; specifications (3) and (4) apply instrumental variable threshold regressions, and specifications (5) and (6) use initial income as threshold variable instead of population density for the purpose of comparison.

Table 5: Threshold Estimation of European Regions, NUTS3, 1980/1981-1996

Dependent variable: GDP per capita Growth	OLS Threshold Estimation		IV Threshold Estimation		OLS Threshold Estimation	
Threshold Variable	Population Density		Population Density		Initial Income	
Specification No.	(1)	(2)	(3)	(4)	(5)	(6)
Constant Center	0.09*** (0.01)	0.08*** (0.02)	0.05* (0.03)	0.12*** (0.02)	0.20 (0.12)	0.23** (0.12)
Constant Periphery	0.13*** (0.03)	0.20*** (0.02)	0.19*** (0.02)	0.23*** (0.02)	0.14*** (0.02)	0.15*** (0.02)
Initial Income Center	-0.004** (0.002)	-0.002 (0.006)	0.001 (0.003)	-0.006** (0.002)	-0.015 (0.01)	-0.018 (0.013)
Initial Income Periphery	-0.009** (0.004)	-0.015*** (0.003)	-0.016*** (0.003)	-0.019*** (0.003)	-0.01*** (0.002)	-0.010*** (0.002)
Population Growth Center	-0.06 (0.08)	0.07 (0.18)	0.49 (0.38)	-0.41** (0.19)	-0.67* (0.34)	-0.778** (0.33)
Population Growth Periphery	-0.99*** (0.17)	-0.09 (0.08)	0.30 (0.20)	-0.08 (0.19)	-0.12 (0.07)	-0.11 (0.08)
Patents	-	0.002*** (0.0005)	-	0.003*** (0.001)	-	0.002*** (0.0006)
Threshold Estimate	0.04	0.29	0.29	0.10	9.22	9.22
SupWald-Test for no Threshold	25.02** (0.02)	18.61* (0.07)	30.07*** (0.00)	19.14* (0.06)	22.16* (0.06)	21.33* (0.09)
Unconditional GDP growth center vs periphery	0.07% (0.65)	.22%*** (0.00)	0.26%*** (0.00)	0.30%*** (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)	1.57*** (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***	0.32	-	-
Moran-I test	0.25**	0.24**	0.22**	0.22**	0.26**	0.24**
Breusch-Pagan test	0.00**	0.00**	0.00***	0.00***	0.00**	0.00**
Joint R^2	0.25	0.31	0.22	0.25	0.25	0.29
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; Breusch-Pagan test for heteroscedasticity: probability of homoscedasticity; Hausman test for significance of instruments; instruments are the birth- and death rate; Moran-I test for spatial autocorrelation (** indicates significance at 5%-level according to the percentile distribution of 1000 bootstraps); Unreported country dummies always included;

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 rates. Those instruments are valid according to a Hausman test in specification (3) but not in specification (4). Now, the unconditional growth rate difference test and the theoretical steady state difference test are significant. The coefficients of population growth change sign, but stay mostly insignificant. 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 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.[45] 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 6.

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 density group.

Hence, we can conclude that divergence in growth processes between centers and peripheries is established on NUTS3 level, while evidence on NUTS2 level is 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

[45] 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.

the activeness of regional economic policy which is very pronounced in Japan[46], 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.

Table 6: 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 (?)		
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);

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

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

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 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.

References

Andrews, Donald W.K., (1993), Tests for parameter instability and structural change with unknown change point, **Econometrica**, Vol. 61, p. 821-856.

d'Aspremont, Claude, Rudolphe Dos Santos Ferreira, and Louis-André Gérard-Varet, (1996), On the Dixit-Stiglitz Model of Monopolistic Competition, **American Economic Review**, Vol. 86, p. 623-629.

Azariadis, Constantine C., (1996), The economics of poverty traps - Complete markets, **Journal of Economic Growth**, Vol. 6, p. 449 - 486.

Baldwin, Richard E., (1999), Agglomeration and endogenous capital, **European Economic Review**, Vol. 43, pp. 253-280.

Baldwin, Richard E., (2001), The core-periphery model with forward-looking expectations, **Regional Science and Urban Economics,** Vol. 31, p. 21-49.

Baldwin, Richard E., and Rikard Forslid, (1999), Incremental trade policy and endogenous growth, **Journal of Economic Dynamics and Control**, Vol. 23, pp. 797-821.

Baldwin, Richard E., and Rikard Forslid, (2000), Trade liberalisation and endogenous growth, **Journal of International Economics**, Vol. 50, p. 497-517.

Baldwin, Richard E., and Rikard Forslid, (2000), The core-periphery model and endogenous growth, **Economica**.

Baldwin, Richard E., Philippe Martin, (1999), Two waves of globalization, **NBER Working Paper**, No. 6904.

Baldwin, Richard E., Philippe Martin, and Gianmarco I. P. Ottaviano, (1998), Global income divergence, trade, and industrialization: the geography of growth take-offs, **Journal of Economic Growth**, forthcoming.

Barro, Robert J., (1991), Economic growth in a cross section of countries, **Quarterly Journal of Economics**, Vol. 106, p. 407-443.

Barro, Robert J., and Xavier Sala-i-Martin, (1992), Convergence, **Journal of Political Economy**, Vol. 100, p. 223-251.

Barro, Robert J., and Xavier Sala-i-Martin, (1995), Economic Growth, McGraw-Hill, New York.

Boldrin, Michele, and Fabio Canova, 2001, Inequality and convergence in Europe's regions: reconsidering European regional policies, **Economic Policy**, Vol., p. 207-253.

Bernard, Andrew B., and Steven N. Durlauf, (1996), Interpreting tests of the convergence hypothesis, **Journal of Econometrics**, Vol. 71, p. 161-173.

Canova, Fabio, 1999, Testing for convergence clubs in income per capita : A predictive density approach, **CEPR Discussion Paper**, No. 2201.

Davies, R.B., (1977), Hypothesis testing when a nuisance parameter is only present under the alternative, **Biometrika**, Vol. 64, p. 247-54.

de la Fuente, Angel, (1998), What kind of regional convergence?, **FEDEA Working Paper** EEE 7.

de la Fuente, Angel, (2000), Convergence across countries and regions: theory and empirics, **CEPR Discussion Paper,** No. 2465.

de la Fuente, Angel, and Xavier Vives, (1995), Infrastructure and education as instruments of regional pollicy: Evidence from Spain. **Economic Policy**, Vol. 20,

p. 11-40.

Diebold, Francis X., and Celia Chen, (1996), Testing structural stability with endogenous breakpoint - A size comparison of analytic and bootstrap procedures, **Journal of Econometrics**, Vol. 70, p. 221-241.

Dixit, Avinash K., and Joseph E. Stiglitz, (1977), Monopolistic competition and optimum product diversity, **American Economic Review**, Vol. 67, p. 297-308.

Durlauf, Steven N., and Paul A. Johnson, (1995), Multiple regimes and cross-country growth behaviour, **Journal of Applied Econometrics**, Vol. 10, p. 365-384.

Durlauf, Steven N., (2001), Manifesto for a growth econometrics, **Journal of Econometrics**, Vol. 100, p. 65-69.

Englmann, Frank C., and Uwe Walz, (1995), Industrial centers and regional growth in the presence of local inputs, **Journal of Regional Science**, Vol. 35, p. 3-27.

Easterly, William, and Ross Levine, (2000), It's Not Factor Accumulation: Stylized Facts and Growth Models, mimeo.

Esteban, Joan Maria, (2000), Regional convergence in Europe and the industry mix: A shift share analysis, **Regional Science and Urban Economics**, Vol. 30, p. 353-364.

Eurostat (1995), Regions: Nomenclature of Territorial Units for Statistics (NUTS), Luxembourg: Office for Official Publications of the European Communities.

Eurostat (2001), Regio Database, Luxembourg: Eurostat, 2001, CD-Rom version and network version.

Fischer, Peter A., and Thomas Straubhaar, (1999), The impact of mobility on regional development. Some empirical evidence for European countries, in: P. de Gijsel, M. Janssen, H.-J. Wenzel, M. Woltering (eds.), Understanding European cross-border labour markets. Issues in Economic Cross-Border Relations, Metropolis-Verlag, Marburg.

Funke, Michael, and Annekatrin Niebuhr, (2001), Threshold effects and regional economic growth - evidence from Germany, mimeo.

Fujita, Masahisa, Krugman, Paul R., Venables, Anthony J., (1999), The spatial economy : cities, regions and international trade, MIT Press, Cambridge MA.

Funke, M., S. Hall, and R. Ruhwedel, (1999) "Shock-Hunting: The Relative Importance of Industry-Specific, Region-Specific and Aggregate Schocks in the OECD Countries", The Manchester School of Economic and Social Studies (MMF Conference Supplement) 67, 49-65.

Galor, Oded, (1996), Convergence? Inference from theoretical models, **Economic Journal**, Vol. 106, p. 1056-1069.

Greene, William H., (1997), Econometric Analysis, Prentice-Hall Inc.

Hansen, Bruce E., (1996), Inference when a nuisance parameter is not identified under the null hypothesis, **Econometrica**, Vol. 64, p. 413 - 430.

Hansen, Bruce E., (1999), Threshold effects in non-dynamic panels: Estimation, testing, and inference, **Journal of Econometrics**, Vol. 93, p. 345-368.

Hansen, Bruce E., (2000), Sample splitting and threshold estimation, **Econometrica**, Vol. 68, p. 575-603.

Krugman, Paul R. (1980), Scale economies, product differentiation, and the pattern of trade, **American Economic Review**, Vol. 70, p. 950-959.

Krugman, Paul R. (1991a), Increasing Returns and Economic Geography, **Journal of Political Economy**, Vol. 99, No. 3, p. 483-499.

Krugman, Paul R., (1991b), History versus Expectations, **The Quarterly Journal of Economics**, Vol. 106, p. 651 - 667.

Krugman, Paul R., and Anthony J. Venables, (1995), Globalization and the inequality of nations, **Quarterly Journal of Economics**, Vol. 110, p. 857–880.

Mankiw, Gregory N., David Romer, and David N. Weil, (1992), A contribution to the empirics of economic growth, **Quarterly Journal of Economics**, Vol. 107, p. 407-37.

Marcet, Albert, and Fabio Canova, (1995), The Poor Stay Poor: Non-Convergence Across Countries and Regions, **CEPR Discussion Paper**, No. 1265.

Martin, P. (1998), Can regional policies affect growth and geography in Europe? **The World Economy**, Vol. 21, No. 6, pp. 757-774.

Martin, Philippe, and Gianmarco I. P. Ottaviano, (1996), Growth and agglomeration, **International Economic Review**, forthcoming.

Matsuyama, Kiminori, (1991), Industrialization, and Indeterminacy of Equilibrium, **The Quarterly Journal of Economics**, Vol. 106, p. 617 - 650.

Neven, D. and Gouyette, C. (1995), Regional convergence in the European Community, **Journal of Common Market Studies**, vol. 33, pp. 47-65.

Overman, Henry, and Diego Puga, (2001), Unemployment clusters across European regions and countries, **Economic Policy**, forthcoming.

Overman, Henry, Stephen Redding, and Anthony J. Venables, 2001, Trade and geography: a survey of empirics, mimeo.

Puga, Diego, European regional policies in light of recent location theories, **CEPR Discussion Paper**, No. 2767.

Quah, Danny T., 1996, Regional convergence clusters across Europe, **European Economic Review**, Vol. 40, p. 951 - 958.

Quah, Danny T., (1997a), Regional cohesion from local isolated actions: I. Historical outcomes, mimeo.

Quah, Danny T., (1997b), Regional cohesion from local isolated actions: II. Conditioning, mimeo.

Redding, Stephen, and Anthony J. Venables, (2000), Economic geography and international inequality, mimeo.

Rey, Sergio J., and Brett D. Montouri, (1999), US regional income convergence: A spatial econometric perspective, **Regional Studies**, Vol. 33, No. 2, p. 143-156.

Stockey, Nancy L., and Robert E. Lucas, Jr., (1989), Recursive methods in economic dynamics, Harvard University Press, Cambridge MA.

Straubhaar, Thomas, (1999), 'International Economics', 'Regional Economics' oder nur noch 'Economics'. 'Wettbewerb der Volkswirtschaften' oder 'wer wirbt um wen'?, (1999), mimeo.

Straubhaar, Thomas, and Martin R. Wolburg, (1999), Brain drain and brain gain in Europe, **Jahrbuecher fuer Nationaloekonomie und Statistik**, p. 574-604.

Urban, Dieter M., (2000), Neoclassical growth, manufacturing agglomeration, and terms of trade, **Centro Studi Luca d'Agliano Working Paper**, No. 136.

Appendix

Appendix 1: Derivation of Growth Equation and Dynamical System.

The corresponding ideal CES price index P_t (in home) for manufacturing goods is found to be:

$$P_t = \left(n_t p_t^{1-\sigma} + n_t^* p_t^{ex*(1-\sigma)}\right)^{\frac{1}{1-\sigma}}, \tag{15}$$

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:[47]

$$p_t = \left(\frac{\sigma}{\sigma-1}\right)\bar{c}\beta A_t^{-1} r_t^{\varepsilon} w_t^{1-\varepsilon} \quad \text{and} \quad p_t^{ex} = \tau^{-1} p_t, \tag{16}$$

where r_t is the return to human capital in the home country at time t and w_t is the wage rate in the home country.[48] Factor demand of firms is given by:

$$\begin{aligned} r_t k_t &= \varepsilon n_t p_t, \\ w_t l_t &= (1-\varepsilon)\, n_t p_t. \end{aligned} \tag{17}$$

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

$$n_t p_t x_t = K_t r_t + w_t L_t \equiv y_t^N. \tag{18}$$

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

$$x_t = \frac{\alpha(\sigma-1)}{\beta} \equiv 1, \tag{19}$$

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:

$$n_t = A_t K_t^{\varepsilon} L_t^{1-\varepsilon}. \tag{20}$$

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:

$$\frac{p_t^{-\sigma} y_t^N}{n_t p_t^{1-\sigma} + q n_t^* (p_t^*)^{1-\sigma}} - \frac{q (p_t)^{-\sigma} y_t^N}{q n_t p_t^{1-\sigma} + n_t^* (p_t^*)^{1-\sigma}} = 1, \tag{21}$$

[47] 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.

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

where $q \equiv \tau^{\sigma-1}$ for notational simplicity. Following again the steps in Urban (2000), we reformulate the goods market equilibrium condition (21) in the following equation where we conveniently define the terms of trade $\rho_t \equiv \frac{p_t^*}{p_t}$ and the relative GDP per capita $Y_t = \frac{n_t^*/L_t^*}{n_t/L_t}$:

$$Y_t = \frac{(\rho_t^\sigma - q)}{\rho_t \left[\rho_t^{-\sigma} - q\right]} \frac{\left(e_t^L L_0\right)}{\left(e_t^{L*} L_0^*\right)}, \tag{22}$$

where we made use of the stochastic processes of L_t and L_t^*. We define for future reference from the equation (22) the correspondence $\rho_t = \rho(Y_t)$ and note that relative producer prices depend positively on the relative GDP per capita and the relative population. Combining (3), (19), (21), and the depreciation assumption, yields:

$$K_{t+1} = \pi_t n_t - C_t, \tag{23}$$

where we define for convenience $\pi_t \equiv (p_t/P_t)$. Moreover,

$$\pi_t^*/\pi_t = \rho_t^{\frac{1-2\sigma}{1-\sigma}} \tag{24}$$

which follows from some manipulations after inserting (15) and (22) into the definitions of π_t and π_t^*. Now, we consider the consumption function that optimizes expected utility of consumers around some steady state to be defined later:

$$C_t = d_0 \pi_t n_t, \tag{25}$$

where $d_0 = 1 - d\varepsilon$ which is derived in appendix 4. We will later confirm this guess to be valid. Inserting (25) and (20) into (23), yields:

$$K_{t+1} = (1 - d_0) \pi_t A_t K_t^\varepsilon L_t^{1-\varepsilon}. \tag{26}$$

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 (25) is valid. Finally, we can express (26) in terms of GDP per capita y_t by noting that $y_t = n_t/L_t$ and making use of (20).

$$y_{t+1} = (1 - d_0)^\varepsilon \pi_t^\varepsilon y_t^\varepsilon \left(\frac{L_{t+1}}{L_t}\right)^{-\varepsilon} A_{t+1}. \tag{27}$$

We proceed by taking the logarithm of the ratio of (27) for the foreign region to (27) for the home region and obtain after some manipulations and use of (24) equation (7) in section 2.1.

Appendix 2: Proof of Proposition 1

In the following we denote fixed points by bars. We set up the steady state conditions from the deterministic counterparts to equations (22) and (7) before taking logarithms by setting the stochastic shocks equal to their mean values as is standard in time-series analysis:

$$f\left(\bar{Y}, \bar{\rho}\right) \equiv \bar{Y} - \left(\frac{1 - d_0^*}{1 - d_0}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{L_0^*}{L_0}\right)^{\frac{\varepsilon}{1-\varepsilon}} \bar{\rho}^{\left(\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)} = 0 \tag{28}$$

$$g\left(\bar{Y}, \bar{\rho}\right) \equiv \bar{Y} - \frac{\bar{\rho}^\sigma - q}{\bar{\rho}\left(\bar{\rho}^{-\sigma} - q\right)} \left(\frac{L_0}{L_0^*}\right) = 0$$

First, we show that there exists at least one steady state equilibrium.

(i) If $\bar{Y}=0$, then $\bar{\rho}\Big|_{f(\bar{Y},\bar{\rho})=0}=0$ and $\bar{\rho}\Big|_{g(\bar{Y},\bar{\rho})=0}=q^{\frac{1}{\sigma}}>0$.

(ii) If $\bar{Y}=\infty$, then $\bar{\rho}\Big|_{f(\bar{Y},\bar{\rho})=0}=\infty$ and $\bar{\rho}\Big|_{g(\bar{Y},\bar{\rho})=0}=q^{-\frac{1}{\sigma}}<\infty$.

Then, there must exist at least one steady state solution by the intermediate value theorem, because the functions of (28) are continuous.

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

$$\bar{\rho}^{\sigma}-q=\left(\frac{1-d^*}{1-d}\right)^{\frac{\varepsilon}{1-\varepsilon}}\left(\frac{L_0^*}{L_0}\right)^{\frac{1}{1-\varepsilon}}\left(\bar{\rho}^{\left(1-\sigma+\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)}-q\bar{\rho}^{\left(1+\frac{\varepsilon(2\sigma-1)}{(1-\varepsilon)(\sigma-1)}\right)}\right). \tag{29}$$

The equation (29) can be transformed into a polynomial of degree 3, which has at most three solutions by Descartes' rule of sign.

Next, we discuss stability. The condition for stability of any steady state $\bar{Y}$, $\bar{\rho}$ is by definition and (7):

$$\varepsilon+\frac{\varepsilon\left(2\sigma-1\right)}{\left(\sigma-1\right)}\frac{d\ln\bar{\rho}}{d\ln\bar{Y}}\Bigg|_{g\left(\bar{Y},\bar{\rho}\right)=0}<1 \tag{30}$$

After a small transformation, we obtain:

$$\frac{d\ln\bar{\rho}}{d\ln\bar{Y}}\Bigg|_{g\left(\bar{Y},\bar{\rho}\right)=0}<\frac{\left(1-\varepsilon\right)\left(\sigma-1\right)}{\varepsilon\left(2\sigma-1\right)}=\frac{d\ln\bar{\rho}}{d\ln\bar{Y}}\Bigg|_{f\left(\bar{Y},\bar{\rho}\right)=0}. \tag{31}$$

The reverse inequality of (31), i.e. $\left(d\ln\bar{\rho}/d\ln\bar{Y}\right)\Big|_{g(\bar{Y},\bar{\rho})=0}>\left(d\ln\bar{\rho}/d\ln\bar{Y}\right)\Big|_{f(\bar{Y},\bar{\rho})=0}$, 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 Y^*, Y^{**}, and Y^{***}, $Y^*<Y^{**}<Y^{***}$, then the equilibria Y^* and Y^{***} must be stable and Y^{**} unstable by the intermediate value theorem, (i) and (ii), and the above inequality. **Q.E.D.**

Appendix 3: Proof of Proposition 4.

Let the home region be the center. We need first an auxiliary result. We note from (23), (25), and proposition 2 that in the steady state

$$\bar{K}=d\frac{\varepsilon\bar{\rho}\bar{n}}{\bar{P}}=d\frac{\bar{r}\bar{K}}{\bar{P}}, \tag{32}$$

where the second equality follows from (17). Hence, the real returns to human capital are equalized across regions in the steady state, i.e.

$$\frac{\bar{r}}{\bar{P}}=\frac{\bar{r}^*}{\bar{P}^*}. \tag{33}$$

Second, notice that $(K_t^*/K_t)\rightarrow 0$ implies that $Y_t\rightarrow 0$, since L_t^*/L_t is bound between 0 and infinity by the assumption of immobility of some workers. But if $(K_t^*/K_t)\rightarrow 0$, 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 $Y_t \to 0$, where the inequality can easily be checked with (22). Then must hold that

$$\frac{r_t/r_t^*}{P_t/P_t^*} \longrightarrow \infty, \text{ as } Y_t \to 0. \tag{34}$$

From the continuity property of real returns to human capital, (33), (34), and the steady state ranking $Y^* < Y^{**} < Y^{***}$, follows that

$$\frac{r_t/r_t^*}{P_t/P_t^*} > 1, \text{ if } Y^* < Y_t < Y^{**} \text{ or } Y_t > Y^{***} \tag{35}$$

and the reverse inequality else.

Now, we are ready for the main proof. There is no migration at a distribution of labour $(L^*/L) = (2-l)/(2+l) < 1$, if there is no incentive for any inhabitant i of the center to move to the periphery in any time period t_0, i.e.

$$E_t\left[\sum_{t=t_o}^{\infty} d^t \ln\left(C_{it}/C_{it}^*\right)\right] > 0, \tag{36}$$

must hold, where

$$\begin{aligned} C_{it} &= d_0 \frac{w_t + r_t K_{it}}{P_t} = d_0 \frac{p_t n_t}{P_t L_t}, \\ C_{it}^* &= d_0 \frac{w_t^* + r_t^* K_{it}^*}{P_t^*}, \\ K_{it+1} &= (1-d_0)\frac{p_t n_t}{P_t L_t}, \\ K_{it+1}^* &= (1-d_0)\frac{w_t^* + r_t^* K_{it}^*}{P_t^*} \end{aligned} \tag{37}$$

and

$$K_{it_0} = K_{it_0}^*, \tag{38}$$

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.

$$E_t\{\ln\left(C_{it_0}/C_{it_0}^*\right)\} > 0, \tag{39}$$

and

$$E_t\left(K_{it_0+1}/K_{it_0+1}^*\right) > 0. \tag{40}$$

The inequality (39) can be rewritten with the help of (17) and (37) as:

$$E_t\left\{\ln\left(\frac{r_{t_0}/P_{t_0}}{r_{t_0}^*/P_{t_0}^*}\right) - \ln\left(\frac{K_{it_0}^*}{K_{it_0}}\right)\right\} > 0, \tag{41}$$

which is true, since the first term in the curley brackets is larger than 1 by (35), as long as the population growth shocks are not too large to switch the steady state from

Y^* to Y^{***}, and the second term is zero by assumption (38). But from (37) and (41) 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 (40) 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 $(l+2)\,/\,(l-2)$. This distribution does not change over time, 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. Hence, the relative distribution remains constant over time to the ratio in period 1 except for temporary population growth shocks. **Q.E.D.**

Appendix 4: Derivation of consumption function.[49]

Finally, we verify the guess on the consumption function *(25)*. The Consumer optimization problem can be stated as:

$$\max_{\{C_t\}} \sum_{t=o}^{\infty} d^t E_t\left[\ln C_t\right] \tag{42}$$

s.t.:

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

together with (20) and the familiar boundary and initial conditions and noting that π_t and n_t are deterministic dynamic processes. The first order conditions can be found to be:

$$\frac{1}{C_t} = dE_t\lambda_{t+1}, \tag{43}$$

$$\lambda_t = d\varepsilon\pi_t n_t K_t^{-1} E_t\lambda_{t+1}, \tag{44}$$

where λ_t is the Lagrange-multiplier associated with the constraint in (42). It must be shown that the first order conditions (43)-(44) are fulfilled for the guess (25).

Combining (43) and (44), taking logarithm, and solving for $\ln\lambda_t$ yields:

$$\ln\lambda_t = -\ln C_t + \ln\varepsilon + \ln\pi_t + \ln n_t - \ln K_t. \tag{45}$$

The logarithm is taken from (44) and equation (45) is inserted:

$$-\ln d - \ln C_t = \ln E_t\left[\frac{\varepsilon\pi_{t+1}n_{t+1}}{C_{t+1}K_{t+1}}\right]. \tag{46}$$

The guess (25) for C_t is forwarded one period and plugged into the right hand side of (46) to yield:

$$\ln E_t\left[\frac{\varepsilon\pi_{t+1}n_{t+1}}{C_{t+1}K_{t+1}}\right] = \ln E_t\left[\frac{\varepsilon}{d_0 K_{t+1}}\right] \tag{47}$$

$$= \ln\varepsilon - d_0 - \ln\left(1-d_0\right) - \ln\pi_t - \ln n_t,$$

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

where the second line is obtained by inserting the constraint in (42). The guess (25) is inserted into the left hand side of (46) and equalized to (47):

$$\ln d + \ln \varepsilon = \ln(1 - d_0). \tag{48}$$

Since the parameter d_0 is chosen to be $d_0 = 1 - d\varepsilon$, the guess (25) fulfills the first order conditions (43) and (44). **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.