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THRESHOLD EFFECTS AND REGIONAL ECONOMIC GROWTH – EVIDENCE FROM WEST GERMANY

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Abstract

We study an overlapping generations model of human capital accumulation with threshold effects using regional data for West Germany. Our basic goal is to shed light on what makes German regions grow. The paper finds that the relative income distribution appears to be stratifying into a trimodal distribution. Thus, application of the threshold model to a real world case, here West Germany, shows that the model might help to explain regional growth patterns.

JEL Classification: J24, O40, R11, C31.

Keywords: regional economic growth, human capital, Germany.

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1. Introduction

Recently, there has been renewed interest among economists in the determinants of economic growth. This resurgence has been motivated by endogenous and semi-endogenous growth theories predicting critical roles for human capital, innovation activities and/or economic policy as engines of growth. With this there have been extensive cross-national studies of what may explain differences in GDP per capita. Part of this empirical literature has choosen to focus on explaining differences in growth within countries by looking, in particular, at regional or city growth. Many of these studies have looked at whether growth rates tend to converge across time. This issue of conditional convergence has permeated the economic growth literature for more than a decade. An enormous volume of references can be cited, and the surveys by de la Fuente (1997), Durlauf and Quah (1999) and Temple (1999) are merely three examples of the amount of interest this topic has generated in the literature.[1] While much of the revival and application of economic growth theory has centered on cross-country patterns, it has also been used to discuss convergence within regional economic systems. In other words, the issue of uneven regional development has also moved to the top of the policy agenda.

Recently, theories of economic growth have suggested that the distribution of GDP per capita of countries or regions may display convergence clubs arising from some threshold level in the endowment of important factors of production. In this paper we use the theoretical frameworks of several of these papers to understand what makes West German regions grow. The empirical analysis will be conducted using cross-sectional regional level data covering the two decades from 1976 to 1996. Our basic goal is to shed further light on what makes West German regions grow. We pursue this goal by analysing the structure of correlation between important characteristics and subsequent productivity growth. Our conclusions suggest that multiple equilibria are indeed important in the German context.

The outline of the paper is as follows. The next section of the paper looks at the theoretical literature. Section 3 describes the dataset in more detail and provides some overall facts about regional growth in West Germany. In section 4 we then present threshold estimation results. A final section concludes.

2. A Simple Motivational Model

Human capital is generally believed to play a crucial role in the process of economic growth. Lucas (1988) has stimulated a large body of literature on the theory of economic growth. His model and subsequent models have focused upon human capital because the accumulation of human capital constitutes the backbone without which today´s global economy could not exist in its present form.

[1]The availability of large international datasets has lent an added impetus to research in this area. A compilation of cross-country growth regressions over the last 10 years is provided in Durlauf and Quah (1999, pp. 277-281). They have collected results on 36 variables and 87 papers. A critical assessment of the econometric growth literature is available in Durlauf (2001).

Human capital accumulation can also generate knowledge spillovers, which lead to higher productivity growth. Moreover, differences of human capital across regions may be associated with threshold effects and therefore persistent growth differentials across regions. These models have some important policy implications. First and foremost, the models imply that investment in human capital is too low from a welfare point of view because the investor reaps only part of the economy-wide benefits. Second, policy can enhance growth by changing the mix of investments.

We now relate our analysis to the recent modelling literature.[2] Suppose the intertemporal isoelastic utility function of agents in each region is given by

$$(1) \qquad u(c) = \begin{cases} \int_0^\infty \frac{c^{1-\sigma}-1}{1-\sigma} e^{-\rho t}\, dt & \text{if } \sigma \in (0,1), \\ \int_0^\infty \ln(c) e^{-\rho t}\, dt & \text{if } \sigma = 1 \end{cases}$$

where c is the single consumption good, ρ is a positive rate of time preference, and σ is the inverse of the intertemporal elasticity of substitution. For the sake of simplicity we assume that regional final goods value added is determined by the constant returns to scale intensive Cobb-Douglas production function

$$(2) \qquad y = k^{\beta} (lh)^{1-\beta}$$

where l is the fraction of time allocated to final good production and k (h) is the regional physical capital (regional human capital) stock.[3] The corresponding physical and human capital accumulation contraints can be expressed as

$$(3) \qquad \dot{k} = Ak^{\beta} (lh)^{1-\beta} - c$$

and

$$(4) \qquad \dot{h} = \delta (1-l) h$$

[2] On a methodological level, the closest work to ours is that of Aghion and Howitt (1998), pp. 327-333. Azariadis and Drazen (1990), Bala and Sorger (2001) and Lucas (1988). Since the models are rather well-known, we provide in the section only rudimentary details and concentrate instead on the results that are relevant for the empirical analysis.

[3] Lucas (1988) has generalised (2) by allowing for human capital spillovers across regions. This introduces the possibility that the laissez-faire solution be socially suboptimal because agents do not internalise the spillovers. We have tested for such spillovers in the empirical work below using various tests for spatial autocorrrelation.

where δ is the productivity of human capital in generating additional human capital. Equation (4) indicates that learning takes time, so that the human capital stock increases only after devoting time to education.[4] Furthermore, equation (4) relies on the „standing-on-shoulders effect“ suggested, for example, by Caballero and Jaffe (1993).[5] In any case, the instantaneous Hamiltonian is then given by

(5) $$H(\cdot) = \frac{c^{1-\sigma}-1}{1-\sigma}e^{-\rho t} + \lambda \left\{Ak^{\beta}(lh)^{1-\beta} - c\right\} + \mu \left\{\delta u h\right\}$$

where $u \equiv 1\text{-}l$ is the fraction of time allocated to human capital formation. It is straightforward to verify that the steady state growth rate g^* in this region is given by

(6) $$g^* = \frac{1-\beta}{\sigma(1-\beta)}(\delta - \rho)$$

where δ > ρ. Last we need the division of time between final goods production and human capital accumulation. The optimal time devoted to human capital accumulation is

(7) $$u^* = \frac{\delta - \rho}{\delta\sigma}$$

Combining (6) and (7) leads to

(8) $$g^* = \delta \; u^*$$

Equation (8) suggests that the regional steady state growth rate is proportional to the productivity of human capital (δ) and the fraction of time allocated to human capital accumulation u^*.[6]

We will now show how threshold effects can emerge in such a textbook model. We consider an extension of the model which is based upon Azariadis and Drazen (1990) and Azariadis (1996). The appeal of the model lies in its simplicity. We start by assuming a two-period OLG model. In every

[4] The microeconomic foundation of human capital accumulation is the sharing of knowledge and skills between employees that occurs through both formal and informal interaction. Jovanovic and Rob (1989) model individuals who augment their human capital through pairwise meetings at which they exchange ideas. In each time period each individual seeking to augment his knowledge meets an agent chosen randomly from a distribution of agents. It is clear the higher the average level of human capital of the agents, the more „luck“ the agents will have with their meetings and the more rapid will be the growth and diffusion of knowledge.

[5] According to the „standing-on-shoulders effect“ an economy relies and builds upon the insights embodied in previous human capital and ideas.

[6] One implication of this endogenous growth model is that there are scale effects associated to human capital accumulation. Jones (1998) has criticised this extreme implication and has described semi-endogenous extensions to the model that are designed to deal with this problem.

period $t \in \{0, 1, 2, ...\}$ a new generation is born. In period 1, the regional economy is summarized by a representative agent with a human capital endowment $h_{1,t}$. Specifically, we assume

(9) $$h_{1,t} = h_{2,t-1}$$

where $h_{2,t-1}$ is the human capital accumulated when old by an individual born at date t-1. In other words, the agent in period 1 inherits the human capital accumulated by the previous generation in period t-1. It remains to specify some dynamics for human capital accumulation in period 2. We suppose that the human capital accumulation constraint in the second period is given by

(10) $$h_{2,t} = \{1 + \delta(u_{t-1})u^{\theta}\}h_{1,t}$$

where $\delta(u_{t-1})$ is a nondecreasing productivity function with concave shape, and $\theta < 1$. The rationale for (10) arises from empirical studies which indicate that the manner in which agents acquire human capital, training and skills is influenced by complex interactions with other agents. Such influences are often collectively referred to as human capital spillovers. The concave shape captures the notion that there are diminishing returns to education.

We now turn to a characterisation of equilibrium human capital accumulation rules. We first consider the case where δ is an arbitrary given constant, i.e. $\delta(u_{t-1}) \equiv \delta$. On the basis of this notation, we can express the consumer optimum as the solution to the two-period (lifetime) objective function[7]

(11) $$\max_{u} (1-u)h_{1,t} + \rho h_{2,t}$$

which is maximised subject to the constraint

(12) $$h_{2,t} = (1 + \delta u^{\theta})h_{1,t}$$

The solution to this problem yields the optimal time allocated to human capital formation

(13) $$u^{*} = (\rho\delta\theta)^{1/1-\theta}$$

and the steady state growth rate

[7] Agents care only about their own consumption, i.e. there is no altruism or bequest motive.

(14) $$g^* = \frac{h_{2,t}}{h_{2,t-1}} = 1 + \delta(\rho\delta\theta)^{\theta/1-\theta}$$

Note that the steady state growth rate again depends upon the productivity of human capital accumulation measured by δ.

Next we consider the case when the human capital technology in (10) exhibits a threshold effect. In particular suppose

(15) $$\delta\,(u_{t-1}) = \begin{cases} \delta_1 & if \quad u_{t-1} \leq u^* \\ \delta_2 & if \quad u_{t-1} > u^* \end{cases}$$

where u^* is the threshold level of u ($0 < u^* < 1$) and $\delta_1 < \delta_2$. What are the implications of equation (15) for catching-up and convergence? Azariadis and Drazen (1990) and Azariadis (1996) show that in this set-up a multiplicity of locally stable equilibria can coexist. The first equilibrium is a low-development trap. When the previous generation has insufficiently invested in human capital and therefore $\delta(u_{t-1}) = \delta_1$, then the current generation receives low levels of human capital in their youth. Such agents then prefer to accumulate too little human capital throughout their lives ($u_1 < u^*$) which leads to a steady state growth rate of the economy given by

(16) $$g_1^* = 1 + \delta_1(\rho\theta\delta_1)^{\theta/1-\theta}$$

Intuitively, if regions have low initial levels of human capital and spillover effects are sufficiently small, then a self-perpetuating low GDP per capita level may occur into which regions are „locked-in". On the other hand, a high-growth equilibrium can occur. In this equilibrium the current generation receives high human capital benefits when young, i.e. $\delta(u_{t-1}) = \delta_2$. Such agents accumulate high levels of human capital ($u_2 > u^*$) which leads to the steady state growth rate

(17) $$g_2^* = 1 + \delta_2(\rho\theta\delta_2)^{\theta/1-\theta}$$

where $g_2^* > g_1^*$. Thus we obtain an endogenous explanation of different regional growth clusters, where regions self-select the class the belong to subsequently. The selection process is based upon market incentives and upon the regions „type". Thus, Azariadis and Drazen (1990) perhaps provide a more convincing story than Lucas (1988) for why regions with unequal human capital endowment grow at different rates.[8] Our subsequent empirical work is based upon the model of economic growth

[8] Redding (1996) has developed an extended model delivering multiple developing paths under more natural assumptions about human capital accumulation. In particular, he allows for complementarities between R&D

given in (16) and (17). However, the potential variations in growth behaviour are likely small relative to the overall variation in the series, and, as a consequence, it can be difficult to discern them in the data. To help circumvent this problem, we use a threshold estimation technique recently suggested by Hansen (2000).

3. Data Description

The analysis here will be conducted using cross-sectional spatial data for West Germany´s planning regions (*Raumordnungsregionen*) for the two decades between 1976 and 1996. These regions comprise several NUTS3 level regions that are linked by intensive commuting. In other words, our regions are economically coherent subregions in a labour market sense. For 71 analysed regions, there exists a relatively good database so that measurement errors should be comparatively minor. As the *Raumordnungsregionen* are determined on the basis of regional labour markets, they also provide a better basis for the analysis of growth processes than possible alternative classifications, especially the counties (*Landkreise*) which represent administrative units. Regional policies are also partly based on these areas. The regional system contains both highly agglomerated areas and rural-peripheral regions. We have used the regional *R&D* density as a proxy for the regional human capital intensity (*H*), i.e. the quality of the labour force.[9] In other words, the variable *H* gives the average number of *R&D* employees per square kilometre over the sample period obtained from the German employment statistics [Bade (1997b)].[10] In empirical studies human capital is usually measured by the educational level of employees or *R&D* employment. Both indicators are characterised by a rather similar spatial structure - a significant centre-periphery differential. With increasing agglomeration of a region, the share of highly skilled labour in total employment or the *R&D* density rises. Compared with agglomerated regions, rural areas are poorly endowed with human capital.[11] The regions also considerably differ with regard to GDP per capita.

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and educational investments. Further, Acemoglu and Zilibotti (2001) argue that international productivity differences can persist as a result of a different supply of skilled workers across regions. They use a „North-South“ type of model, therefore it could be argued that their model is not fully applicable to our dataset. However, if one thinks of their model as a continuum of skill differences across regions, rather than a dichotomy between the North and the South, then their results could be extended to the group of regions analysed here.

[9] We have not used conventional secondary enrollment rates as a proxy for human capital because there is very little variation across the regions (secondary schooling is mandatory in all of them). As a result, the impact of human capital on growth would be difficult to detect. A further problem is that schooling variables only measure the quantity of schooling, not the quality.

[10] Given the likely existence of long and variable lags between *H* and its impact on growth, it seems more reasonable to work with a measure of average human capital intensity during the relatively long period. Averaging out the *H* variable over time also has the practical advantage of eliminating most of the noise attributable to short-term errors of measurement and cyclical behaviour of data.

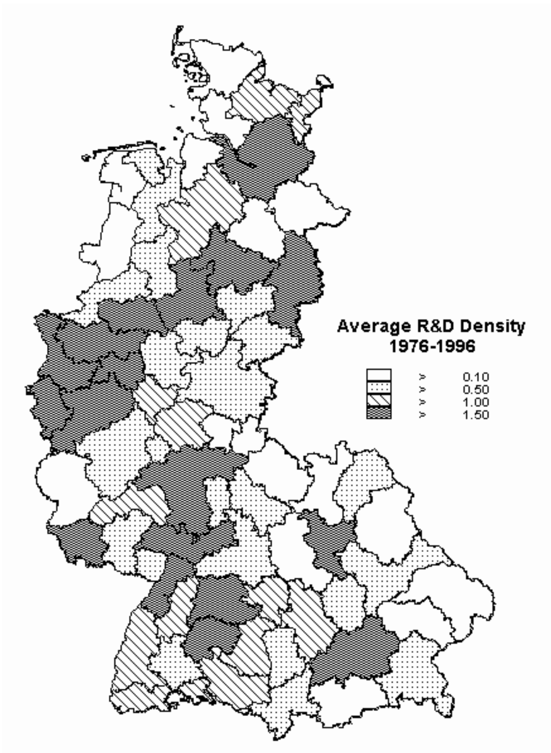
[11] For empirical evidence on corresponding regional disparities in Germany see Gehrke and Legler (1998) or ZEW (2000).

Table 1: Descriptive Statistics for the Regional Cross Section

Variable	Mean	Standard Deviation	Minimum	Maximum
H	1.70	2.10	0.13	9.71
$\ln(y_{76})$	10.56	0.13	10.28	10.87
$\ln(y_{96})$	11.47	0.13	11.20	11.89

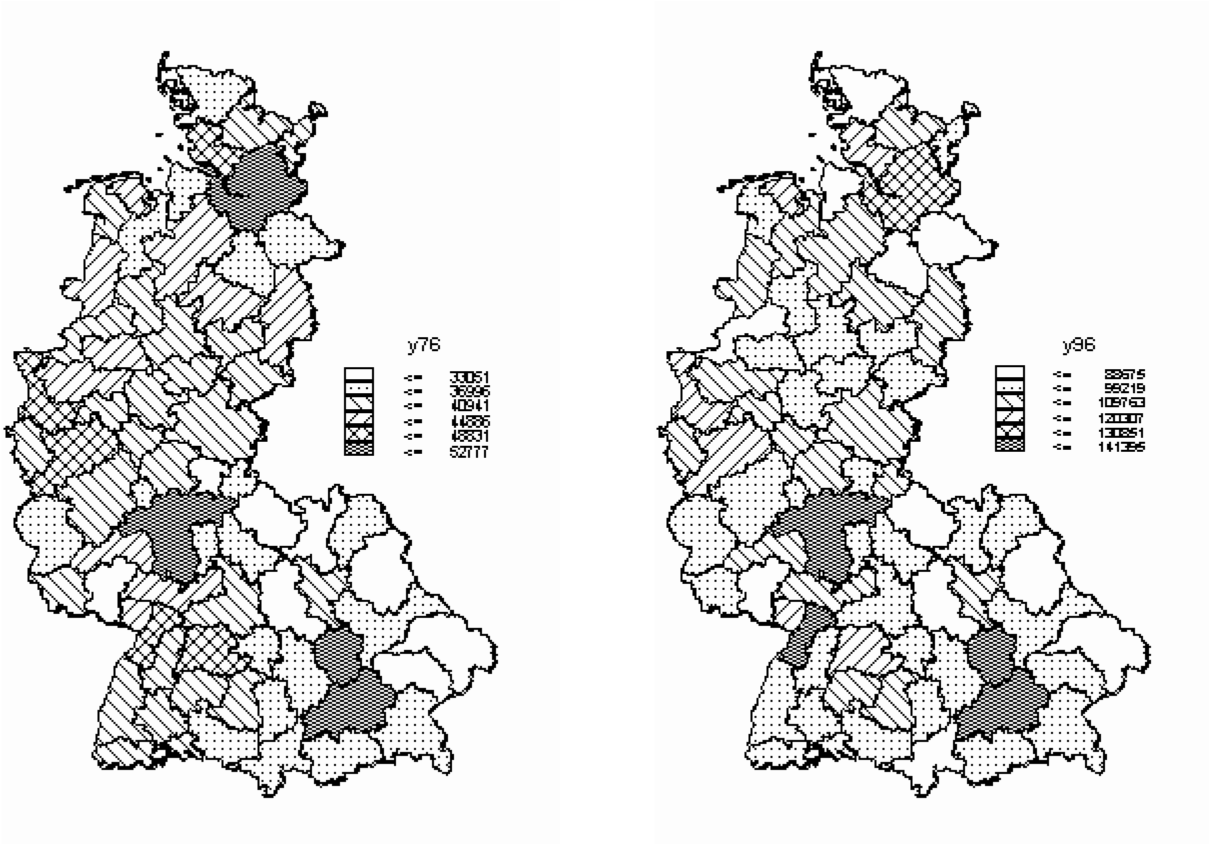
GDP per capita in 1976 (y_{76}) and 1996 (y_{96}) is measured by gross value added per employee. The corresponding data are not available from official statistics at such a small regional scale. Thus, estimates of regional employment and gross value added based on information from official statistics have to supply the necessary data [Bade (1997a)].[12] Economic performance has varied substantially across Germany´s *Raumordnungsregionen*. Figure 1 and 2 provide a visual impression of the spatial structures of human capital and productivity in West Germany. We see on Figure 1 and 2 that there exist spatial clusters as well. A high concentration of human capital characterises the agglomerations especially in the western and southern parts of West Germany, whereas the human capital intensity is comparatively low in most northern agglomerations. However, the spatial structure of the *H* variable is first of all marked by the striking disparities between the highly agglomerated areas and the rural peripheral regions. More or less the same centre-periphery-differential can be observed for GDP per capita.

Figure 1: Regional Human Capital Intensity



[12] For a detailed description of estimation method see Bade and Niebuhr (1999).

Figure 2: Regional GDP per Capita 1976 and 1996



The next step was to investigate the productivity convergence hypothesis in our cross-regional dataset.[13] To do this, we have have estimated the following „classical“ conditional convergence equation in which the growth rate is also an increasing function of *H*. Thus, the equation emphasises the role of human capital as a main engine of long-run growth:

(18) $$\ln(y_{i,96}) - \ln(y_{i,76}) = \alpha + \beta \ln(y_{i,76}) + \gamma(H_i) + \varepsilon_i$$

[13] In recent years researchers have progressively shifted their attention towards panel data sets and multivariate time series techniques [see, for example, Caselli et al. (1996) and Islam (1995)]. Pooling cross-sectional and time series information within a panel would abviously allow to distinguish more carefully between variation in space and time and to control for region-specific effects. Despite this critique, we will conduct our analysis using a cross sectional analysis for two reasons. First, the threshold estimation procedure for panel data suggested in Hansen (1999) does only allow to estimate thresholds in static (non-dynamic) panel data models. Second, as yet panel data procedures paying attention to spatial dependence are still in their infancy. An initial promising panel data approach towards allowing for spatial dependence is available in Driscoll and Kraay (1998).

Table 2: Regression Results For Regional Income Growth 1976-1996

Explanatory variables	OLS	ML - Spatial Lag
$\ln(y_{76})$	-0.014** (3.15)	-0.011** (2.83)
H	$4.7\cdot10^{-4}$ (1.45)	$4.5\cdot10^{-4}$ (1.85)
τ [$\gamma_E = 0.6$]		0.49** (2.82)
R^2_{adj}	0.12	
AIC	-593.0	-597.5
Jarque-Bera	10.5**	18.6**
Koenker-Bassett Breusch-Pagan	8.3*	 17.1**
Moran´s I	3.3** (0.4)[1)] [0.1-0.8][2)]	
LM_{ERR}	5.7** (0.6) [0.4-0.7]	2.8 (0.9) [-]
LM_{LAG}	9.6** (0.5) [0.3-0.8]	

Notes: ** (*) denotes significance at the 0.01 (0.05) level; [1)] corresponding distance decay γ_E; [2)] range of γ_E with significant spatial autocorrelation of the error term at the 0.05 level. The OLS *t*-statistics are based upon White's heteroscedasticity-consistent standard errors.

The regression analysis aims at examining the robustness of equation (18). The structural instability implied by the threshold model presented above suggests that a simple cross-sectional model that ignores the existence of convergence clubs should be misspecified. In Table 2 the results of the cross-sectional regressions are presented. The first column shows the estimates of a common OLS regression for the entire cross section, based on equation (18). The regression yields coefficients with expected sign for both the initial income level [$\ln(y_{76})$] and the human capital intensity (H). However, only the coefficient of $\ln(y_{76})$ is significant at the 0.01 level.[14] The explanatory power of the model is rather modest as indicated by the R^2_{adj}. Moreover several tests point to a misspecification. According to the Jarque-Bera test the assumption of a normal error distribution is violated. The Koenker-Bassett

[14] Bernard and Durlauf (1996) have argued that the initial-output regression approach tends to reject the null hypothesis of no convergence too often in the presence of multiple output equilibria. Thus, one should interpret

test suggests that heteroscedasticity might be a problem as well. And finally, the tests for spatial autocorrelation, Moran's *I* and Lagrange multiplier tests for spatial lag dependence (LM_{LAG}) and spatial error dependence (LM_{ERR}), provide strong evidence of the presence of spatial dependence. This reflects the stylised facts that faster (slower) growing regions tend to be geographically clustered. Therefore we now turn to a spatial econometric analysis. In the second column the results for a spatial lag model are presented. We included a spatially lagged dependent variable in order to capture spatial effects and eliminate the misspecification due to omitted spatial dependence, as indicated by the corresponding tests in column 1. The spatial lag model was estimated with different spatial weights matrices. We applied binary weights (common border of the regions) and a number of weights matrices based on a distance decay function (negative exponential function with varying distance decay parameter).[15] A spatial lag model with distance-based weights and a relatively high distance decay parameter [$\gamma_E = 0.6$] achieves the best fit according to the Akaike Information Criterion (AIC). The inclusion of the spatially lagged income growth reduces the residual autocorrelation to insignificance. Moreover, the positive and significant coefficient of the spatial lag τ points to highly localised spillover effects characterising regional growth in West Germany. However, taking into account spatial effects does not remedy all specification problems associated with the model. The Jarque-Bera statistic and the Breusch-Pagan test suggest that the model given by equation (18) plus a spatial lag is still misspecified.

One obvious problem of the conditional β-convergence estimation results in Table 2 is that they provide only a partial view of the convergence process. They focus exclusively on the average of the relative income distribution of regions. Although this statistic provides valuable insights into the convergence process, inferences based solely on the behaviour of this statistic are therefore incomplete. In particular, the answer to the question of whether or not the poor regions are catching up with the rich, depends on how the shape of the entire regional relative income distribution has changed over time, and not simply on the behaviour of the average of the distribution. The approach taken in this paper is to exploit more fully the information contained in the shape of the relative income distribution and the way in which it has changed over time. To do this, in the spirit of Quah (1997), we first provide some nonparametric kernel estimates of the relative income distribution of West Germany´s *Raumordnungsregionen* based upon the relative rankings of the regional per capita income in 1976 and 1996. In the first step, the real per capita incomes were rescaled as a fraction of Munich´s per capita income such that the range of the distribution is restricted to lie between 0 and 1.[16] In the

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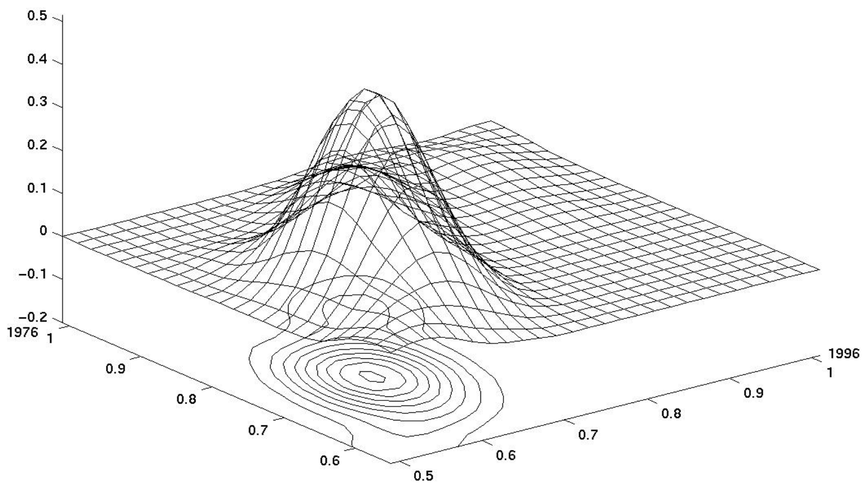
the cross-sectional result with caution. Goddard and Wilson (2001) have shown that cross-sectional estimation of convergence equations is hazardous if there is convergence towards heterogeneous steady states.

[15] All weights matrices are row-standardized. The distance-based weights are given by: $w_{ij}^* = \exp(d_{ij} \cdot \ln(1-\gamma_E)/D_{MIN})$, where d_{ij} denotes the distance between the regions *i* and *j*, D_{MIN} is the average distance between immediately neighbouring regions and γ_E is the distance decay parameter.

[16] We have used the region with the hightest per capita income (Munich) as a numeraire. The choice is arbitrary but has no impact on the analysis. We have used the data-based bandwith selection suggested by Silverman (1986).

next step, biweight (quartic) kernel estimates were calculated. The results are presented in two ways – as a three dimensional diagram and as a contour plot. The horizontal axes measure regional per capita income in 1976 and 1996 respectively. The vertical axis measures the filtered relative frequency, in percent. In other words, the height of the distribution shows the frequency with which a particular growth experience occurred between the two time periods. Points of the distribution that lie along the diagonal represent unchanged relative incomes, i.e. complete persistence in the distribution. A movement to the right of the diagonal indicates improvement in relative income ranking, while a movement to the left suggests a worsening in the relative income ranking between the initial and terminal years. What do the intradistribution dynamics for the entire period 1976 – 1996 look like? The kernel shows that the dominent experience among western Germany´s regions was that relative incomes were between 60 and 70 percent of Munichs´s income in 1976 and remained in that interval until 1996. This picture of apparent immobility is, however, not entirely correct. Along the diagonal of the panel, the entire distribution has slightly skewed to the left. This implies that although most regions remained in the interval between 60 and 70 percent, several shifted to the lower end of that interval until 1996. Even more interestingly, some initially rich regions have gravitated to the left to form a second cluster (local maximum). The initial visual impression therefore is that there is a tendency towards a bimodal distribution („twin peaks" or „convergence clubs"). The contour plot confirms this impression.[17]

Figure 3: Distribution Dynamics over the Period 1976 to 1996



[17] There is even visual evidence that there exists a third cluster (a „bulge" in the upper tail of the distribution) of regions with relative incomes between 90 and 100 percent in both years, albeit a very weak one.

4. Threshold Estimation Results

For the model in section 2 to have sharp predictions, one would need to know the number and the location of the human capital thresholds. In this section we will therefore provide firmer econometric ground on whether convergence clubs can be identified using the threshold estimation technique suggested by Hansen (2000). The approach is based on a very simple idea. The model with a single threshold takes the form

$$(19) \qquad y_i = \alpha_i + \beta'_1 x_i I\left(q_i \le \gamma\right) + \beta'_2 x_i I\left(q_i > \gamma\right) + e_i$$

where the dependent variable y_i is a scalar, x_i is a vector of regressors, $I(\cdot)$ is an indicator function, the threshold variable q_i is a scalar, and e_i is an iid $N(0, \sigma^2)$. The subscript indexes the regions $\{1 \le i \le n\}$. Equation (19) can be re-written as

$$(20) \qquad y_i = \begin{cases} \alpha_i + \beta'_1 x_i + e_i & if \quad q_i \le \gamma \\ \alpha_i + \beta'_2 x_i + e_i & if \quad q_i > \gamma \end{cases}$$

The threshold model therefore allows the regression parameters to differ depending on the value of q_i.[18] This implies that the procedure allows formal verification of the number of convergence clubs in the cross-section. Hansen (2000) has suggested a practical and straightforward method to estimate γ using least squares techniques and to construct asymptotically valid confidence intervals for γ.[19] *F*-tests can then be used to test for threshold effects ($\beta_1 \neq \beta_2$), and likelihood ratio tests $LR(\gamma)$ can be constructed to test the hypothesis H_0: $\gamma = \gamma_0$. In other words, the major innovation of the elegant technique is to treat the number and the size of the thresholds as unknown. Furthermore, the procedure allows to test whether the identified threshold effect is statistically significant.

An additional problem is the possibility of multiple thresholds. Bai (1997a, 1997b, 1999) shows that (mechanically) proceeding sequentially in testing for thresholds, i.e. test first for one threshold against no threshold; then conditional on the results of the first test, test for the existence of a threshold in each of the two subsamples and so on, produces consistent estimates of the number and the location of the thresholds. However, when there are multiple thresholds, and one tests for the presence of one threshold only, the estimated break point is consistent for any of the existing break points and its location depends upon which of the breaks is „stronger". If this is the case, Bai (1997a, 1997b, 1999) has suggested to refine the estimate of the thresholds. That is, if two thresholds are identified at n_1 and n_2, one should re-estimate n_1 over the interval $[1, n_1]$ and n_2 over $[n_1, n]$. Each refined estimator of the

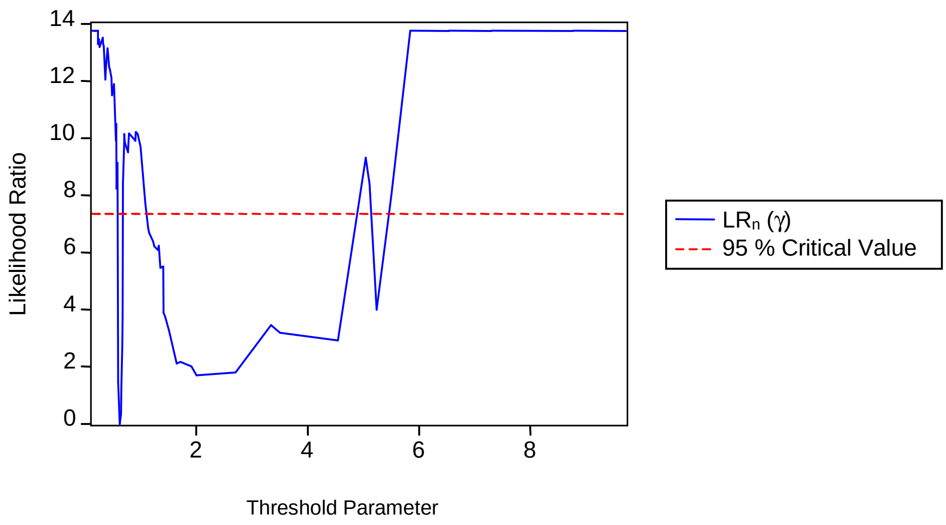
[18] The threshold variable q_i may be an element of x_i.

[19] The computationally easy procedure determines γ as that value that minimises the concentrated sum of squared errors function.

location of the threshold has then the same properties as the estimator obtained in the case the sample has a single break point.[20]

Following this computationally convenient sequential procedure we allow the number of thresholds to be unknown and endogenously determined by the data. We have used the human capital intensity variable (*H*) as our threshold variable to determine threshold effects in equation (18).[21] Figure 4 displays a graph of the normalised likelihood ratio sequence LR(γ) when estimating a single-threshold model. The least squares estimate of γ is the value that minimises this graph, which occurs at γ_1 = 0.6198. The asymptotic 95% critical value of 7.35 is also plotted (dotted line). The tight 95% confidence interval can be found by the values of γ_1 for which the likelihood ratio lies beneath the dotted line. The result shows that there is reasonable evidence for a two-regime specification. Furthermore, Figure 4 indicates that there may be a second dip in the likelihood ratio. Thus the single threshold likelihood conveys information that suggests that there may be a second threshold in the regression. Following the procedure suggested by Bai (1997a, 1997b, 1999), we have therefore searched for a double threshold. This sequential procedure using subsamples leads to a second significant threshold which occurs at γ_2 = 1.6449.[22] The graph for this second threshold is displayed in Figure 5 We have also tried to further split the subsamples in order to test for a third threshold. The resulting *H* threshold estimate γ_3 = 5.8378, however, turned out insignificant (bootstrap p-value p_3 = 0.49). Thus we conclude that there is a double threshold effect in equation (18).

Figure 4: Likelihood Ratio Sequence in the Single Threshold Model



[20] The main limitation of the above theory is that is is confined to least-squares estimation of thresholds. There is yet no extension to GMM estimation.

[21] This is consistent with the Azariadis and Drazen (1990) model described above in which a multiplicity of locally stable equilibria can be generated by differences in human capital.

[22] Both thresholds are significant, with bootstrap p-values of p_1 = 0.05 and p_2 = 0.02, respectively. Note, however, that there is considerable uncertainty about the exact value of the second threshold and therefore about the proper division of *Raumordnungsregionen* into convergence clubs.

Figure 5: Likelihood Ratio Sequence in the Double Threshold Model

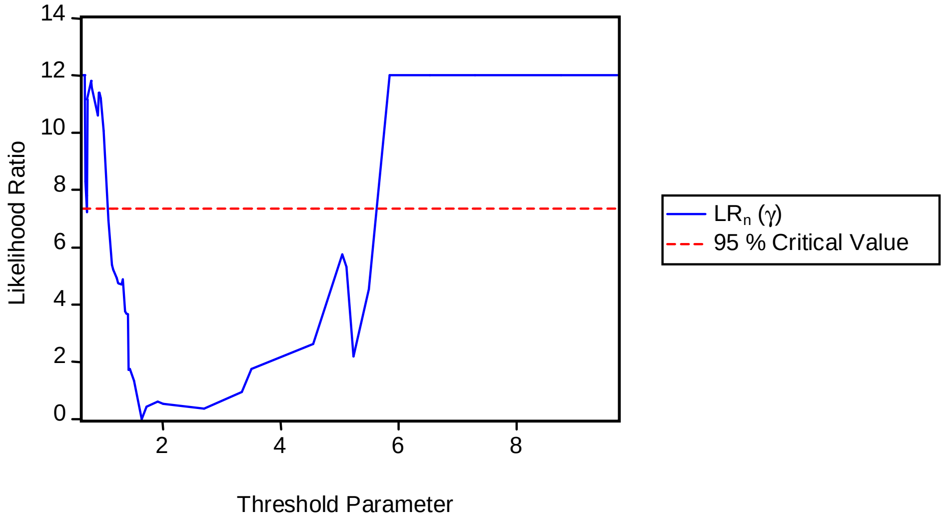
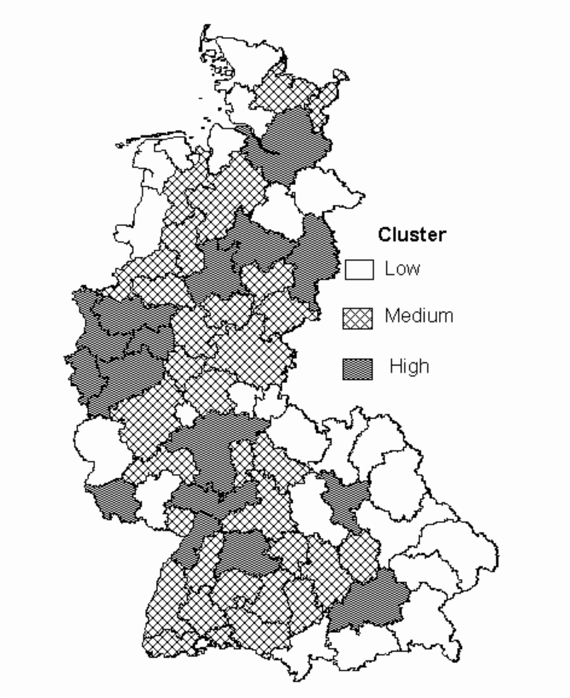


Table 3 reports the resulting clustering of *Raumordnungsregionen* into the three clubs. The three clusters display some distinct geographical pattern and are consistent with a multiple-equilibria growth model. The resulting geographical cluster structure is also exhibited in Figure 6.

Table 3: Low, Medium and High Club Regions

Cluster	Regions
Low	Vogelsberg, Mittelfranken, Lüneburg, Trier, Schleswig, Donau-Wald, Oberpfalz-Nord, Oberland, Dithmarschen, Landshut , Emsland, Südheide, Ostfriesland, Fulda, Main-Rhön, Bremerhaven/Unterweser, Oberfranken-West, Allgäu, Regensburg, Westpfalz, Südostoberbayern, Oberfranken-Ost, Wilhelmshaven, Limburg
Medium	Oldenburg, Nordhessen, Mittelrhein-Westerwald, Donau-Iller (By.), Südpfalz, Münster-Nord, Sauerland, Ingolstadt, Franken, Osnabrück, Paderborn, Göttingen, Würzburg, Schwarzwald-Baar-Heuberg, Hildesheim, Bayrischer Untermain, Nordschwarzwald, Augsburg, Südlicher Oberrhein, Ostholstein, Ostwürttemberg, Hochrhein-Bodensee, Bremen, Siegen, Bodensee-Oberschwaben, Mittelholstein, Mittelhessen, Donau-Iller (Bw.), Rheinhessen-Nahe, Münster-Süd, Neckar-Alb
High	Bielefeld, Saarbrücken, Braunschweig, Hannover, Hamburg, Aachen, Wuppertal-Hagen, Karlsruhe, Köln-Bonn, Rhein-Neckar, Rhein-Main, Nürnberg, Düsseldorf, München, Ruhr, Stuttgart

Figure 6: Convergence Clubs in Western Germany



There are 16 regions in the high *H*-club, 31 regions characterised by a medium human capital intensity, and 24 regions in the low *H*-club. What do regions in the same cluster have in common? The three groups of regions determined by the threshold estimates correspond rather precise with different spatial categories. The high *H*-club almost exclusively consists of the large agglomerations in West Germany. There are only two exceptions to this rule. The agglomeration Bremen falls in the medium club and the region Braunschweig, although an area with relatively low population density, is assigned to the high *H*-club. The latter case can be traced back to the automobile industry located in the region. As a centre of automobile industry in Germany, the region also achieves a high level of R&D activity at the European scale.[23] In contrast, the low *H*-group covers most of the rural-peripheral regions in West Germany. According to the criteria accessibility, population density and GDP per capita, these areas distinguish from the other West German regions. Finally, the medium *H*-club covers a more mixed group of regions, including the agglomeration Bremen, two rural-peripheral regions and a number of low density areas that take an intermediate position between the agglomerations and the rural-peripheral regions. Thus, overall the grouping derived from the threshold estimation reflects dissimilar endowments and attributes between highly agglomerated areas and more rural regions in West Germany and are therefore intuitively reasonable.

[23] See Beise et al. (1998). In 1997 the region "Braunschweig" attained the highest R&D expenditure as a percentage of GDP among all NUTS 2 regions [Laafia (2001)]. The only real surprise is that Saarbrücken turns out to be a member of the first club.

Table 4: Tests for Equality of Means Across Convergence-Clubs

Variable	F-Test	Club-Mean		
		low	medium	high
$\ln(y_{96}/y_{76})$	9.1**	0.048	0.044	0.045
$\ln(y_{76})$	29.5**	10.45	10.57	10.70
$\ln(y_{96})$	14.6**	11.41	11.44	11.60
rd_{7696}	85.2**	0.40	1.04	4.92

Notes: ** denotes significance at the 0.01 level. The basic idea of the F-test is that if the subgroups (clubs) have the same mean, then the variability between the sample means (between clubs) should be the same as the variability within any club.

We applied mean equality tests to check whether the structural instability, i.e. the existence of multiple equilibria indicated by the threshold estimates is reflected by the regional data. *F*-tests were carried out for the grouping into three clubs and several variables. The results of the *F*-tests for income growth between 1976 and 1996 [$\ln(y_{96}/y_{76})$], the human capital intensity (H) and the income level in 1976 and 1996 [$\ln(y_{76})$, $\ln(y_{96})$] are presented in Table 4. The corresponding club-means are given as well. The null hypothesis of equal club-means is clearly rejected for all analysed variables at the 0.01 level. The differences among the groups are most obvious for the threshold variable. Thus, the mean equality tests confirm the grouping identified by the threshold estimates. According to the results, the three clubs significantly differ with respect to income level, growth and human capital intensity.

5. Conclusion

In this paper we have taken seriously the comment by Harberger (1987, p. 256) who has asked „what do Thailand, the Dominican Republic, Zimbabwe, Greece, and Bolivia have in common that merits their being put in the same regression“. Instead of using traditional cross-sectional regression techniques to determine the existence of (conditional) convergence, we test for the existence and the significance of thresholds and therefore multiple equilibria across western Germany´s *Raumordnungs-regionen*. Our conclusion can be simply stated. The main result is that the 71 West German regions are clustering towards three distinctive income clubs, which causes the distribution or relative incomes to become stratfied into a trimodal distribution.[24] The implication is that, for example, Ostfriesland, Göttingen and Munich don´t have very much in common that merit their being put in the same regression. This finding is consistent with what a number of other authors have found looking at other

[24] This result casts doubt upon the efficiency of the German fiscal transfer system which has been designed to compensate for regional disparities arising from asymmetric regional shocks. The forms and scale such socially desirable government interventions should take are beyond the scope of this paper and constitute a research agenda in their own right. The same applies to the scale and type of „big push“ policies.

countries and time periods.[25] Although threshold estimation techniques take somewhat more computation time than plain OLS regression, their benefits more than outweigh the cost of applying them. We do not claim that theshold effects are omnipresent, but we believe that it is important to check for their presence more routinely in a rigorous fashion, before they can be assumed away. We hope that his paper will serve as a springboard and will aid in making such testing a more common practice in applied regional economics.

[25] Canova (1999) has used Bayesian techniques, Durlauf and Johnson (1995) have used regression tree analysis and Quah (1996) has computed transition probability matrices to determine the number and the evolution of clubs in various datasets. Cheung and Pascual (2000) have used multivariate time series techniques to determine convergence in output across the G7 countries. Their results lend support to the notion of convergence clubs. Our research on Germany is complimentary to these earlier studies.

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