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CONVERGENCE ANALYSIS OF ECONOMIC GROWTH PATHS

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Abstract

The neoclassical growth model, more precisely, the extended Solow Model is starting point of this thesis. Theoretical work leads to a non linear factor model, describing the log real income with a common factor describing the common development of all individuals in a panel and an idiosyncratic component, measuring the relative share of the common component. As the idiosyncratic factor cannot be estimated straightly, the graphical illustration of the relative transition paths give an impression of the country-specific evolution. Investigation of the transition path and its development leads to the construction of statistical tests, measuring convergence in a panel. The observed inhomogeneity in the panels is the incentive for the cluster analysis. With two different clustering algorithms, the panels are divided into several clubs where more signs of convergence occur than in the single panel analysis before. The used panels are a World Panel, an Africa Panel, a Europe Panel and a selection of 20 high developed OECD countries.

Der Ausgangspunkt dieser Arbeit ist das neoklassische Wachstumsmodell, genauer gesagt ein erweitertes Solow Modell. Nach theoretischen Vorarbeiten führt der Weg zu einem nichtlinearen Faktormodell, welches zur Beschreibung des logarithmierten pro Kopf Einkommen herangezogen wird. Ein gemeinsamer Faktor beschreibt die gemeinsame Entwicklung aller Individuen im jeweiligen Panel, wohingegen eine idiosynkratische Komponente den jeweiligen Anteil eines Individuums am gemeinsamen Pfad misst. Da dieser individuenspezifische Faktor schwer zu schätzen ist, versucht man mittels graphischer Illustration der relativen Übergangspfade die länderspezifischen Entwicklungen zu veranschaulichen. Die genauere Untersuchung der Übergangspfade und deren Entwicklung führt zur Konstruktion eines statistischen Tests, welcher die Konvergenz in den Panels überprüft. Die dadurch ersichtliche Inhomogenität diverser Panels führt zur Cluster Analyse selbiger. Mit zwei verschiedenen Cluster Algorithmen werden die Panels in verschiedene Clubs unterteilt, wo nun mehrere Anzeichen von Konvergenz vorhanden sind im Vergleich zur Analyse der Gesamtpanels. Die verwendeten Panels sind ein Welt Panel, ein Afrika Panel, ein Europa Panel sowie eine Auswahl von 20 hoch entwickelten OECD Ländern.

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GDP	Gross Domestic Product
OECD	Organisation for Economic Co-operation and Development
NIE	Newly Industrialised Economy
NIC	Newly Industrialised Country
PPP	Purchasing Power Parities

1 INTRODUCTION

Studying the growth of nations, the patterns in economic development, finding models for simulating our history and for estimating our future was a central aim of many economists, mathematicians and many other scientists. For decades, actually centuries, nations had their own market system, their own currency, their own technological progress which was not as much influenced by their neighbours than it is now. Since the industrial revolution, the diffusion of technologies increased a lot, trade agreements between countries or regions came up and the globalisation got pushed. With this development, the western economies grew faster than ever before, and also inequality between developing and developed countries increased. In Lucas (2002), the author discusses the enormous income inequality after the industrial revolution. Lucas also points out that this inequality could be transient.
This statement concerns many economists, trying to proof its content. For analysing this topic, a suitable model is needed with which allows for heterogeneity in technological progress and also in initial levels. However, it should be also possible to derive convergence patterns.

As suggested by Sala-i-Martin (1997), Howitt & Mayer-Foulkes (2005) and Parente & Prescott (1994), a neoclassical growth model with heterogenous technological progress fulfills many conditions which are necessary for dealing with macroeconomic panel data.

Phillips & Sul (2005) and Phillips & Sul (2009) developed a non linear factor model for log per capita real income:

$$\log y_{it} = a_{it} + x_{it}t = b_{it}\mu_t \tag{1.1}$$

where y_{it} is the per capita income, a_{it} stands for the transitional dynamics for real effective capital and $x_{it}t$ denotes the idiosyncratic time path of technological progress. The formulation which is used later in this thesis is $\log y_{it} = b_{it}\mu_t$ where μ_t is an aggregated common behaviour of the data $\log y_{it}$ and b_{it} the individual transition factor which should explain country wise differences over the time. This model can be derived from a expanded Solow Model which is shown in Chapter 2. A central point is expanding the equation

$$\log y_{it} = \log A_0 + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta t} + xt \tag{1.2}$$

with allowing heterogenous technological growth x_{it} (instead of x) which leads to a heterogenous convergence rate β_{it} (instead of β). A_O is the initial technological level, $\tilde{y}_i^*$ is the steady state level for real effective per capita income. The development of b_{it} of different countries which are put together in a panel could provide interesting information of economic transition and convergence patterns. As the estimation of b_{it} is not possible without many restrictions, Phillips & Sul (2007) suggest focusing on the relative transition $h_{it} := \log y_{it}/\overline{\log y_t}$ where $\overline{\log y_t}$ denotes the cross-section average of per capita real income. As the relative transition paths stay in a direct connection to b_{it}, this topic is introduced with many examples in Chapter 3, where also transition against a benchmark group is studied. The data which is used there (and also in the following chapters) is also described and mentioned (with source) in Chapter 2. To measure the distance between those paths in Chapter 4, the econometric theory for analysing convergence is provided with some first examples for the log-t-convergence test. The panels which are used are a OECD country selection, a Europe panel, an Africa panel and a big World panel. Those panels often show strong signs of heterogenity in developement of the relative transition paths. Signs for convergence are very rare. One reason could be convergence of subpanels wherefore two clustering methods are introduced in Chapter 5. The first method is a algorithm developed by Phillips & Sul (2007) with some new features. The other algorithm is a simple hierarchical clustering method which is provided to have a comparison to the first one. This comparison is also part of Chapter 5 as some simple β-convergence tests and other graphics for supporting the clustering results which are listed in detail in the appendix.

2 Theoretical Basis and Data Description

In the following, some mathematical tools will be needed for interpretation and preparation of the data. Until the data is ready for the final econometric models, it has to be transformed in certain manners. The theory behind the tools and transformations as well as the description of the used data is the focus of the following chapter.

2.1 Data Description

The data which is used in this paper is open source data from the Maddison Project and is available on *http://www.ggdc.net/maddison/maddison-project/orihome.htm*. The data file consists of time series of 144 different countries and their real GDP per capita on an annual basis in Geary Khamis dollars, more commonly known as the international dollars.

It is a hypothetical unit of currency that has the same purchasing power parity (PPP) that the U.S. dollar had in the United States at a given point in time. In this data set, the year 1990 is used as the benchmark year for comparisons that run through time. It is based on the twin concepts of purchasing power parities (PPP) of currencies and the international average prices of commodities.

The length of the time series varies a lot. Many European and many countries of the Western World have data entries since 1870, while the time series of African and Latin American countries start in 1950 in most cases.

The countries in the set are the following:

Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Bahrain, Bangladesh, Belgium, Benin, Bolivia, Bosnia, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoro Islands, Congo Brazzaville, Congo Kinshasa, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Czechoslovakia, Denmark, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Finland, France, Gabon, Gambia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea Bissau, Haiti, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kuwait, Laos, Lebanon, Lesotho, Liberia, Libya, Macedonia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, North Korea, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Romania, Rwanda, Sao Tomé and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovenia, Somalia, South Africa, South Korea, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syria, Taiwan, Tanzania, Thailand, Togo, Trinidad, Tunisia, Turkey, UAE, Uganda, United Kingdom, Uruguay, USA, Venezuela, Vietnam, Yemen, Yugoslavia, Zambia, Zimbabwe.

In the list above, also Czechoslovakia and Yugoslavia are included which are not existing any more. The data for those countries after their breakup is aggregated data generated by their follower countries. The reason for keeping those two countries in the set is, that it is of economic interest how the follower countries are developing in comparison to the aggregated mean of their former brother states.

2.2 Neoclassical Growth Model

In this thesis the underlying model to approach our data is a neoclassical growth model with heterogenous technological progress. Sala-i-Martin (1997), Howitt & Mayer-Foulkes (2005) and Parente & Prescott (1994) suggested similar models and Phillips & Sul (2005) and Phillips & Sul (2009) developed the following nonlinear factor model for log per capita real income:

$$\log y_{it} = a_{it} + x_{it} t = b_{it} \mu_t \tag{2.1}$$

where a_{it} stands for the transitional dynamics for real effective capital for country i at the time t. $x_{it}t$ denotes the idiosyncratic time path of technological progress. The econometric interpretation of μ_t is an aggregated common behavior of the data $\log y_{it}$. The model formulation is based on neoclassical theory, which means that the growth model is a Solow Model. On the next few pages, the derivation of 2.1 is described step by step.
The model assumptions for a Solow Model are:

- Production function:

$$Y_t = F(K_t, A_t L_t) \tag{2.2}$$

  where Y_t stands for the output at time t, K_t for the capital input, L_t for the labour input, A_t for the level of technology and $A_t L_t$ for the effective labour.

The production function has to fulfill following conditions:

- Constant returns to scale:

$$F(cK_t, cA_tL_t) = c(F(K_t, A_tL_t) \text{ for all c} \geq 0 \tag{2.3}$$

- Positive and declining marginal products of capital and labour

$$\frac{\partial F(\cdot)}{\partial K_t} > 0 \text{ and } \frac{\partial^2 F(\cdot)}{\partial K_t \partial K_t} < 0 \tag{2.4}$$

and

$$\frac{\partial F(\cdot)}{\partial L_t} > 0 \text{ and } \frac{\partial^2 F(\cdot)}{\partial L_t \partial L_t} < 0 \tag{2.5}$$

- Both production factors are necessary:

$$F(0, A_tL_t) = 0 \text{ and } F(K_t, A_t0) = 0 \tag{2.6}$$

- Inada conditions are satisfied:

$$\lim_{K_t \to 0} \frac{\partial F(\cdot)}{\partial K_t} \to \infty \text{ and } \lim_{K_t \to \infty} \frac{\partial F(\cdot)}{\partial K_t} \to 0 \tag{2.7}$$

and

$$\lim_{L_t \to 0} \frac{\partial F(\cdot)}{\partial L_t} \to \infty \text{ and } \lim_{L_t \to \infty} \frac{\partial F(\cdot)}{\partial L_t} \to 0 \tag{2.8}$$

The extended Solow Model which is used in this thesis is defined by the equations:

$$\begin{aligned} Y_t &= F(K_t, A_tL_t) = C_t + I_t \\ \dot{K}_t &= I_t - \delta K_t \\ I_t &= sY_t \\ \dot{L}_t &= nL_t \\ \dot{A}_t &= xA_t \end{aligned} \tag{2.9}$$

where C_t is the consumption, I_t the investments, s the savings rate, δ the rate of depreciation, n the growth rate of the input factor labour and x the growth rate of the level of technology.

Growth rates of model variables are denoted with γ[1].

[1] The growth rate of the level of technology is denoted by $\gamma_A = x$.

The equations $\dot{L}_t = nL_t$ and $\dot{A}_t = xA_t$ are differential equations and their solution is:

$$\begin{aligned} A_t &= A_0 e^{xt} \\ L_t &= L_0 e^{nt} \end{aligned} \tag{2.10}$$

where A_0 and L_0 denote the initial values.

Beside the aggregated levels of Y_t and K_t, there is also a per capita formulation and the per effective capita formulation:

$$\begin{aligned} y_t &= \frac{Y_t}{L_t} \text{ output per capita} \\ k_t &= \frac{K_t}{L_t} \text{ capital stock per capita} \\ \tilde{y}_t &= \frac{Y_t}{A_t L_t} \text{ output per unit of effective labour} \\ \tilde{k}_t &= \frac{K_t}{A_t L_t} \text{ output per unit of effective labour} \end{aligned} \tag{2.11}$$

The production function $F(K_t, A_t L_t)$ can be transformed to the production function in terms of effective labour with dividing by $A_t L_t$ and using the "constant returns to scale"-property of F:

$$\begin{aligned} Y_t &= F(K_t, A_t L_t) \\ \tilde{y}_t &= F(\frac{K_t}{A_t L_t}, 1) =: f(\tilde{k}_t) \end{aligned} \tag{2.12}$$

With the assumptions and the equations of 2.9, a balanced growth path and the growth rates of the model variables can be derived. First of all, one has to rewrite the capital accumulation equation

$$\dot{K}_t = I_t - \delta K_t = sY_t - \delta K_t = sF(K_t, A_t L_t) - \delta K_t \tag{2.13}$$

In terms of per-capita effective labour units:

$$\frac{\dot{K}_t}{A_t L_t} = s\frac{F(K_t, A_t L_t)}{A_t L_t} - \delta \frac{K_t}{A_t L_t} = sf(\tilde{k}_t) - \delta \tilde{k}_t \tag{2.14}$$

The evolution of $\dot{\tilde{k}}_t$ is

$$\dot{\tilde{k}}_t = \frac{d\frac{K_t}{A_tL_t}}{dt} = \frac{\dot{K}_t}{A_tL_t} - \frac{K_t}{A_tL_t^2}\dot{L}_t - \frac{K_t}{A_t^2L_t}\dot{A}_t = \frac{\dot{K}_t}{A_tL_t} - \tilde{k}_t\frac{\dot{L}_t}{L_t} - \tilde{k}_t\frac{\dot{A}_t}{A_t} = \frac{\dot{K}_t}{A_tL_t} - n\tilde{k}_t - x\tilde{k}_t \quad (2.15)$$

Combining the last two results leads to the fundamental equation:

$$\dot{\tilde{k}}_t = sf(\tilde{k}_t) - (\delta + n + x)\tilde{k}_t \quad (2.16)$$

The steady state value $\tilde{k}^*$ is obtained by setting $\dot{\tilde{k}}_t = 0$. With using a Cobb Douglas Production Function of the form

$$F(K_t, A_tL_t) = K_t^\alpha (A_tL_t)^{1-\alpha} \quad (2.17)$$

one can derive

$$\tilde{k}^* = \left(\frac{s}{n+x+\delta}\right)^{\frac{1}{1-\alpha}} \quad (2.18)$$

which is the steady state value for $\tilde{k}$. In this point, we have $\dot{\tilde{k}}_t = 0$ and $\gamma_{\tilde{k}} = 0$. Since $\tilde{y}_t = f(\tilde{k}_t)$, and $\gamma_{\tilde{k}} = 0$, $\gamma_{\tilde{y}} = 0$. Beside that, some other variables are still growing and are determining the balanced growth path for the observed economy. For the per capita variables we get:

$$\begin{aligned} k &= \tilde{k}A && \Big| \ln(\cdot),\ \frac{d(\cdot)}{dt} \\ \gamma_k &= \gamma_{\tilde{k}} + \gamma_A = x \end{aligned} \quad (2.19)$$

$$\begin{aligned} y &= \tilde{y}A && \Big| \ln(\cdot),\ \frac{d(\cdot)}{dt} \\ \gamma_y &= \gamma_{\tilde{y}} + \gamma_A = x \end{aligned} \quad (2.20)$$

For γ_Y and γ_K:

$$\begin{aligned} \tilde{k} &= \frac{K}{AL} && \Big| \ln(\cdot),\ \frac{d(\cdot)}{dt} \\ \gamma_{\tilde{k}} &= \gamma_K - \gamma_L - \gamma_A = \gamma_K - n - x \\ \Rightarrow \gamma_K &= n + x \end{aligned} \quad (2.21)$$

$$\begin{aligned} \tilde{y} &= \frac{Y}{AL} && \Big| \ln(\cdot),\ \frac{d(\cdot)}{dt} \\ \gamma_{\tilde{y}} &= \gamma_Y - \gamma_L - \gamma_A = \gamma_Y - n - x \\ \Rightarrow \gamma_Y &= n + x \end{aligned} \quad (2.22)$$

The growth rates of the investment and the consumption can be derived analogously. Summing up the results, in the equilibrium, the variables are growing with following rates:

- L grows at rate n
- A grows at rate x
- K grows at rate $n+x$
- Y grows at rate $n+x$
- $\frac{Y}{L} = y$ grows at rate x
- $\frac{K}{L} = k$ grows at rate x
- $\frac{Y}{AL} = \tilde{y}$ grows at rate 0
- $\frac{K}{AL} = \tilde{k}$ grows at rate 0

It can be shown that the transitional dynamics for real income per effective labour can be written as:

$$\log \tilde{y}_t = \log \tilde{y}^* + (\log \tilde{y}_0 - \log \tilde{y}^*)e^{-\beta t} \tag{2.23}$$

where $\log \tilde{y}^*$ is the steady state level of effective log per capita real income, $\log \tilde{y}_0$ the initial level and β the transition parameter which is given by:

$$\beta = \frac{1-\alpha}{n+x+\delta} \tag{2.24}$$

The equations $y = \frac{Y}{L}$, $\tilde{y} = \frac{Y}{AL}$ and $A_t = A_0 e^{xt}$ lead to

$$y_t = A\tilde{y}_t = A_0 e^{xt} \tilde{y}_t \tag{2.25}$$

taking the logarithm

$$\log y_t = \log A_0 + \log e^{xt} + \log \tilde{y}_t = \log A_0 + xt + \log \tilde{y}_t \tag{2.26}$$

With replacing $\log \tilde{y}_t$ in equation 2.26 with the right hand side of equation 2.23 we get:

$$\log y_t = \log A_0 + \log \tilde{y}^* + (\log \tilde{y}_0 - \log \tilde{y}^*)e^{-\beta t} + xt \tag{2.27}$$

As this thesis deals with panel data, the variables in equation 2.27 get a subindex i for distinguishing between the countries:

$$\log y_{it} = \log A_0 + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta t} + xt \tag{2.28}$$

In a Solow Model, there is usually homogenous technological progress, an assumption which doesn't fit in our case, because then, cross-section income heterogeneity would be difficult to explain. Allowing heterogenous initial levels of technology A_{i0}, heterogenous and time dependent technological progress x_{it} and a heterogenous transition parameter β_{it} (temporal and transitional heterogeneity), log y_{it} can be written as:

$$\log y_{it} = \log A_{i0} + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta_{it}t} + x_{it}t = a_{it} + x_{it}t \tag{2.29}$$

where

$$a_{it} = \log A_{i0} + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta_{it}t} \tag{2.30}$$

and

$$\beta_{it} = \beta - \frac{1}{t}\log\left\{1 - d_{i1}\int_0^t e^{\beta p}(x_{ip} - x)dp\right\} \tag{2.31}$$

where $d_{i1} = \frac{1}{\log k_{i0} - \log k_i^*}$, x stands for the common growth rate of technology. More details on how the transition parameter β_{it} is derived are to be found in the Technical Appendix of Phillips & Sul (2009).

β_{it} depends on the whole time profile of the technology growth rate until t. Furthermore, the speed of convergence parameter β_{it} is an increasing function of the technological progress x_{it}. This can be explained with the following interpretation: If a country has a very low level of technology, it is harder to adopt technologies from other countries which are far ahead. The bigger the stock of technology is, the higher the diffusion of technology between countries will occur which leads to faster convergence towards the steady state. For homogenous technology growth rate x, the relative income differential $(\log y_{it} - \log y_{jt})$ is mainly explained by the initial real effective per capita income. However, during the transition period, where $x_{it} \neq x$, the differential between the growth rates $(x_{it} - x_{jt})$ also contributes to the difference in the trajectories of log y_{it} and log y_{jt}. For closer investigation of transitional dynamics one like to recall 2.29.

$$\log y_{it} = \log A_{i0} + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta_{it}t} + x_{it}t = a_{it} + x_{it}t$$

$$a_{it} = \log A_{i0} + \log \tilde{y}_i^* + (\log \tilde{y}_{i0} - \log \tilde{y}_i^*)e^{-\beta_{it}t} \quad \underrightarrow{t \to \infty} \quad \log \tilde{y}_i^* + \log A_{i0} \tag{2.32}$$

which leads to the conclusion that the long run path of log y_{it} is determined by the term $x_{it}t$. As the model looks like in 2.1, in both elements a_{it} and x_{it}, idiosyncratic components are included. The growth path $x_{it}t$ is presumed to have elements which are common across economies. Some economies share more, some share less. This is why μ_t is now introduced and used to represent the common growth component and 2.1 is transformed to the following formula:

$$\log y_{it} = x_{it}t + a_{it} = \left(\frac{x_{it}t + a_{it}}{\mu_t}\right)\mu_t = b_{it}\mu_t \tag{2.33}$$

With this transformation, μ_t is the common component and b_{it} is the idiosncratic element which measures the relative share in μ_t of country i at time t. b_{it} and its evolution is of big interest. It is dependent on the growth rate path of x_{it} and the a_{it}. Further a_{it} $\overrightarrow{t \to \infty}$ $\log \tilde{y}_i^* + \log A_{i0}$, which implicates the dependence on the initial technical endowment and the steady-state level of the real per capita income.

2.3 Adjustment of Data

As mentioned in the beginning, this thesis is focussed on macroeconomic time series, respectively the per capita real income of certain countries all over the world. The length of the time series varies between 60 and 130 years, depending on the region. Such time series consist, in theoretical terms, of a trend, a cycle and of course an error term.

This equation illustrates the underlying situation:

$$\log y_{it} = b_{it}\mu_t + \kappa_{it} \tag{2.34}$$

where $b_{it}\mu_t$ represents the long term evolution as κ_{it} represents fluctuations, which occur frequently in economic data. Different tools can be used to separate these two components from each other. This fluctuation is a so called business cycle which can be removed with the following method:

2.3.1 Hodrick Prescott Filter

Many macro econometric tools focus on the trend, which is also of bigger interest in this thesis, wherefore a specific tool for separating cycle and trend is needed. A conventional way is using filtering methods, particularly in this thesis the Hodrick-Prescott Filter. This is a tool used for constructing a decomposition between cycle and trend, and for making time series stationary. It got known through the paper Hodrick & Prescott (1997).

2.3.1.1 Definition

Their framework is that a time series y_t is the sum of a trend component g_t and a cyclical component c_t.

$$y_t = g_t + c_t \quad \text{for} \quad t = 1, ...T \tag{2.35}$$

The procedure is to solve the following equation:

$$\min_{(g_t)_{t=1}^T} \left(\sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 \right) \tag{2.36}$$

where $c_t = y_t - g_t$ and λ is a penalty for which guarantees more smoothness the higher the parameter is chosen.

The second term $\sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 = 0$ is the sum of the squares of the trend component's second differences. This term penalizes variations in the growth rate of the trend component. The larger the value of λ the higher is the penalty. Furthermore, it is recommended in Hodrick & Prescott (1997) how to choose λ depending on the time steps in the data. For yearly data simulation studies resulted in choosing $\lambda = 100$.

3 The Economic Transition

3.1 Long Run Equilibrium and Convergence

Following the ideas and motivations of Phillips & Sul (2007), the starting point is the general case with two macroeconomic variables X_{it} and X_{jt} with stochastic trends. In the case that these two time series are thought to be in a long run equilibrium, they are hypothesised to be cointegrated. There are various testing procedures to test wether this time series are cointegrated or not. Cointegration tests usually need long time series, a fact that can lead to problems while dealing with too short panel data regarding the time span. Equation 2.33 shows that the evolution of the log real income per capita is dependent on the factors b_{it} and μ_t as the difference between two time series in the panel is given by $\log y_{it} - \log y_{jt} = (b_{it} - b_{jt})\mu_t$. If the difference of these two time series is a stationary process, we call this stochastic process cointegrated. It can happen that the rate of convergence of b_{it} is slow, wherefore the difference is not cointegrated, but asymptotically cointegrated. However, in the case, if the speed of divergence of μ_t is faster than the speed of the convergence of $(b_{it} - b_{jt})$, the residual $(b_{it} - b_{jt})\mu_t$ may retain non stationary characteristics and standard cointegration tests will then typically have low power in detecting the asymptotic co-movement. Hence, for analysing co-movements and convergence, some different econometric methods are needed.

In this chapter, we will discuss the fact how to interpret the dynamics that different economies face, and further, what types of convergence can occur in the investigated panel data.

We will distinguish between two types of convergence:

- Absolute convergence (also called level convergence):

$$\lim_{t\to\infty} (\log y_{it} - \log y_{jt}) = 0 \quad \forall\, i \text{ and } j \tag{3.1}$$

The absolute convergence of a cluster called C means that all the trajectories $\log y_{it}$ for all $i \in$ C converge.

- Relative convergence (also called growth convergence):

$$\lim_{t\to\infty} \frac{\log y_{it}}{\log y_{jt}} = 1 \ \forall \ i \text{ and } j \tag{3.2}$$

Under certain assumptions, the relative convergence of a cluster called D implicates that the growth rates of y_{it} for all $i \in$ D converge.

If following condition holds for all i in a club D, it implicates relative convergence:

$$\lim_{t\to\infty} b_{it} = b \tag{3.3}$$

On the first view, both definitions look very similar and one could think that they are equivalent. Therefore, the following example is provided:

Let $\mu_t = t$ and let Economy 1 follow the path $\log y_{1t} = (1+t^{-\alpha})t$ for $\alpha > 0$ and Economy 2 evolves as $\log y_{2t} = t$. This implicates that $b_{1t} = (1+t^{-\alpha})$ and $b_{2t} = 1$. Considering 3.1 leads to $\log y_{1t} - \log y_{2t} = t^{1-\alpha}$. This difference diverges to positive infinity if $0 \leq \alpha < 1$, which means that there is no absolute convergence between Economy 1 and 2. On the other side $\frac{\log y_{1t}}{\log y_{2t}} = 1 + t^{-\alpha}$ for $0 \leq \alpha < 1$, which leads to relative convergence of the two economies. To show the connection to the so-called growth convergence, let us consider:

$$\lim_{t\to\infty}(\Delta\log y_{1t} - \Delta\log y_{2t}) = \lim_{t\to\infty}[t^{1-\alpha} - (t-1)^{1-\alpha}] = 0 \text{ for } 0 < \alpha < 1 \tag{3.4}$$

3.2 Theoretical Introduction to Transition Paths

Without restrictions and structural assumptions on b_{it} and μ_t in 2.33, an estimation of the coefficients b_{it} is not possible. Hence, it is mentioned in Phillips & Sul (2007) that a plausible option could be letting b_{it} follow an AR(1) process while μ_t evolves like a random walk. The following approach shows an alternative way to gain information about the coefficient b_{it} without putting such strong conditions on b_{it} and μ_t as mentioned before. The idea is, as Phillips & Sul (2007) did, to use the relative transition coefficient which is defined as follows:

$$h_{it} = \frac{\log y_{it}}{\frac{1}{N}\sum_{i=1}^{N} \log y_{it}} = \frac{b_{it}}{\frac{1}{N}\sum_{i=1}^{N} b_{it}} \tag{3.5}$$

Obviously, μ_t gets eliminated as it is not a country dependent variable but only time dependent variable. The advantage is, that h_{it} is easy to calculate as the yearly real GDP per capita data is provided for the whole panel. This method doesn't deliver values for b_{it}, but if h_{it} has specific development, one can also make a statement about b_{it}. h_{it} measures the relative departure of the common steady state growth path μ_t. Different patterns of evolution can occur regarding the the relative transition paths. Subgroups of a panel can converge towards a constant which is different to 0, which is an indication for subgroup convergence. Growth convergence occurs if:

$$h_{it} \rightarrow 1, \forall\, i, \text{as } t \rightarrow \infty \quad (3.6)$$

as 3.6 implicates 3.3.

3.3 Graphical Illustrations of Transition Paths

Regarding the theory, relative transition paths are divided into 3 different phases (Phillips & Sul (2009) page:1159):

- **Phase A:** Slow growth in relation to the other economies and low level of the relative transition path is characteristic of this phase
- **Phase B:** The economic performance begins to turn from decreasing to increasing in relation to the other economies
- **Phase C:** In this phase the economies are catching up and start converging.

The graphical illustration of this 3 phases is shown in Figure 3.1 for Economy 1: Slow growth in the beginning, then the turn from decreasing to increasing economic performance, and the catching up phase in the end. In contrast to Economy 1, the other two economies (Economy 2, Economy 3) converge monotonically to unity. However, they have different initialisations and different transition as Path 3 shows an advanced industrial economy, while Path 2 is a typical transition path for a newly industrialised and fast-growing economy.

In the following subsections, some illustration of transition paths will be presented. Before calculating those paths, the Hodrick Prescott Filter is used on panel data. The next step is generating the transition paths. Afterwards, all the h_{it}-curves are smoothed by using the Bezier-Method[1]. Furthermore, the graphs are presented in two ways with and without benchmarking) where two types are distinguished.

Benchmarking of a subgroup against one country:

- Select a country b as benchmark country and select a subgroup K out of the panel.

[1] The Bezier-Method is a method for interpolation. In this thesis, for $n+1$ data points, a Bezier-Polynom of degree n is calculated.

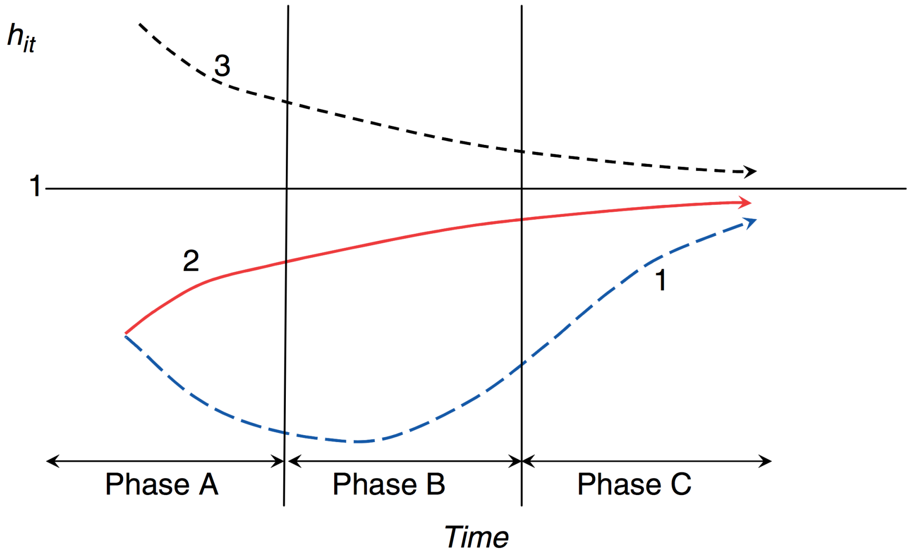

Figure 3.1: Relative transition curves h_{it} and phases of transition

- Let N_K be the number of countries in K. As b is a single country, the number of countries in $K \cup \{b\}$ is $N_K + 1$.
- Calculate the transition path h_{it} as in 3.5: $h_{it} = \frac{\log y_{it}}{\frac{1}{N_K+1}\sum_{i \in K \cup \{b\}} \log y_{it}}$ for $i \in K$.
- Taking the cross sectional average excluding b : $h_{Kt} = \frac{1}{N_K}\sum_{i \in K} h_{it}$.

Benchmarking of a subgroup against a group of countries:

- Select a group B as benchmark group and select a subgroup K out of the panel.
- Let N_K be the number of countries in K, and N_B the number of countries in the benchmark group B. The number of countries in the merged group $B \cup K$ is $N_k + N_B$.
- Calculate the transition path h_{it} as in 3.5: $h_{it} = \frac{\log y_{it}}{\frac{1}{N_K+B_K}\sum_{i \in K \cup B} \log y_{it}}$ for $i \in K \cup B$.
- Calculating the subgroups share of the benchmark group : $h_{Kt} = \frac{\frac{1}{N_K}\sum_{i \in K} h_{it}}{\frac{1}{N_B}\sum_{i \in B} h_{it}}$.

The first procedure is the same as in Phillips & Sul (2009), the second one is amended. Phillips & Sul (2009) calculated the transition path against a benchmark group exactly in the same way as for the benchmark against one country, with $h_{Kt} = \frac{1}{N_K}\sum_{i \in K} h_{it}$. This method faces problems when it comes to big numbers of countries in the group K because the cross sectional average $\frac{1}{N_K}\sum_{i \in K} \log y_{it}$ gets more biased the bigger the number of this group gets.

3.3.1 Transition Paths of Western OECD Countries

This section is about the following 20 western OECD countries and their economic transition over time:

Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland.

In Figure 3.2, the transition paths of 20 western OECD countries are plotted. As mentioned in the data description, those time series are the longest in the panel. Beginning in 1870, the economies differed a lot regarding real GDP per capita. Furthermore, one can see that through the Second World War, some countries increased their economic power in relation to others. For instance, on the one hand, countries like the USA, which did not suffer under destruction and devastation, faced a positive economic effect. On the other hand, Austria's and Germany's GDP per capita decreased in relation to the other countries. Starting in 1950 the catch up phase for the relatively poorer countries (for instance Portugal and Spain) began with long periods of stable economic growth.

In the OECD panel, there are countries which may fit in a panel concerning geographical and economical terms. Based on this statement, 5 different panels are built. Their transition curves are calculated against the benchmark of the USA (Figure 3.3). The corresponding subgroups are:

- Group 1: United Kingdom, New Zealand, Australia, Canada
- Group 2: Austria, Germany, Italy
- Group 3: Portugal, Spain, Greece
- Group 4: Finland, Sweden, Norway
- Group 5: France, Belgium, Denmark, Netherlands, Switzerland

Japan is not included in any group because of economical, geographical and political reason. Nearly all the countries, respectively subgroups, struggled during the time of the Second World War. Similar to Figure 3.2, after the war, the catch-up period for the European countries began. Subgroup 1, 4 and 5 are very close to the relative transition parameter 1 in the end of the time line, which means that the real GDP per capita of those countries is relatively close to the one of the USA. The panel with the South European countries Portugal, Spain and Greece is the one with the biggest distance to the USA, but, however has reduced the residue a lot over the last decades. This is very typical for phase C transition. The period around the Second World War could be interpreted as phase B for all subgroups except Group 1, as it is a turning point in the transition curves.

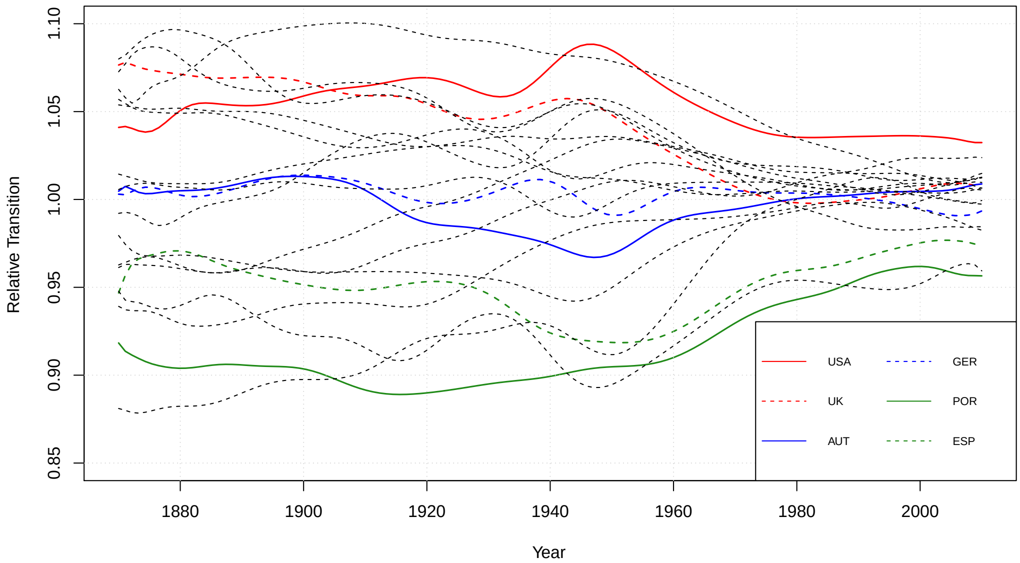

Figure 3.2: Transition paths of 20 western OECD countries

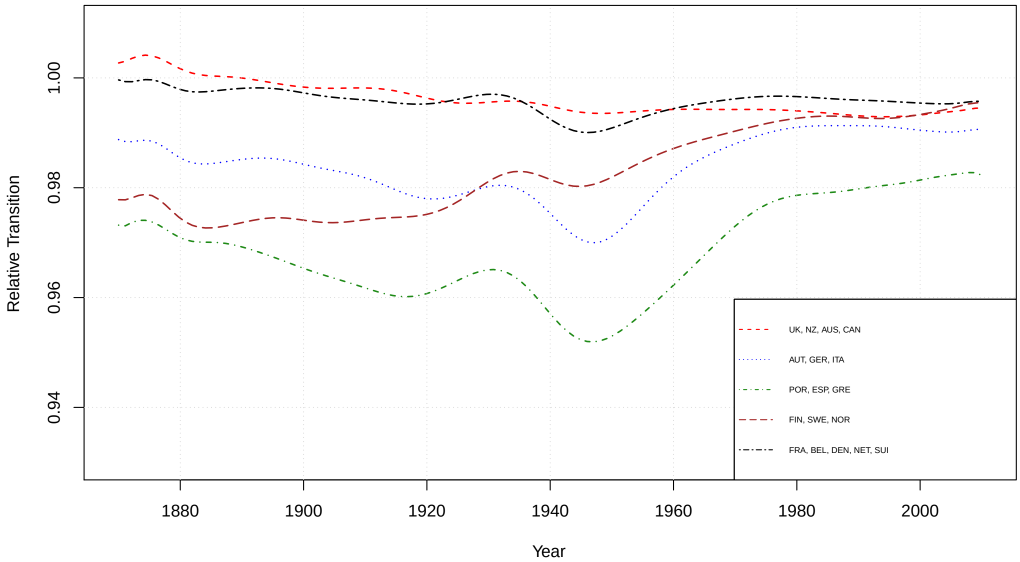

Figure 3.3: Relative Transition Paths with USA as Benchmark

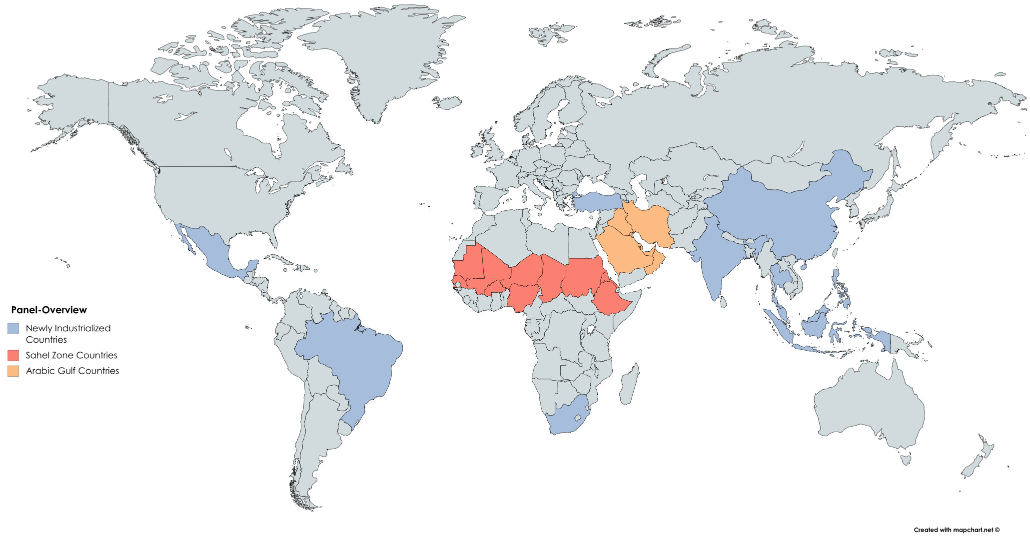

Figure 3.4: Overview of NIE, Sahel Zone and the Arabic Gulf States

3.3.2 Transition Paths of India, Korea and China

India, Korea (South Korea) and China are the so-called big Asian economies. One can see (Figure 3.5) that those three countries had a similar evolution over the last decades but they differ in their final level. The 20 OECD countries serve as benchmark. In the beginning, all 3 countries were in transition period B, as, Korea sooner than China and India, they entered period C, which means, they started to catch up with the OECD countries. At the end of the timeline (2010), Korea is very close to 1 which means that they already converged against the mean GDP per capita of the benchmark set.

3.3.3 Transition Paths of the Asian Dragons and NIEs

The Four Asian Dragons or Four Asian Tigers are the wealthy high-tech industrialised developed countries of Taiwan, Singapore, Hong Kong and South Korea which underwent rapid industrialisation, technological innovation and development and also maintained exceptionally high growth rates between the mid-1950s and early 1990s. [2] Theses four countries, which are located relatively close to each other, had a similar economic growth period in the second half of the 20th century. Therefore, they are put together in one panel. Also, as the Four Asian Dragons, the transition of three Newly Industrialised Economies (NIE) of Asia, which are Indonesia, Malaysia and Thailand, and their transition path is shown in Figure 3.6. The Newly Industrialised Economies, sometimes also called Newly Industrialised Countries (NIC), are actually a bigger group than just those three countries. In Figure 3.4,

[2] Quote from *https://en.wikipedia.org/wiki/Four_Asian_Tigers*

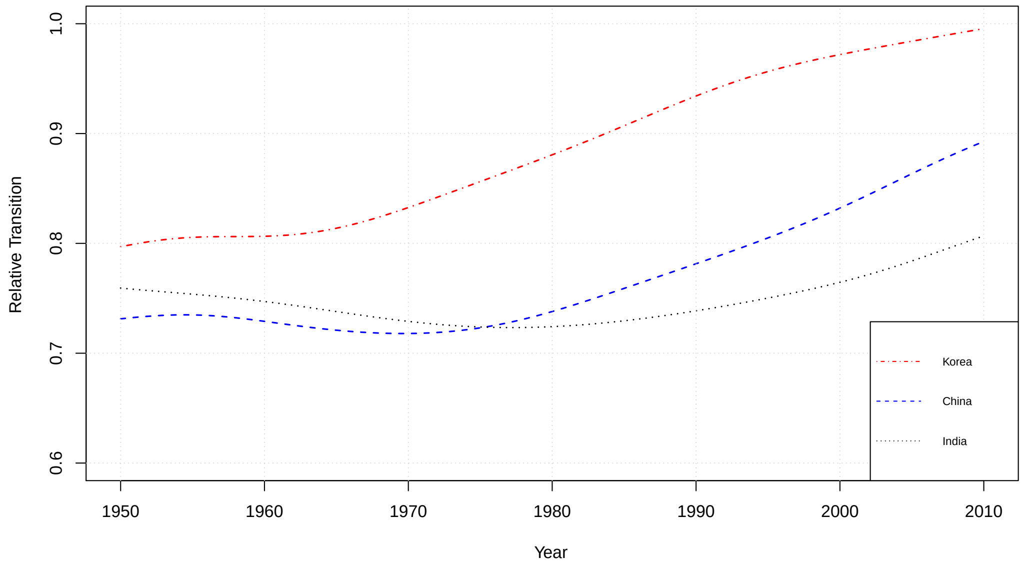

Figure 3.5: Transition of China, Korea and India with OECD as Benchmark

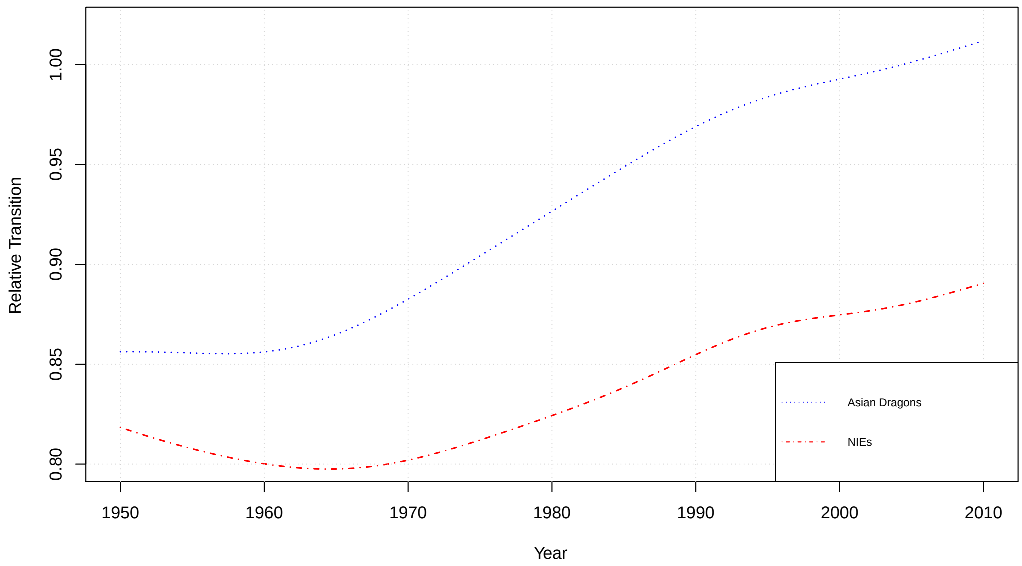

Figure 3.6: Transition of Asian Dragons and NIEs with OECD as Benchmark

all blue countries are rated as NIEs. This paper focuses on just this small selection of them. In Figure 3.6, one could interpret that both panels leave phase B between 1950 and 1970 and enter phase C. The 4 Asian Dragons exceeded the value of 1 which means that they are already ahead of the mean transition curve of the OECD countries. The three Asian NIEs still need some time to catch up.

3.3.4 Transition Paths of Latin America & Caribbean Countries, Sub-Saharan African Countries and Middle East & North African Countries

In this section, the following panels are used :

- **Latin America & Caribbean Countries:** Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad, Uruguay, Venezuela,
- **Sub Saharan African Countries:** Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Chad, Comoro Islands, Congo Brazzaville, Congo Kinshasa, Cote d'Ivoire, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe
- **Middle East & North African Countries:** Algeria, Egypt, Iran, Jordan, Morocco, Syria

In Figure 3.7, one can see the departure of all the 3 panels from the selected OECD countries beginning in 1950. With big differences in the initial levels of the transition paths, the panels have a similar development in the beginning, however, the Sub Saharan African Countries are far behind the other 2 panels. The whole picture shows examples for transition phase A with different initial levels. The Latin American countries where way closer to the OECD countries in the middle of the last century, it seems that they entered transition phase B though. The same interpretation goes for the other 2 panels, since their transition path also reached the turning point. As they have lower levels, the phase of convergence will probably take longer.

3.3.5 Transition Paths of Countries of the Sahel Zone and the Arabic Gulf States

In this section the following panels are used :

- **Arabic Gulf States:** Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, UAE (United Arabic Emirates)
- **Sahel Zone States:** Burkina Faso, Chad, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan

These panels are also visualised in Figure 3.4, where the Sahel Zone Countries are displayed in red, while the Arabic Gulf States are coloured in orange.

The Arabic Golf States do not only share a geographical connection. With big reserves of raw oil and partly gas, most of the 8 countries which the panel contains entered a phase of big economic growth beginning in the middle of the 20th century due to high oil extraction rates (especially Kuwait, Qatar, UAE and Saudi Arabia). Compared to these countries, others in the panel like Iraq, Iran and Oman seem to be relatively poor. Especially Iraq, which was a relatively wealthy country until 1980, but then entered a period of war, civil rebellion and terrorism, which is manifested in economic depression. This period has not ended yet.

On the other side, we deal with the panel of the Sahel Zone Countries, which are the African countries located south of the desert, the Sahara, and north of the sub tropical area. These countries of course share similar climate which is a very important factor for African countries, as the agricultural sector is usually bigger than the industrial one. The Sahel Zone has suffered from famines for many years in many areas, and it is also an area where climate change has big influence on daily life. The richest countries are Nigeria and Sudan, the poorest are Niger and Eritrea[3].

Figure 3.8 shows the transition paths of the panels mentioned above. Again as in the section before, the development is similar, however the initial values differ. The transition path of the Gulf States was close to the value 1, which means that the GDP per Capita didn't differ a lot compared to the OECD mean. In the middle of the 1970's, their economies started to depreciate, which could be explained by the oil shocks in this period. After the 70's, the Gulf States entered the transition phase A. One could interpret that they reached the turning point in the late 90's. The Sahel Zone Countries also faced phase A from 1950 to 1980, reached the turning point and entered phase B in the middle 90's.

[3] Eritrea is not in included in the data set.

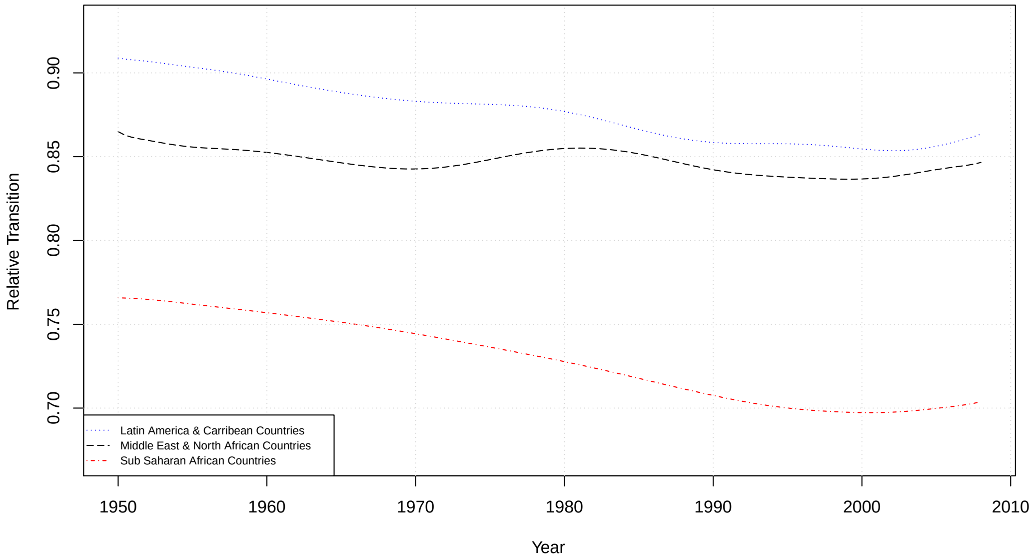

Figure 3.7: Transition of Latin American & Caribbean Countries, Sub Saharan African Countries and Middle East & North African Countries with OECD as Benchmark

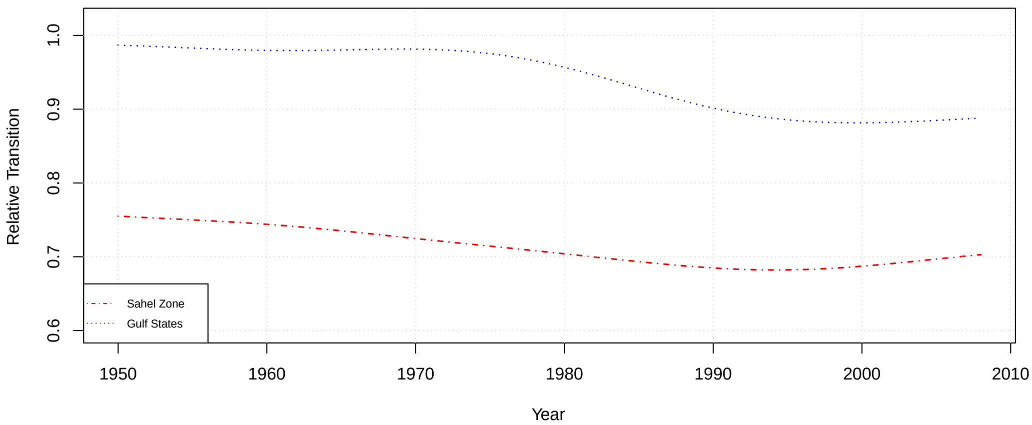

Figure 3.8: Transition of Gulf Sates and the States of the Sahel Zone with OECD as Benchmark

4 Construction of the Convergence Test

In Chapter 3.2 it is mentioned what convergence means in terms of economic data as well as which types of convergence exists. Based on this theory, this chapter is about how to construct a convergence test which can be used for finding patterns in the panels e. g. finding convergence clusters.

4.1 The Log t Convergence Test

The starting point in this section is the single factor model, which was presented in Chapter 2.

$$\log y_{it} = a_{it} + x_{it}t = b_{it}\mu_t \tag{4.1}$$

The fact of growth convergence of country i towards country j depends explicitly on the following condition:

$$(b_{it} - b_{jt}) \to_p 0 \tag{4.2}$$

For this reason, it seems to be appropriate to make this condition a central point in the test construction. As it is difficult to estimate b_{it} in statistical terms, it is more convenient to use equation 3.5 and the connection between h_{it} and b_{it}. This equation eliminates the common growth component, which is an advantage, because it is of great interest how the country-specific and time-dependent variables develop. To measure convergence more precisely, we define the mean square transition differential:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 \tag{4.3}$$

One can see that it provides the quadratic distance measure for the panel from the common limit at a certain time t. In case of convergence $H_t \to 0$ as $t \to \infty$, otherwise the distance stays positive, which can mean that it converges to a non-zero constant, or also that it diverges with growing time t. It also can remain bound without converging. In the case of short time series, it is difficult to distinguish between converging to 0 and converging against a non-zero constant, as long as statistical tools are not taken into account. To strengthen the meaningfulness of the mean square transition differential, we need a model such as Phillips & Sul (2007) invented, whose test is based on a simple one sided t-test, with the H_0 of convergence against the alternative H_1 of non-converge or partial convergence among subgroups. The following semi parametric model for the transition coefficients is the core of the testing procedure:

$$b_{it} = b_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}} \tag{4.4}$$

where the individual transition factor b_{it} is split in a time-independent part b_i and a time dependent part $\frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}}$. The components satisfy the following conditions:

A1 ξ_{it} is iid(0,1) with finite fourth moment $\mathbb{E}(\xi_{it}^4) = \mu_{4\xi}$ over i for each t and is weakly dependent and stationary over t with auto covariance $\gamma_i(h) = E(\xi_{it}, \xi_{it+h})$ satisfying $\sum_{h=1}^{\infty} h|\gamma_i(h)| < \infty$. Partial sums of ξ_{it} and $\xi_{it}^2 - 1$ over t satisfy the panel functional limit laws:

$$\frac{1}{\sqrt{T}} \sum_{t=1}^{[Tr]} \xi_{it} \Rightarrow B_i(r) \text{ as } T \to \infty \text{ for all } i \tag{4.5}$$

$$\frac{1}{\sqrt{T}} \sum_{t=1}^{[Tr]} (\xi_{it}^2 - 1) \Rightarrow B_{2i}(r) \text{ as } T \to \infty \text{ for all } i \tag{4.6}$$

where B_i and B_{2i} are independent and form independent sequences of Brownian motions with variances ω_{ii} and ω_{2ii} over i.

A2 The limits

$$\lim_{N\to\infty} N^{-1} \sum_{i=1}^{N} \sigma_i^2 = v_{\psi}^2, \quad \lim_{N\to\infty} N^{-1} \sum_{i=1}^{N} \sigma_i^4 = v_{4\psi} \tag{4.7}$$

$$\lim_{N\to\infty} N^{-1} \sum_{i=1}^{N} \sigma_i^2 \omega_{ii} = \omega_{\xi}^2, \quad \lim_{N\to\infty} N^{-1} \sum_{i=1}^{N} \sigma_i^4 \omega_{2ii} = \omega_{\eta}^2 \tag{4.8}$$

$$\lim_{N\to\infty} N^{-2} \sum_{i=2}^{N} \sum_{j=1}^{i-1} \sigma_i^2 \sigma_j^2 \sum_{h=-\infty}^{\infty} \gamma_i(h)\gamma_j(h) \tag{4.9}$$

all exist and are finite.

A3 Sums of $\psi_{it} = \sigma_i \xi_{it}$ and $\sigma_i^2(\xi_{it}^2 - 1)$ over i satisfy the limit laws

$$N^{-1/2} \sum_{i=1}^{N} \sigma_i \xi_{it} \Rightarrow \; N(0, v_\psi^2) \tag{4.10}$$

$$N^{-1/2} \sum_{i=1}^{N} \sigma_i^2 (\xi_{it}^2 - 1) \Rightarrow \; N(0, v_{4\psi}(\mu_{4\xi} - 1)) \tag{4.11}$$

as $N \to \infty$ for all t, and the following joint limit laws

$$T^{-1/2} N^{-1/2} \sum_{t=1}^{T} \sum_{i=1}^{N} \sigma_i \xi_{it} \Rightarrow \; N(0, \omega_\xi^2) \tag{4.12}$$

$$T^{-1/2} N^{-1/2} \sum_{t=1}^{T} \sum_{i=1}^{N} \sigma_i^2 (\xi_{it}^2 - 1) \Rightarrow \; N(0, \omega_\eta^2) \tag{4.13}$$

$$T^{-1/2} \sum_{t=1}^{T} N^{-1} \sum_{i=2}^{N} \sum_{j=1}^{i-1} \sigma_i \sigma_j \xi_{it} \xi_{jt} \Rightarrow \; N(0, \lim_{N \to \infty} N^{-2} \sum_{i=2}^{N} \sum_{j=1}^{i-1} \sigma_i^2 \sigma_j^2 \sum_{h=-\infty}^{\infty} \gamma_i(h) \gamma_j(h)) \tag{4.14}$$

hold as $N, T \to \infty$.

A4 The function $L(t)$ is a slowly varying function, increasing and divergent at infinity. Possible choices for $L(t)$ are for instance $\log(t)$ or $\log(t+1)$.

If $a \geq 0$ the parameter b_{it} converges to b_i. The bigger α is, the faster the convergence is, which makes also a difference in the type of convergence.

The type of convergence of course depends on the characteristics of the common trend variable μ_t. Phillips & Sul (2009) suggest either a random walk with drift or a trend stationary process. The difference $\log y_{it} - \log y_{jt}$ has the following development:

$$\log y_{it} - \log y_{jt} = \mu_t (b_{it} - b_{jt}) \approx O_p(t) \cdot O_p\left(\frac{1}{L(t) t^\alpha}\right) = O_p(t^{1-\alpha} L(t)^{-1}) \tag{4.15}$$

One can see for $\alpha \geq 1$ that $\lim_{t \to \infty} \; O_p(t^{1-\alpha} L(t)^{-1}) \; = 0$ which leads to the convergence of the difference $\log y_{it} - \log y_{jt}$, which leads to level convergence. For $0 \leq \alpha < 1$, one can just guarantee the convergence of the b_{it}, which leads to growth convergence. Assuming that μ_t is following a I(1) process without trend, $\alpha \geq 0.5$ leads to level convergence. In the case that μ_t follows a I(2) process, $\alpha \geq 1.5$ is necessary for level convergence.
The supposition of having a common trend component which is following random walk with drift, or a trend stationary process, is quite plausible from the economic perspective

in time of globalisation. For this reason, in this thesis, we demand that $\alpha \geq 1$ for level convergence.

Summing up the discussion above, if $\alpha \geq 0$ the individual transition factors b_{it} converge. If we add this condition to the condition that $b_i = b_j$ for $i \neq j$, growth convergence can be derived which is a reasonable hypothesis H_0:

$$H_0 : b_i = b \;\&\; \alpha \geq 0$$

since

$$\lim_{t\to\infty} b_{it} = b \;\text{ iff }\; b_i = b \;\text{ and }\; \alpha \geq 0$$
$$\lim_{t\to\infty} b_{it} \neq b \;\text{ iff }\; b_i \neq b \;\text{ and }\; \alpha < 0$$

against the alternative

$$H_A : \{b_i = b \;\forall\; i \text{ with } \alpha < 0\} \text{ or } \{b_i \neq b \text{ for some } i \text{ with } \alpha \geq 0, \text{ or } \alpha < 0\}$$

The role of the slowly varying function $L(t)$ is that it ensures convergence even when $\alpha = 0$. The necessary regularity conditions on σ_i and ξ_{it} to ensure rigorous asymptotics for the regression are mentioned in Phillips & Sul (2007) in Appendix B. Based on the Null it is now of interest to create a fitting regression equation, which is explained step by step. As mentioned before, the semi parametric model for b_{it} is the starting point:

$$b_{it} = b_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}}$$

together with 3.5 and $\bar{b} = N^{-1}\sum_{i=1}^{N} b_{it}$ one can easily derive the following form:

$$h_{it} - 1 = \frac{b_{it} - N^{-1}\sum_{i=1}^{N} b_{it}}{N^{-1}\sum_{i=1}^{N} b_{it}} = \frac{b_{it} - \bar{b}}{\bar{b}} \tag{4.16}$$

Taking the squares and sum up over t leads to:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{b_{it} - \bar{b}}{\bar{b}}\right)^2 = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(b_{it} - \bar{b}\right)^2}{\bar{b}^2} \tag{4.17}$$

where the nominator is an estimator for the variance of b_{it}. This estimator converges, with growing sample, against the true variance of b_{it}. Under the conditions of the H_0 of a homogenous common trend effect, we have $b_i = b$ for all i. With the simplification $\sigma_i = \sigma$ we get:

$$\bar{b} = \frac{1}{N}\sum_{i=1}^{N} b_{it} = b + \frac{1}{N}\frac{\sigma}{L(t)t^{\alpha}}\sum_{i=1}^{N}\xi_{it} \xrightarrow{N\to\infty} b \tag{4.18}$$

This leads to:

$$\lim_{N\to\infty}\frac{1}{N}\sum_{i=1}^{N}\left(b_{it}-\bar{b}\right)^2 = Var(b_{it}) = Var\left(b+\frac{\sigma\xi_{it}}{L(t)t^{\alpha}}\right) = \left(\frac{\sigma}{L(t)t^{\alpha}}\right)^2 \tag{4.19}$$

Combining 4.17, 4.18 and 4.19 leads to the limiting form of the transition distance H_t:

$$H_t \xrightarrow{N\to\infty} \frac{\left(\frac{\sigma}{L(t)t^{\alpha}}\right)^2}{b^2} = \frac{\sigma^2}{b^2L(t)^2t^{2\alpha}} \tag{4.20}$$

$$\log\left(\frac{H_1}{H_t}\right) \approx \log\left(\frac{\frac{\sigma^2}{b^2L(1)^2 1^{2\alpha}}}{\frac{\sigma^2}{b^2L(t)^2t^{2\alpha}}}\right) = \log\left(\frac{L(t)^2t^{2\alpha}}{L(1)^2}\right) = 2\log(L(t)) + 2\alpha L(t) - L(1)^2 \tag{4.21}$$

Without the simplification $\sigma_i = \sigma$, deriving the limiting form is more difficult. For detailed stepwise derivation, see Phillips & Sul (2007). The following result is taken from their work H_t has the limiting form:

$$H_t \backsim \frac{A}{L(t)^2t^{2\alpha}} \tag{4.22}$$

for growing t and some constant A. Replacing the slowly varying function $L(t)$ with $\log(t)$, one can derive the central regression equation, very similar to 4.21:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log(\log(t)) = a \ + \ \gamma\log(t) + u_t \text{ for } t = T_0,....,T \tag{4.23}$$

Obviously, $\gamma = 2\alpha$, u_t stands for the error term in the regression, a is a constant, summing up everything which is not time dependent. $T_0 = [rT]$, for some $r > 0$, Phillips & Sul (2007) suggest a value from the interval $[0.2, 0.3]$, which led to the decision of taking $r = 0.25$. The reason for this time series cut is that there should be more emphasis on the later part of the series.

The term $-2\log(\log(t))$ serves as a penalty term under the alternative. This means, in case of club convergence[1], H_t converges to a non zero positive constant which would mean that $\log\left(\frac{H_1}{H_t}\right)$ converges towards a positive constant:

$$H_A : b_{it} \rightarrow \begin{cases} b_1 \text{ and } \alpha \geq 0 \text{ if } i \in G_1 \\ b_2 \text{ and } \alpha \geq 0 \text{ if } i \in G_2 \end{cases} \tag{4.24}$$

where the number of individuals in G_1 and G_2 aggregates to N. For some b_1 and b_2, so that

$$b_1 = \lim_{N\rightarrow\infty} N_1^{-1} \sum_{i \in G_1} b_{it}, \;\; b_2 = \lim_{N\rightarrow\infty} N_2^{-1} \sum_{i \in G_2} b_{it}$$

and

$$h_{it} = \frac{b_{it}}{N^{-1}\sum_i b_{it}} \rightarrow \begin{cases} \frac{b_1}{\lambda b_1 + (1-\lambda) b_2} & i \in G_1 \\ \frac{b_2}{\lambda b_1 + (1-\lambda) b_2} & i \in G_2 \end{cases}$$

This limits of h_{it} lead to the convergence of H_t to a non zero constant. In the case of multiple club convergence, the weighted limits look similar.

If there is club convergence, the log t convergence test should detect non-convergence which is shown by a non positive estimator for γ. The penalty term leads to slow decrease of the left hand side of the regression equation which leads to a weakly negative estimator of γ. Shortly summed up, the penalty term in the regression gives the test discriminatory power to distinguish between overall convergence and club convergence. As the penalty term is a very slowly growing function, in case of overall convergence, the estimator will sill stay positive as the left hand side of the equation will still grow with time.
As the error term u_t can not be guaranteed as an i.i.d process, HAC standard errors are used in the regression to provide robust estimators against heteroscedasticity and autocorrelation. The interesting result of the regression is not just the sign of the coefficient γ as also the magnitude is of interest. If $\gamma = 2\alpha \geq 0$ and the common growth component μ_t follows a random walk with drift or a trend stationary process, the value will imply level convergence. If $2 > \gamma \geq 0$, then this speed of convergence corresponds to relative convergence which means that the growth rates converge over time.

[1] Club convergence means that there is a structure of 2 ore more clubs in a panel. Inside these clubs convergence occurs.

4.2 The Empirical Evidence and Testing

After constructing the testing procedure, it is now about to use this econometric tool on panel data. Therefore different panels are used.

- 20 OECD Countries which were used earlier
- 29 European countries from the World Panel, mentioned in the Data Description
- 52 African countries from the World Panel
- 144 countries from all over the world, forming the World Panel

4.2.1 T-Test

The log t convergence test is based on the regression:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log(\log(t)) = a \ + \ \gamma\log(t) + u_t \text{ for } t = T_0, ..., T \qquad (4.25)$$

wich is estimated with HAC standard errors. The coefficient γ is tested against the alternative $H_1 : \gamma \leq 0$. The critical value for this hypothesis testing is the $t_{0.05}$-quantile, as it is a one-sided t-test. This critical value converges to -1.65 with growing sample size. Therefore, the $H_0 : \gamma > 0$ is rejected if the t-value $t_{\hat{\gamma}}$ for γ is below -1.65.

4.2.2 Interpretation of Empirical Results

In Table 4.1, the convergence tests of the four different panels with varying time frames are shown: with the estimator of γ in the third, the corresponding t-value in the fourth and its standard deviation in the fifth column. There is no estimator above 2, which means that non of the four panels show level convergence which is also reasonable from the economic perspective, as even in the smaller sets as the OECD panel the gap between the poorest country and the richest is relatively big. However, the OECD set is the only one which shows at least relative convergence for the period 1940-2001 and the overall period 1870-2010. This means that growth rates may converge, but the levels do not. All the other panels in all their periods show significantly negative values for $\hat{\gamma}$. This leads to reject the H_0 of the hypothesis testing which further leads to the evidence of divergence structure or club convergence. This result directly leads to the idea of cluster mechanisms in order to find out which clubs in the panels show convergence structure.

Table 4.1: Convergence Tests of the 4 Panels

Panels	Time	$\hat{\gamma}$	$t_{\hat{\gamma}}$	SE($\hat{\gamma}$)
20 OECD Countries	1870-1929	-0.47	-5.79	0.08
	1911-1970	-0.18	-0.77	0.24
	1940-2001	1.03	10.30	0.10
overall test	1870-2010	1.57	3.80	0.40
29 European Countries	1955-1988	-0.44	-17.46	0.03
	1960-1993	-0.86	-5.14	0.17
	1965-1998	-1.27	-7.32	0.17
	1970-2003	-1.38	-37.90	0.04
	1975-2008	-0.92	-8.08	0.03
overall test	1952-2010	-0.94	-59.92	0.02
52 African Countries	1955-1988	-0.88	-35.50	0.03
	1960-1993	-0.88	-38.56	0.02
	1965-1998	-0.95	-277.4	< 0.01
	1970-2003	-1.08	-33.20	0.03
	1975-2008	-1.18	-25.26	0.05
overall test	1950-2008	-1.12	-16.34	0.07
World Panel (144 Countries)	1955-1988	-0.81	-36.55	0.02
	1960-1993	-0.82	-60.92	0.01
	1965-1998	-0.85	-45.41	0.02
	1970-2003	-0.90	-72.62	0.01
	1975-2008	-0.90	-44.63	0.02
overall test	1952-2008	-0.83	-54.37	0.02

5 Clustering Methods and Empirical Testing

As one can see in chapter 4.2, convergence over a full panel is not a realistic assumption which leads to the idea of data-clustering, as club-convergence could be reason of rejection for the H_0 in many cases. Therefore, two different clustering algorithms are presented, compared and the results will be set against each other in terms of computation time, sensibility and economic meaningfulness of the results. For all the following data and clustering analysis, the used panel data is filtered with the Hodrick Prescott filtering method, described in Chapter 2.

5.1 Clustering by Phillips and Sul

5.1.1 The Algorithm

In Phillips & Sul (2007), the two authors present an algorithm for clustering convergence clubs. In this thesis, this algorithm is implemented with some new features. The parameter d^*, which will be introduced in the following steps, can be set to any value. Phillips and Sul used the fixed value -1.65 which is the $t_{0.05}$-quantile of the t-distribution with growing number of degrees of freedom[1].

Step 1 (Cross section ordering): Before the algorithm starts, the data has to be ordered in a certain way. In this case, as the panel data consists of real per capita income data of various countries, the ordering is done by sorting the last entries of the taken time series by its size, beginning with the highest per capita income. With this cross section ordering, a first influence on the final clustering is manifested.

Step 2 (Core Group Formation): It is about finding the core group with the size k^* which is detected by an optimisation problem. The subgroup $G_k = \{1, 2, ..., k\}$ (the k highest

[1] The number of degrees of freedom for a t-distribution grows with the sample size

individuals in the panel) is formed for $2 \leq k \leq N$, and the convergence test statistic $t_k = t(G_k)$ is computed for the subgroup. The size of the core group is chosen by following criteria:

$$k^* = arg \max_{2 \leq k \leq \tilde{K}} \{t_k\} \text{ where } \tilde{K} = arg \min_{2 \leq k \leq N} \{t_k > d^*\} \tag{5.1}$$

This optimisation of the t-value reduces the overall type 1 error[2]. If the condition $t_k > d^*$ does not hold for $k = 2$, the highest individual in G_k is forming an own club and the step is repeated with new subgroups G_{2j} where $3 \leq j \leq N$.

Step 3 (Sieve Individuals for Club Membership): In this step, all the individuals which are not in the core group G_{k^*} are added one by one and the corresponding t-value is computed:

$$t_{k^*i} = t(G_{k^*} \cup \{i\}) \text{ for } i \in \{k^* + 1, ...N\} \tag{5.2}$$

After this is done for all individuals $i \in \{k^* + 1, ...N\}$, the log t regression is done for the expanded group which consists now of all the individuals i which fulfill $t_{k^*i} \geq c^*$, where c^* is the critical value for joining the core group, or not.

If the t-value for the expanded group is above d^*, a club is found. If not, the step has to be repeated with a higher value for c^*. Higher c^* implies less risk of adding individuals to a club where they do not really fit. Phillips & Sul (2009) mention that $c^* = 0$ as initial value is highly conservative and could lead to a bigger number of clubs than necessary. For long time series, they suggest to set $c^* = -1.65$ which is the asymptotic 5% critical value of the log t regression.

Remark: In this thesis, the conservative assumption $c^* = 0$ is used in contrast to Phillips & Sul (2009) where the authors use the fixed value of $c^* = -1.65$ for the decision of forming a club or not. The advantage here is that with higher values than -1.65 the algorithm has to find clubs with stronger evidence of convergence. However, in Phillips & Sul (2009), the result of "not significantly divergent" is sufficient to form a club. The disadvantage is that the algorithm could lead to a big number of formed clubs. To face this problem, the algorithm is extended for one more step, step 5.

Step 4 (Recursion and Stopping Rule): Form a group with the individuals (countries) which remain outside of the club in step 3. Put them together in one panel. If their $t_{\hat{\gamma}} > d^*$ the algorithm terminates and the last cluster is created. If $t_{\hat{\gamma}} < d^*$ repeat step 1-3 to check if this group can be subdivided in convergence clubs. If there is no k in step 2 for which

[2] see Phillips & Sul (2007) on page 24

$t_k > d^*$, we conclude that the remaining individuals diverge.

Step 5 (Club Merging): This an extra extension to the algorithm before. After the first 4 steps, the result of the algorithm could be a way too big number of clusters. Reason therefore may be a too high value for c^*. Conservative clustering can lead to more clubs than necessary. For this situation, an extra function called merging function is implemented. Phillips & Sul (2007) mentioned this idea and did it manually. The implemented merging function is checking the $t_{\hat{\gamma}}^{i,i+1}$ for two merged neighbour clubs i and $i+1$.

$$max(t_{\hat{\gamma}}^{i,i+1}) \quad \text{for i= 1,....C} \quad \text{s. t.: } t_{\hat{\gamma}}^{i,i+1} > c^* \tag{5.3}$$

where C is the number of clubs, and c^* is the critical value which stands for the minimum value for $t_{\hat{\gamma}}^{i,i+1}$ for merging two clubs. This step can be done as long as the number of demanded clubs (extra parameter in the function) is reached. If the number of possible clubs exceed the number of demanded clubs, the function put the last k clubs in a divergence club to reach the number of desired clubs. Phillips & Sul (2009) also formed the last club in their paper to a divergence club as there cannot be guaranteed a convergence club for every individual.

5.1.2 The Empirical Results

The club order, beginning with 1 (up to 3 in the Europe Panel, up to 4 in the Africa Panel, up to 5 in the World Panel), is also a economic ranking. In Club 1, one will find the biggest mean GDP per capita which is getting less from club to club.

For all the panels, the same time frames were taken - but of course a different number of clubs. The algorithm above leads to varying numbers of clusters for almost every time frame. Therefore, step 5, e. g. the implemented function, has an optional parameter for the resulting number of clubs. If the number of clubs cannot be reached with merging, this means putting two clubs together which still converge after the fusion, the last clubs which exceed the number of clubs are put together in a cluster. This also leads to the fact that all the clubs at least show relative convergence, with exception of the last club, which can also show signs of divergence.
For the three following panels, the parameter d^* and c^* from the algorithm is set to 0.

For all the cluster analysis in the following sections, the same time windows are used. For some countries, a very long history of data is available: for the OECD countries for instance since 1870. If we reduce the time frame to the window 1955-2008, the data is available for all the countries which are used in the cluster analysis. This time frame is divided in 5 overlapping periods.

- Period 1 : 1955-1988
- Period 2 : 1960-1993
- Period 3 : 1965-1998
- Period 4 : 1970-2003
- Period 5 : 1975-2008

Every period has the length of 33 years because Phillips & Sul (2009) used the same length in their analysis.

For reasons of clarity and comprehensibility, all tables are included in the appendix.

5.1.2.1 World Panel

For the World Panel, the club number of 5 is chosen as this is the result of clustering algorithm of the first time frame and at the same time, it is the number of clubs Phillips & Sul (2009) used for clustering a World Panel - however, with a smaller number of countries and shorter time series. In Table 5.1, one can see all the important estimators, standard deviations, and t-values for every single club in every time frame. There is just sign of divergence in Club 5, all the other clubs show convergence or at least no sign for significantly negative estimators for $\hat{\gamma}$. Also no club shows absolute convergence which is reasonable from the economic perspective. A group of more than 20 countries spread over the world will probably not converge to the same level of real per capita income in the next years. The frequent occurrence of relative convergence is interesting though. For closer interpretation, we have to take a look which club contains which countries.

In Table A.1, the countries and the club membership in each period is listed. As the list is quite long, we focus on an interesting selection of countries where an economic interpretation is possible. With very few exceptions, the western OECD countries are always member of Club 1. Many countries switch between two clubs over the periods. For example, the Eastern European countries switch between Club 2 and 3. Higher developed South American, Asian or Near East countries switch between Club 1 and 2. The majority of the members of Club 4 and 5 are African countries which also makes sense from the economic perspective. The reason why many countries worsened over the periods is, that Club 5 grew from 3 members in Period 1 to 35 members in Period 5. This is an indication for an ongoing growth of the gap between the developing countries and the developed ones.
With a closer look on the winners and losers regarding the results, one can see that the

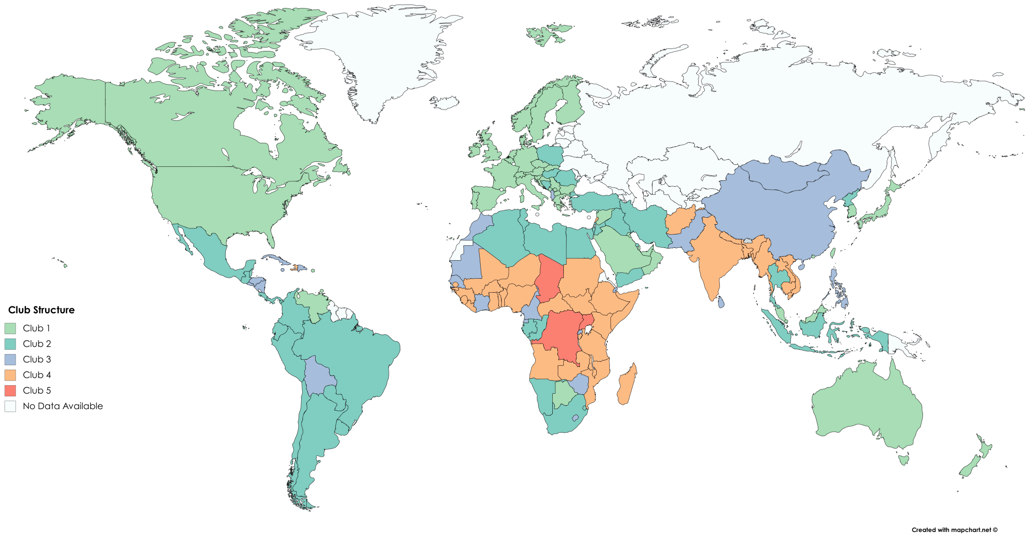

Figure 5.1: The Club Structure of World Data in Period 1 (1955-1988)

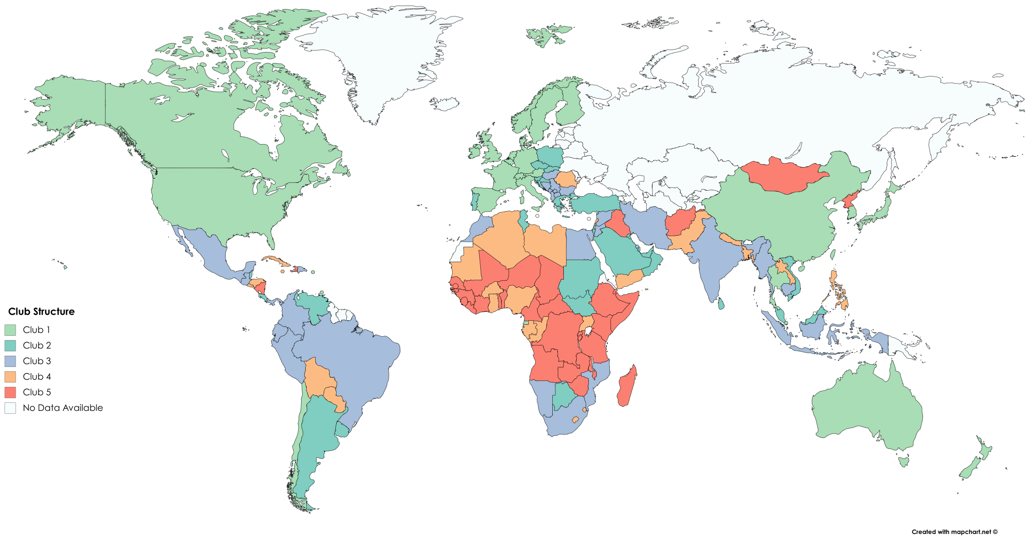

Figure 5.2: The Club Structure of World Data in Period 5 (1975-2008)

Table 5.1: Clustering Results of the World Panel

	Club 1	Club 2	Club 3	Club 4	Club 5
1955-1988					
$\hat{\gamma}$	0.38	0.13	0.006	0.06	-0.73
SE($\hat{\gamma}$)	0.11	0.14	0.05	0.12	0.39
$t_{\hat{\gamma}}$	3.60	0.93	0.12	0.52	-1.90
Club-Size	45	36	25	35	3
1960-1993					
$\hat{\gamma}$	0.02	0.04	0.01	0.02	0.25
SE($\hat{\gamma}$)	0.003	0.07	0.13	0.03	0.18
$t_{\hat{\gamma}}$	7.18	0.60	0.10	0.62	1.36
Club-Size	42	32	33	33	4
1965-1998					
$\hat{\gamma}$	0.22	0.12	0.22	0.13	-0.32
SE($\hat{\gamma}$)	0.07	0.10	0.012	0.17	0.05
$t_{\hat{\gamma}}$	3.16	1.21	19.12	0.80	-6.65
Club-Size	38	27	24	34	21
1970-2003					
$\hat{\gamma}$	0.25	0.26	0.18	0.22	0.20
SE($\hat{\gamma}$)	0.004	0.05	0.10	0.12	0.004
$t_{\hat{\gamma}}$	60.63	4.74	1.76	1.80	53.67
Club-Size	33	34	28	28	21
1975-2008					
$\hat{\gamma}$	0.60	0.20	0.19	0.03	-0.44
SE($\hat{\gamma}$)	0.17	0.08	0.006	0.074	0.03
$t_{\hat{\gamma}}$	3.61	2.54	29.65	0.44	-12.78
Club-Size	31	22	32	24	35

majority of countries which worsened by 2 clubs or more are almost exclusively African countries, with few exceptions. (*Serbia, Bulgaria, Macedonia, Syria, Yugoslavia, Montenegro, Gabon, Romania, Libya, Paraguay, Algeria, Swaziland, Congo Brazzaville, Yemen, Djibouti, Nicaragua, Côte d Ivoire, Cameroon, Mongolia, Sao Tomé and Principe, Zimbabwe, Senegal, Rwanda, Iraq and North Korea.*)
In this list, there are 3 Eastern European countries which had similar growth as the Western OECD countries in the earlier periods but couldn't keep up with them in the later periods. Besides some Arabic and Latin American countries, as mentioned before, the majority are African countries. To be precise, a very big part are Western African countries which stems from the fact that most of the eastern African countries have never been part of Club 3 or higher in the first place, so they couldn't have been downgraded by 2 clubs. However, many Western African countries had decent economic growth because of the export of raw materials such as oil, gas, rare earths or gold. This reason gave them an growth advantage over other African countries in the early periods. However, many of them couldn't keep their position in the economic ranking for different reasons.

Iraq and North Korea had the biggest decline in the results of this paper. Iraq suffered long periods of war, as well as Rwanda did. Libya and Algeria faced civil wars and unstable political systems.

In respect to the results listed in Table A.1, there are also some winners which improved by two clubs: *China, Equatorial Guinea, Vietnam and Sudan*.The oilfields in the south of Sudan have been significant to the economy since the latter part of the 20th century. With rising oil revenues, the Sudanese economy was booming around the turn of the millennium. As 2008 is the last year the data set covers for Sudan, the influence of the declared independence of South-Sudan is not considered here. *In Equatorial Guinea, the discovery of large oil reserves in 1996 and its subsequent exploitation have contributed to a dramatic increase in government revenue*[3]. As of 2004, Equatorial Guinea has been the third-largest oil producer in Sub-Saharan Africa. Its oil production has risen from 220,000 barrels only two years earlier to 360,000 per day[4]. Vietnam and China entered a period of big economic growth in the latter part of the 20th century because of a booming industrial sector.
Figures 5.1 and 5.2 give a raw first impression of how the development in the panel took place[5]. The relapse of Africa may be the most noticeable change as well as the divergence of the Latin American economies as they have been on similar level in Period 1.

[3] Quote from: *https://en.wikipedia.org/wiki/Equatorial_Guinea*
[4] Justin Blum (7 September 2004). "U.S. Oil Firms Entwined in Equatorial Guinea Deals". washingtonpost.com. Retrieved 9 July 2008.
[5] The first and the last period is chosen for all the following visualisations, to get an impression which developments took place over the whole timeframe.

5.1.2.2 Africa Panel

For closer investigation of the economical progress of the African countries, the continent is also treated with the club analysis like the World Panel. With a few exceptions, the whole continent is available with time series of all countries except Western Sahara, Eritrea and some small countries. In the maps which are shown in this thesis (beginning with Figure 5.1), Sudan is already divided into Sudan and South-Sudan. The two countries are coloured the same, as the data stops before the declaration of independence of South Sudan. In Table A.2, the entire results of the algorithm are listed, the corresponding testing output for every club in every period is listed in Table 5.2. Figure 5.3 and Figure 5.4 serve as a visualisation of the tabular results of Period 1 and Period 5. Club 1 is "blocked" by Mauritius in the first 3 periods which is because of the high real income per capita and growth with which no other country could compete back in this time. Only in the last two periods, some countries entered the fist club which is still very small in the end with just 4 members. None of the clubs is showing signs of absolute convergence, but of course, as it is a condition of the algorithm, all the clubs show relative convergence, except the divergence Club 4[6]. In Figure 5.3, one can see the higher development in the north and in the south of the African continent as well as in the middle-west coast part where Cameroon, Equatorial Guinea, Gabon and Congo Brazzaville is located. The results of Period 5 (Figure 5.4) still show the northern and the southern part as relatively richer, but it is considerable that many of the countries in the tropical, subtropical and Sahel Area got downgraded from Club 3 to Club 4. A mentionable upgrade took place for Sudan, from Club 3 to Club 2, which can be explained through the increasing oil market. Club 1 has grown by 3 members, which are the Seychelles, Equatorial Guinea and Tunisia.

5.1.2.3 Europe Panel

The algorithmic results for the Europe panel are listed in Table A.3, the corresponding testing output for each club in each period is listed in Table 5.3. Figures 5.5 and 5.6 show the results of the algorithm in coloured maps. The Kosovo, which is shown as an independent country on the maps, is coloured the same as Serbia, as in the 5 periods which are observed, the Kosovo has not been an independent country. In the results of Table 5.3, one can see that there is no sign for absolute convergence in none of the clubs. Club 3 is a divergence club in all the 5 periods, the other two clubs show relative convergence in the 5 periods. Except for the first period, the club size seems to be very stable. In Period 1, some of the balkan countries are part of Club 1 (Serbia, Croatia, Slovenia), but over time, their GDP development cannot compete with the one of the Western European countries. This is why

[6] with one exception in Period 2

Table 5.2: Clustering Results of the Africa Panel

	Club 1	Club 2	Club 3	Club 4
1955-1988				
$\hat{\gamma}$	0	0.03	0.09	−0.17
SE($\hat{\gamma}$)	0	0.019	0.10	0.26
$t_{\hat{\gamma}}$	0	1.44	0.93	−0.66
Club-Size	1	17	30	4
1960-1993				
$\hat{\gamma}$	0	0.07	0.09	0.13
SE($\hat{\gamma}$)	0	0.10	0.003	0.11
$t_{\hat{\gamma}}$	0	0.68	30.22	1.15
Club-Size	1	19	20	12
1965-1998				
$\hat{\gamma}$	0	0.14	0.033	−0.39
SE($\hat{\gamma}$)	0	0.04	0.07	0.09
$t_{\hat{\gamma}}$	0	3.24	0.47	−4.33
Club-Size	1	17	16	18
1970-2003				
$\hat{\gamma}$	0.32	0.46	0.29	−1.03
SE($\hat{\gamma}$)	0.21	0.10	0.18	0.11
$t_{\hat{\gamma}}$	1.54	4.50	1.65	−9.74
Club-Size	4	11	12	25
1975-2008				
$\hat{\gamma}$	0.04	0.51	0.16	−1.28
SE($\hat{\gamma}$)	0.03	0.12	0.14	0.02
$t_{\hat{\gamma}}$	1.40	4.33	1.21	−82.90
Club-Size	4	14	19	15

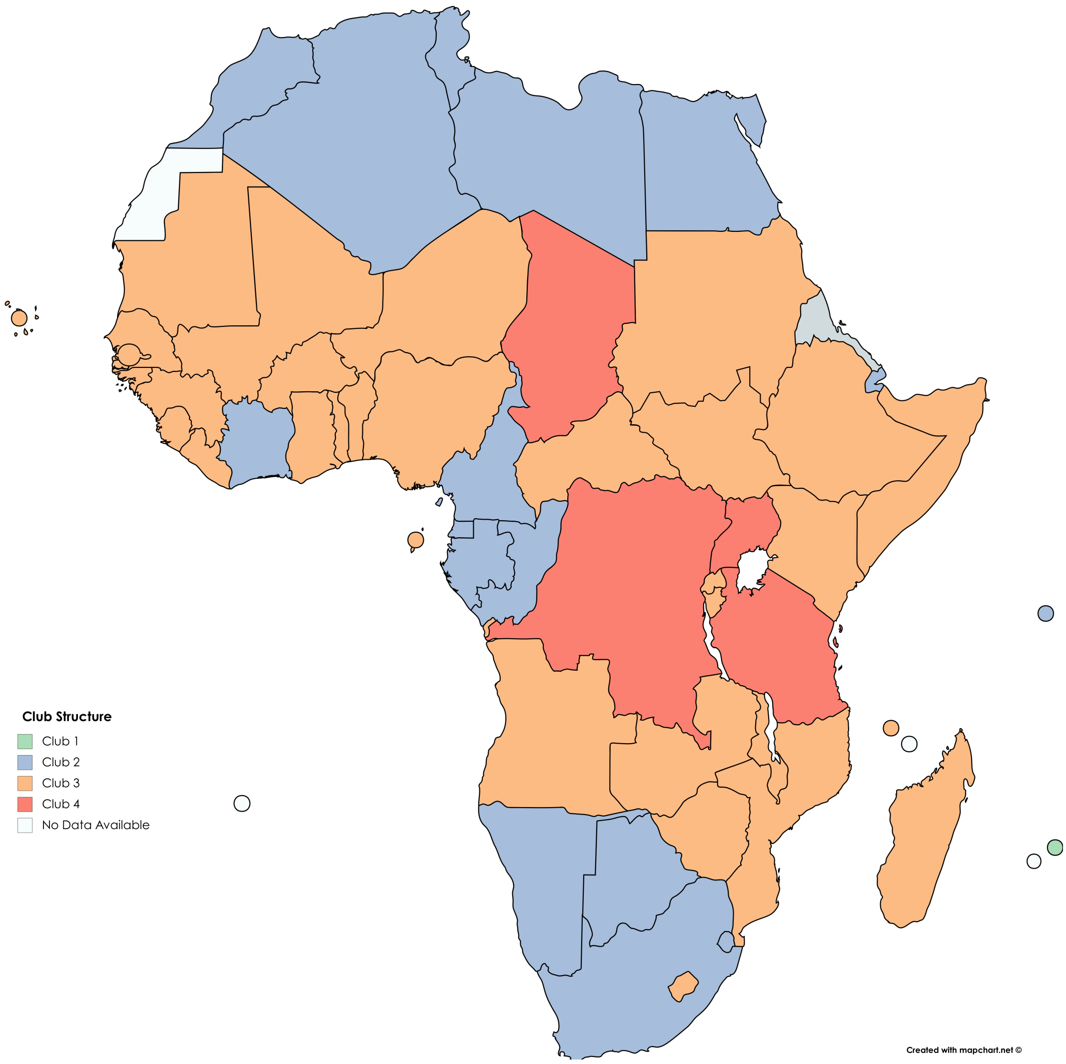

Figure 5.3: The Club Structure of Africa Data in Period 1 (1955-1988)

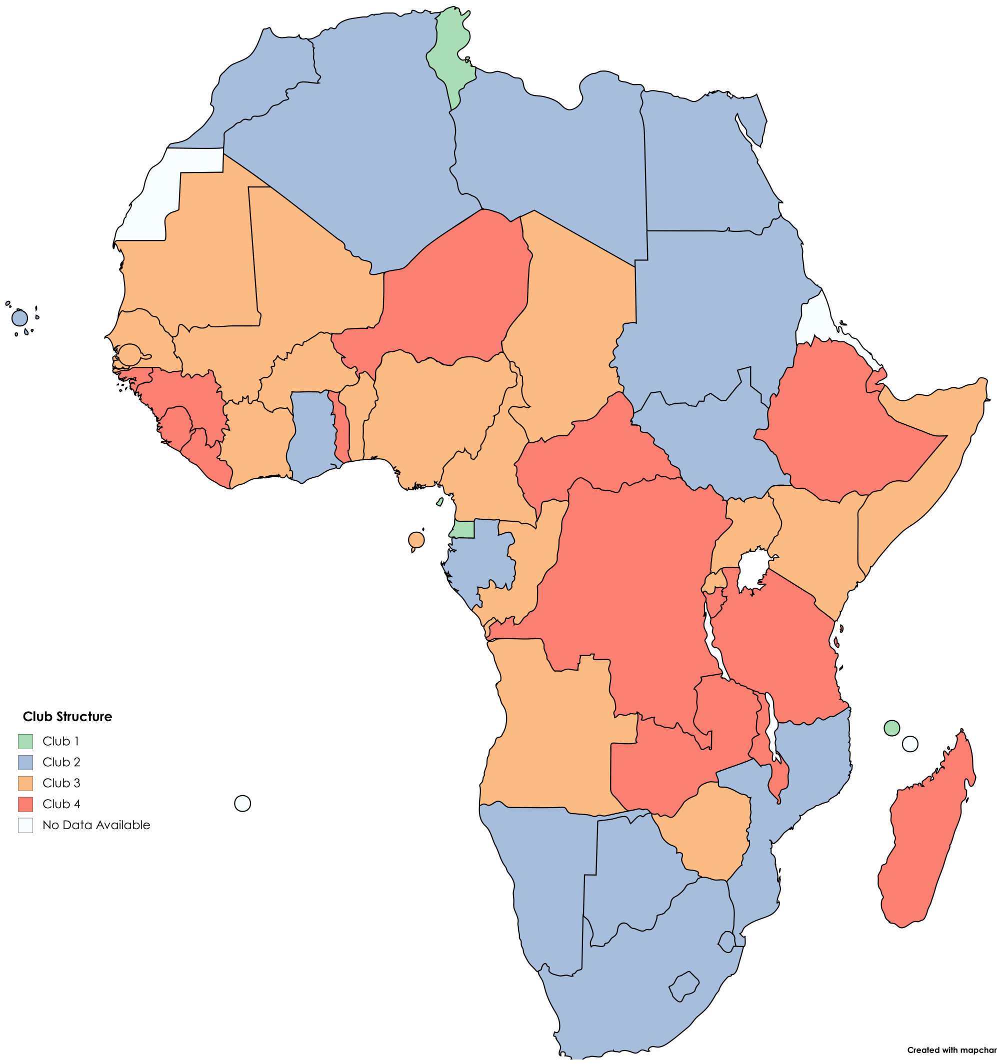

Figure 5.4: The Club Structure of Africa Data in Period 5 (1975-2008)

Table 5.3: Clustering Results of the Europe Panel

	Club 1	Club 2	Club 3
1955-1988			
$\hat{\gamma}$	0.01	0.25	-1.47
SE($\hat{\gamma}$)	0.02	0.06	0.08
$t_{\hat{\gamma}}$	0.71	4.03	-19.00
Club-Size	20	7	2
1960-1993			
$\hat{\gamma}$	0.12	0.80	-0.83
SE($\hat{\gamma}$)	0.09	1.38	0.05
$t_{\hat{\gamma}}$	1.34	0.58	-15.76
Club-Size	15	2	12
1965-1998			
$\hat{\gamma}$	0.22	1.15	-1.14
SE($\hat{\gamma}$)	0.03	1.14	0.05
$t_{\hat{\gamma}}$	8.87	1.013	-25.20
Club-Size	14	2	13
1970-2003			
$\hat{\gamma}$	0.26	1.88	-0.85
SE($\hat{\gamma}$)	0.13	0.22	0.06
$t_{\hat{\gamma}}$	2.03	8.41	-14.51
Club-Size	15	2	12
1975-2008			
$\hat{\gamma}$	0.08	1.24	-0.61
SE($\hat{\gamma}$)	0.05	0.33	0.09
$t_{\hat{\gamma}}$	1.56	3.76	-6.91
Club-Size	15	2	12

Club 1 is shrinking over time. In the periods 2 to 5, it just contains members of the EU15[7][8], Switzerland and Norway. In Figure 5.6, the border between Club 1 and Club 2/3 is he way the Iron Curtain took, including the border of former Yugoslavia and neglect the fact that Eastern Germany would be on the eastern side of the Iron Curtain.

5.2 Hierarchical Clustering

In order to compare the results of the algorithm above, a second clustering algorithm was implemented. It is a very basic algorithm with heuristic theory. The disadvantage of the

[7] Was the number of member countries in the European Union prior to the accession of ten candidate countries on 1 May 2004. The EU15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

[8] Luxembourg as one of the EU15 members, is the only member which is not included in the dataset

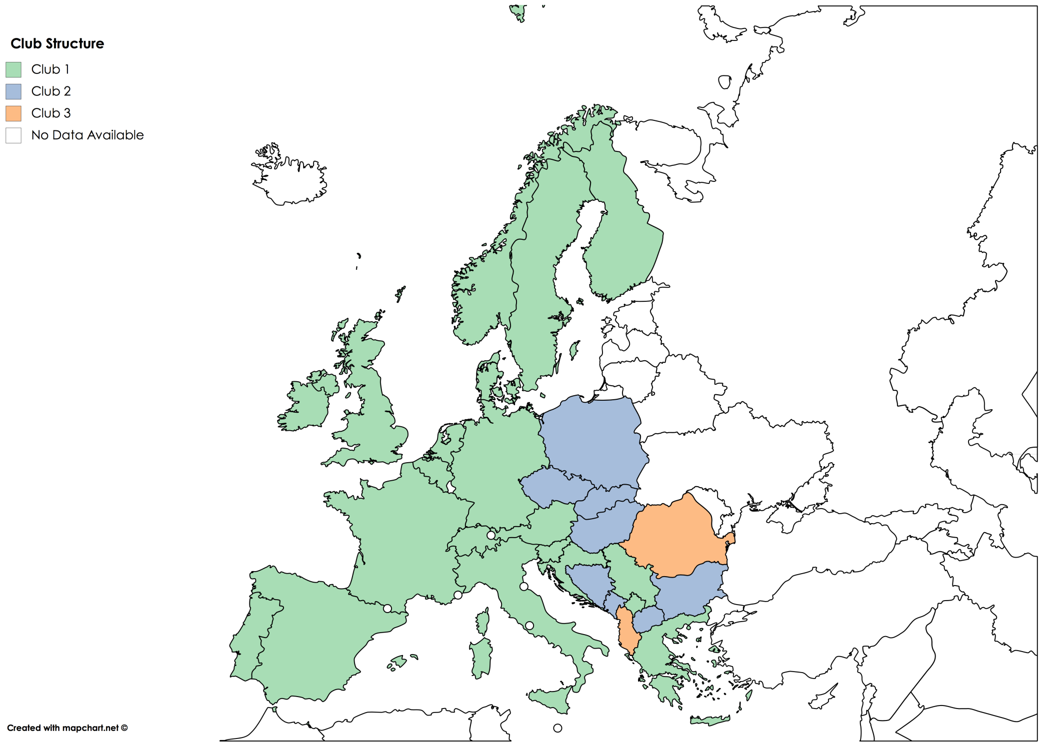

Figure 5.5: The Club Structure of Europe Data in Period 1 (1955-1988)

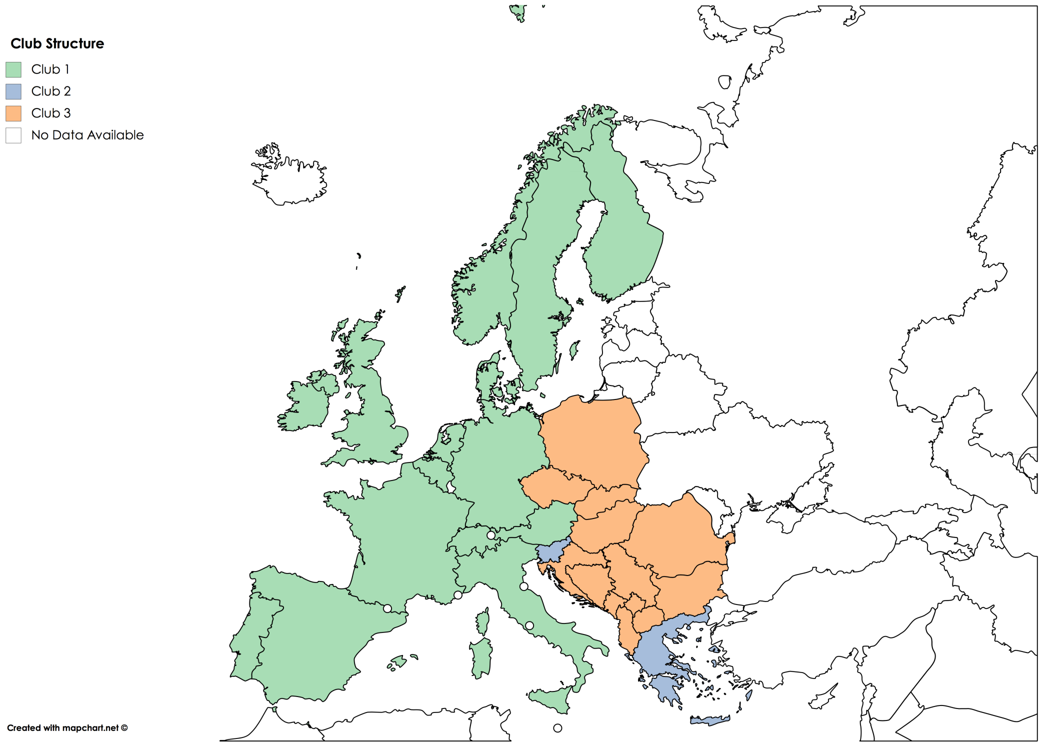

Figure 5.6: The Club Structure of Europe Data in Period 5 (1975-2008)

algorithm of Phillips and Sul is that there may is a lot of bias of the result because of the preordering. For this reason, the following algorithm has no pre-ordering. The decision of forming clubs is done by hierarchical criteria which is in this case the output of the log t regression.

5.2.1 The Algorithm

Step 1 (Club Assignment): In the first step, every single individual - which, in our case, is a country - enters its own club. So in the initial step, the number of clubs equals the number of countries.

Step 2 (The Distance Matrix): As it is necessary for a hierarchical clustering, a distance matrix is used for decision-making. It looks as follows:

$$D = \begin{bmatrix} t_{\hat{\gamma},12} & t_{\hat{\gamma},13} & \cdots & t_{\hat{\gamma},1j} \\ & t_{\hat{\gamma},23} & \cdots & t_{\hat{\gamma},2j} \\ & & \ddots & \vdots \\ & & & t_{\hat{\gamma},j-1j} \end{bmatrix} \tag{5.4}$$

where $t_{\hat{\gamma},ij}$ is the t-value of the log t regression of Club i and Club j. Only the upper triangle of the matrix has to be calculated.

Step 3 (Maximisation and Merging): In this step, the maximum value and its position of the distance matrix D is calculated. If the maximum is in the matrix position $[i, j]$, the i-th and the j-th club get merged to one club which is Club i now. Afterwards, go back to step 2 with the new club assignment until the desired number of clubs is reached.

Step 4 (Post algorithmic resorting): This step is an additional step to the 3 steps before and is implemented as an extra function which takes the result of the algorithm described in the three steps before. Now, there is a assignment for every country to one of the clubs 1 to C. Because this hierarchical clustering turns into merging big clubs shortly before terminating, it can happen that some countries fit better into another club. The central matrix for this step is this one:

$$O = \begin{bmatrix} o_{11} & o_{12} & \cdots & o_{1C} \\ o_{21} & o_{22} & \cdots & o_{2C} \\ \vdots & \vdots & \vdots & \vdots \\ o_{N1} & o_{N2} & \cdots & o_{NC} \end{bmatrix} \in \mathbb{R}^{N \times C} \tag{5.5}$$

where N is the number of countries and C is the number of clusters. An entry o_{ij} is organised as follows: It means that the basic assignment is taken with the change that country i gets assigned to Club j. Then all the t-values for the clubs are calculated and are summed to

one value. From this sum, one subtract the sum of the t-values from the basic assignment. The difference of these two sums is represented by o_{ij}. Then, the maximum value of matrix O is taken because it means the best reassignment for the club structure. This decision is tied to a further condition: the reassignment must have a positive influence on the t-value of the leaving **and** of the receiving club. This step is done as long as there is an reassignment which fulfills both conditions.
Remark: There is no critical value used in the whole algorithm and this is done on purpose. The prefixed number of clusters is taken from the results of the algorithm of Phillips and Sul. However, the algorithm can lead to more than just one divergence cluster which is the risk and the tradeoff when renouncing econometric restrictions.
Another problem which occurs is that there is no perfect control over the order of the clubs. As the data doesn't get pre-ordered, Club 1 doesn't have to be the club with the highest mean GDP per capita. Therefore, a post-ordering is implemented which orders the clubs by the club-means of the last entry, beginning with the highest, which guarantees the same ordering as in the algorithm of Phillips and Sul.

5.2.2 The Empirical Results

5.2.2.1 World Panel

The results of the hierarchical clustering of the World Panel are listed in detail in the appendix in Table A.4. The test results including the t-values as well as the club size standard deviation and the estimator for γ itself is processed in Table 5.4. As one can see in Table 5.4, some of the clubs do not show convergence. This problem was discussed in the description of the algorithm above. More specifically this concerns the following Clubs in the mentioned periods: Club 2 in Period 1, Club 5 in Period 4, Club 3 in Period 5 and Club 5 in Period 5. All the other clubs show relative convergence, there is no club with absolute convergence. Compared to Table 5.1, in Table 5.4 many clubs show very high t-values as there is standard deviation of the estimator of γ very close to zero. As the aim of the hierarchical clustering is maximising the t-values, it is no surprise that those values are higher than in the other algorithm. Figures 5.7 and 5.8 show the visualisation of the algorithmic results for the World Panel. As Club 2 in Period 1 is not a convergence club, one has to pay attention to the interpretation, however the reason probably is the containment of a few countries. It is nevertheless striking that nearly all Latin American countries are part of Club 2. The western OECD countries again, as in the other clustering algorithm, form the first club which is a convergence club - of course with some additions from all over the world. Africa shows more development on northern and southern end of the continent, which makes sense from the point of view of economic history. The poorer regions are located in the tropical and

Table 5.4: Hierarchical Clustering Results of the World Panel

	Club 1	Club 2	Club 3	Club 4	Club 5
1955-1988					
$\hat{\gamma}$	0.209	−0.360	0.413	0.080	0.288
SE($\hat{\gamma}$)	0.011	0.052	0.023	0.000	0.021
$t_{\hat{\gamma}}$	19.147	−6.943	18.046	385.203	13.857
Club-Size	39	50	12	33	10
1960-1993					
$\hat{\gamma}$	0.112	0.091	0.119	0.047	0.330
SE($\hat{\gamma}$)	0.022	0.000	0.002	0.027	0.000
$t_{\hat{\gamma}}$	5.058	600.411	69.889	1.755	1374.541
Club-Size	26	26	38	35	19
1965-1998					
$\hat{\gamma}$	0.058	0.022	0.191	0.440	0.013
SE($\hat{\gamma}$)	0.028	0.000	0.000	0.001	0.178
$t_{\hat{\gamma}}$	2.025	493.957	86035.432	363.797	0.073
Club-Size	33	31	28	28	24
1970-2003					
$\hat{\gamma}$	0.542	0.070	−0.051	0.020	−0.621
SE($\hat{\gamma}$)	0.081	0.000	0.031	0.004	0.075
$t_{\hat{\gamma}}$	6.723	170.513	−1.620	5.664	−8.268
Club-Size	17	21	56	37	13
1975-2008					
$\hat{\gamma}$	0.550	0.044	−0.015	0.135	−0.941
SE($\hat{\gamma}$)	0.000	0.000	0.087	0.001	0.014
$t_{\hat{\gamma}}$	50284.209	2025.370	−0.172	133.824	−65.042
Club-Size	23	27	52	28	14

sub tropical area of Africa and in the southern region of the Asian mainland, from Vietnam to Afghanistan. This is interesting from a special point of view: This area made a big step forward over the periods to Period 5 (Figure 5.8). Without going into too much detail, Asia made a step forward while Africa and also Latin America made a step backwards. To discuss the big winners and losers regarding the algorithmic results, one has to emphasise the countries which lost or gained two levels. As Club 2 in Period 1 is not a convergence club, Period 2 is taken as initial period and is compared to the 5th. In relation to this two clustering results, it is considerable that there is just one country which got downgraded by two clubs. Syria is related to Club 1 in Period 2 and is part of Club 3 in Period 5. Regarding the winners, one has to mention that this group only contains Equatorial Guinea and Sudan. Those countries were also part of the winners concerning the clustering results of Phillips and Sul's algorithm. This comparison shows that there is not as much movement between the time frames as in the other algorithm which can be partly explained by not considering Period 1.

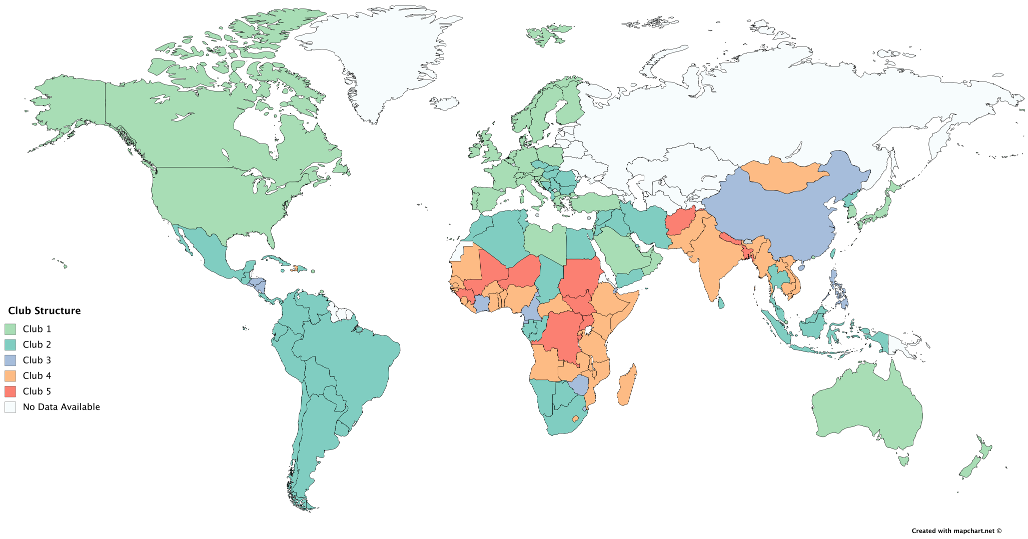

Figure 5.7: The Club Structure of World Data in Period 1 (1955-1988) - Hierarchical Clustering

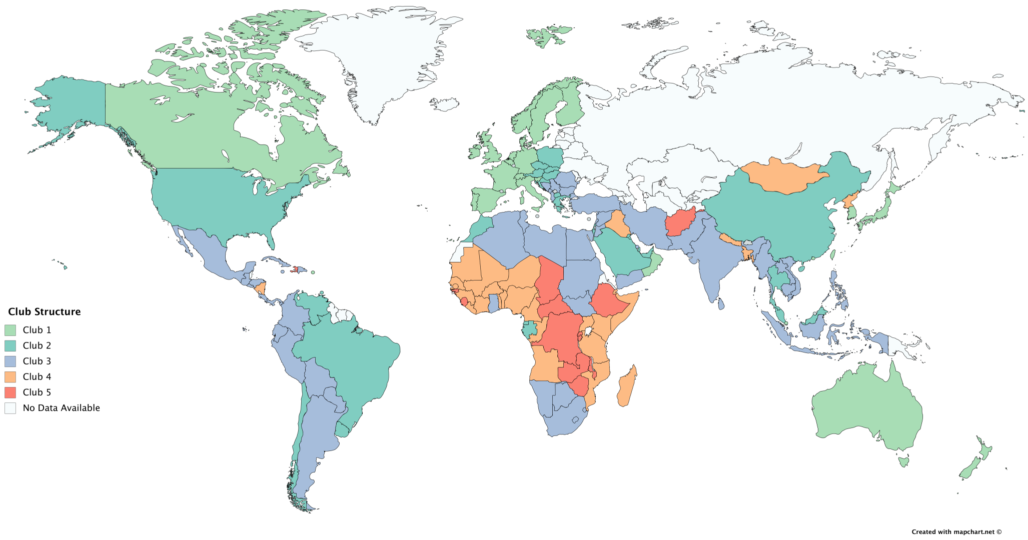

Figure 5.8: The Club Structure of World Data in Period 5 (1975-2008) - Hierarchical Clustering

Table 5.5: Hierarchical Clustering Results of the Africa Panel

	Club 1	Club 2	Club 3	Club 4
1955-1988				
$\hat{\gamma}$	0.057	1.050	0.154	0.178
SE($\hat{\gamma}$)	0.132	0.141	0.000	0.050
$t_{\hat{\gamma}}$	0.431	7.467	453.904	3.569
Club-Size	15	4	25	8
1960-1993				
$\hat{\gamma}$	0.874	−0.772	0.119	0.155
SE($\hat{\gamma}$)	0.036	0.259	0.000	0.041
$t_{\hat{\gamma}}$	24.216	−2.982	498.028	3.811
Club-Size	7	8	19	18
1965-1998				
$\hat{\gamma}$	0.111	0.223	0.195	−0.163
SE($\hat{\gamma}$)	0.003	0.000	0.021	0.108
$t_{\hat{\gamma}}$	34.126	15099.550	9.122	−1.514
Club-Size	11	11	13	17
1970-2003				
$\hat{\gamma}$	2.271	0.340	0.095	−0.798
SE($\hat{\gamma}$)	1.679	0.001	0.026	0.203
$t_{\hat{\gamma}}$	1.353	287.598	3.668	−3.929
Club-Size	2	11	22	17
1975-2008				
$\hat{\gamma}$	0.678	0.148	0.164	−1.347
SE($\hat{\gamma}$)	0.047	0.094	0.004	0.112
$t_{\hat{\gamma}}$	14.327	1.578	38.404	−11.988
Club-Size	3	15	20	14

5.2.2.2 Africa Panel

The detail results for the Africa panel are listed in Table A.5, the corresponding testing output in Table 5.5. The divergence clubs are Club 4 in Period 3, 4 and 5, as well as Club 2 in Period 2. All the other clubs show characteristics of relative convergence, however, one club shows signs of absolute convergence: Club 1 in Period 4. This club only consists of 2 countries, Mauritius and Equatorial Guinea, which makes the result a little less remarkable. Comparing Figure 5.9 and Figure 5.10, the step backwards of almost the whole continent is noticeable. As in the results of the World Panel, the northern and southern end of Africa is higher developed in Period 1, while the middle part is poorly developed throughout, with a few exceptions (Congo Brazzaville, Equatorial Guinea, Gabon, Cote d Ivoire, Sierra Leone and Gabon). In Period 5, the structure of the continent seems to be the same, just with a club shift of 1 or 2 clubs downgrade. The big exception, as in the results of A.2, is Sudan.

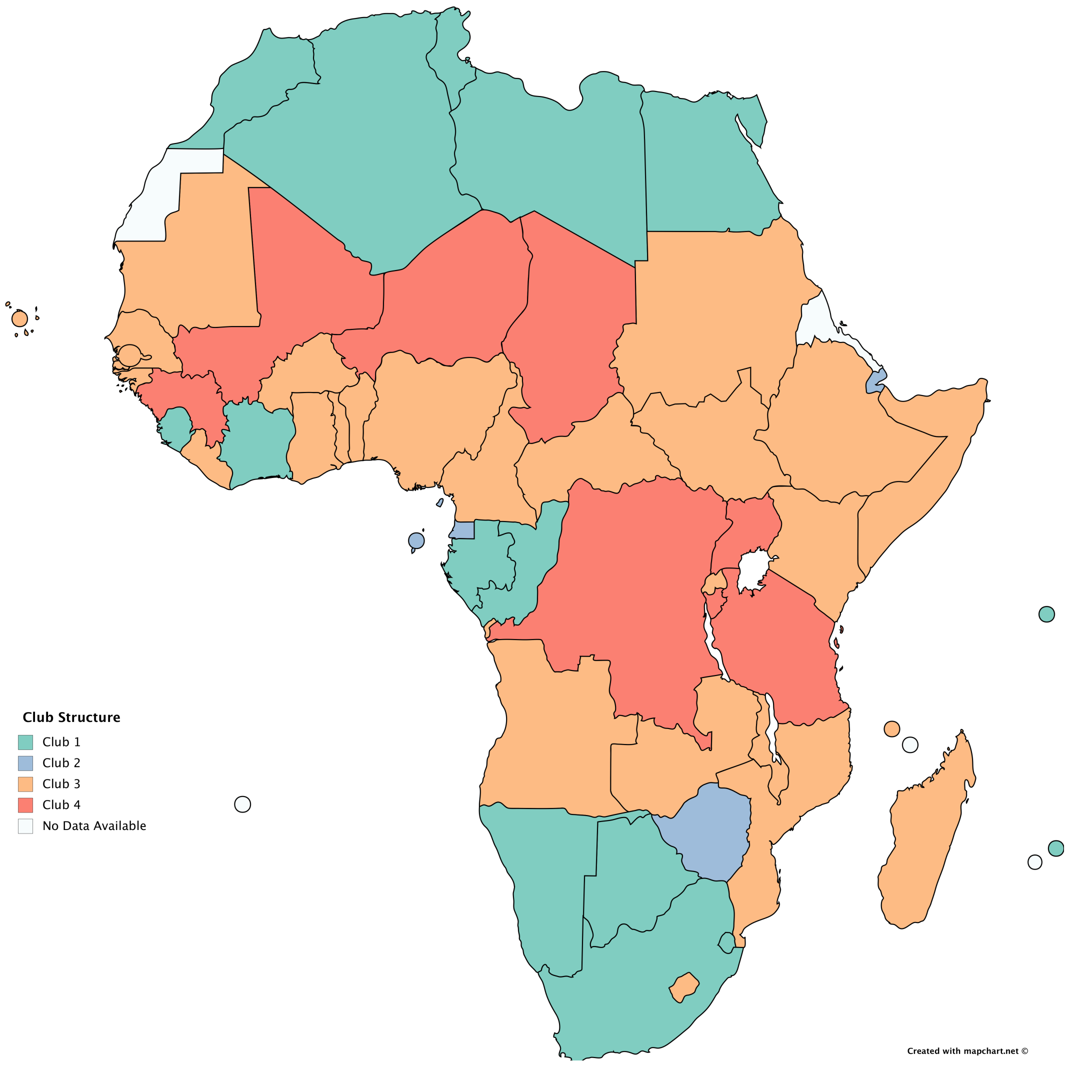

Figure 5.9: The Club Structure of Africa Data in Period 1 (1955-1988) - Hierarchical Clustering

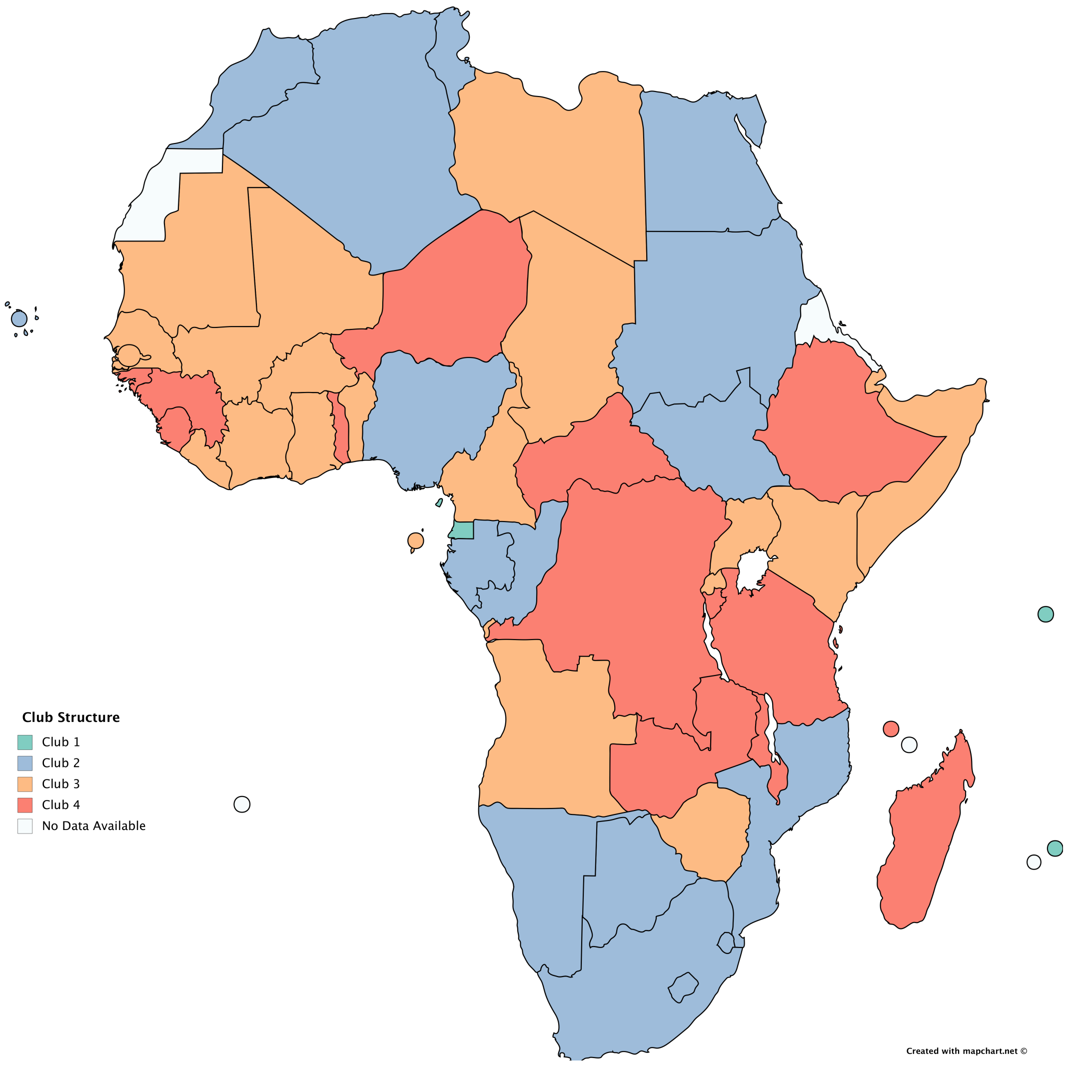

Figure 5.10: The Club Structure of Africa Data in Period 5 (1975-2008) - Hierarchical Clustering

Table 5.6: Hierarchical Clustering Results of the Europe Panel

	Club 1	Club 2	Club 3
1955-1988			
$\hat{\gamma}$	0.168	0.259	−1.471
SE($\hat{\gamma}$)	0.013	0.051	0.077
$t_{\hat{\gamma}}$	13.160	5.082	−19.009
Club-Size	18	9	2
1960-1993			
$\hat{\gamma}$	0.013	−1.171	−0.850
SE($\hat{\gamma}$)	0.014	0.861	0.044
$t_{\hat{\gamma}}$	0.899	−1.361	−19.419
Club-Size	16	3	10
1965-1998			
$\hat{\gamma}$	0.158	−1.166	−0.300
SE($\hat{\gamma}$)	0.038	0.104	0.092
$t_{\hat{\gamma}}$	4.123	−11.170	−3.243
Club-Size	15	11	3
1970-2003			
$\hat{\gamma}$	−0.297	−0.086	−0.221
SE($\hat{\gamma}$)	0.027	0.103	0.213
$t_{\hat{\gamma}}$	−11.199	−0.834	−1.039
Club-Size	17	4	8
1975-2008			
$\hat{\gamma}$	−0.495	1.799	0.148
SE($\hat{\gamma}$)	0.093	0.002	0.156
$t_{\hat{\gamma}}$	−5.307	754.510	0.949
Club-Size	18	3	8

5.2.2.3 EUROPE PANEL

The hierarchical clustering results for the Europe Panel are listed in Table A.6, the corresponding testing output in Table 5.6, where one can see the big troubles the algorithm faced. A lot of divergence clubs make it difficult to provide meaningful interpretations. Because of this lack of econometric and statistical support, a closer look on the club data is waived. One could cautiously claim that the structure is similar to the results in A.3, where an east to west trend is visible. The clustering algorithm was also carried out with the aim of getting 4 clubs in order to raise the chance of generating convergence clubs. This attempt also failed because it just spited Club 3 into two clubs, which were still largely divergent, and it did not affect the size of Club 1 and Club 2.

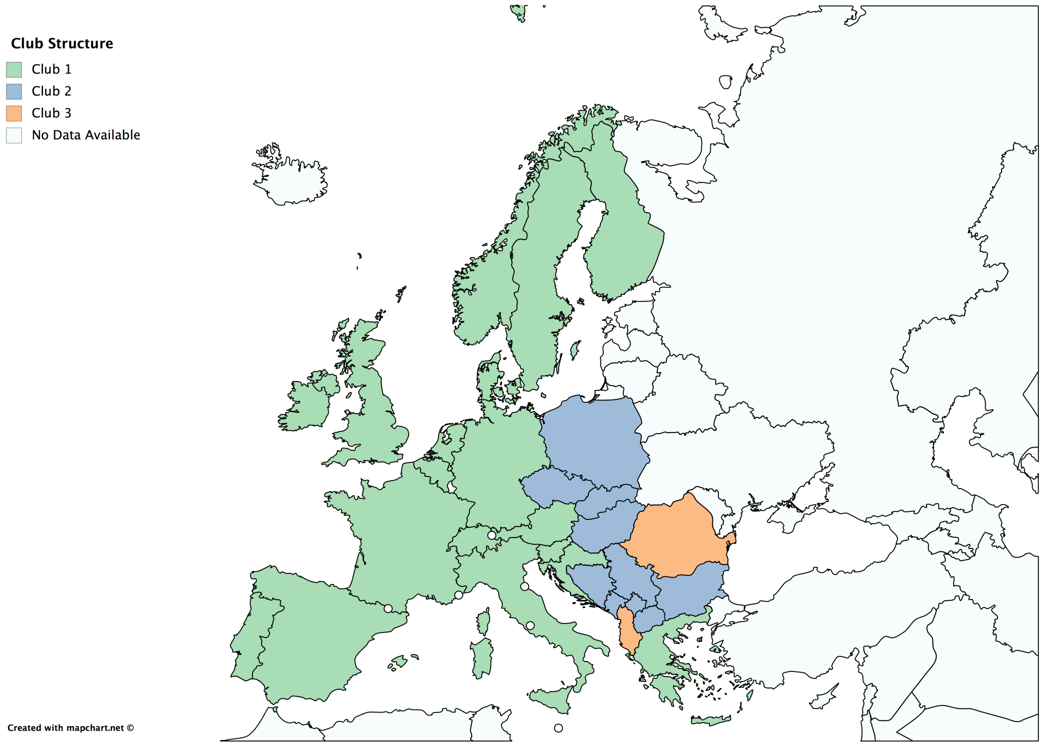

Figure 5.11: The Club Structure of Europe Data in Period 1 (1955-1988) - Hierarchical Clustering

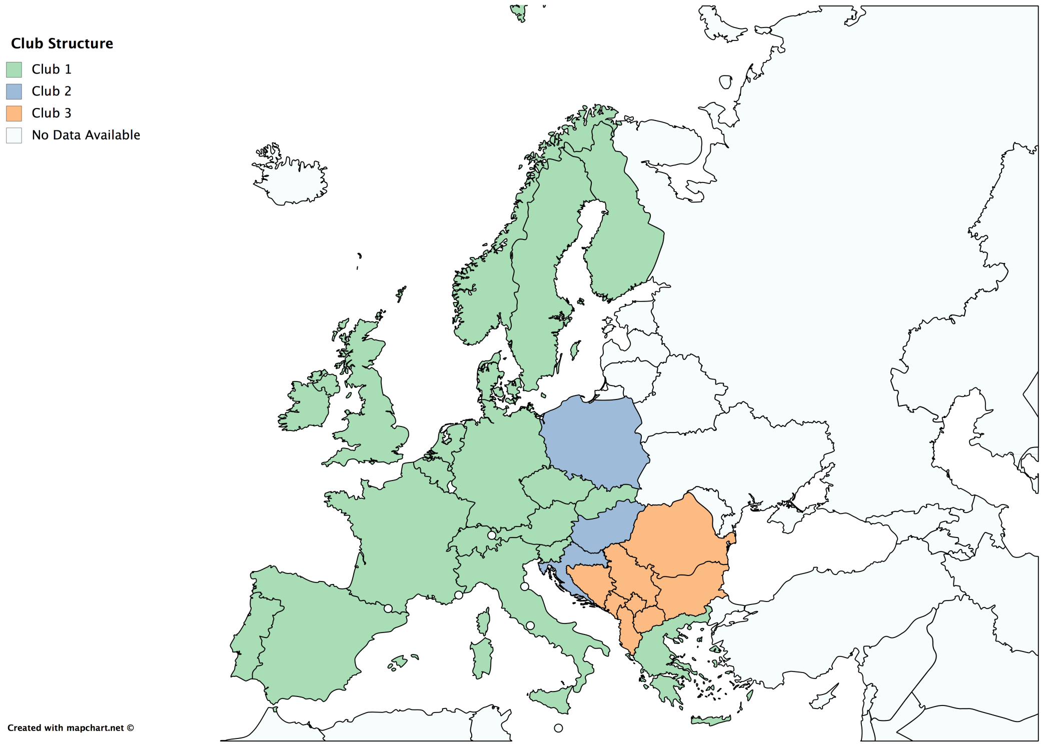

Figure 5.12: The Club Structure of Europe Data in Period 5 (1975-2008) - Hierarchical Clustering

5.3 Comparison of the Results of the Algorithm

5.3.1 Deviation Between the Algorithms

In the subsections before, two different algorithms with advantages and disadvantages are described step by step. Also, their results are listed in the appendix as well as partly visualised with maps. One way to compare the algorithms is calculating the deviation. Let c_{ij1} be the club assignment of Country i in Period j in Algorithm 1 (Phillips and Sul), and c_{ij2} the club assignment of Country i in Period j in Algorithm 2 (Hierarchical Clustering). Then, the deviation between the two algorithms of Country i in Period j is defined as: $d_{ij} = c_{ij2} - c_{ij1}$. In Figure 5.13, the deviation of the two algorithms is shown. Deviation 1 occurs if for instance USA get listed in Club 1 in Period 1 in the Algorithm by Phillips and Sul, however in the hierarchical clustering USA is listed in Club 2.
Comparing the two results for the World Panel, more than 60 % of the results match. Just a few percent show a deviation which is bigger than -1 or 1. There is also no over or underestimating as for the World results, the percentage for 1 is a lot bigger but for the Africa results and the Europe results, it is the other way round. The matching also gets bigger for the African Panel (70 %) and for the Europe Panel (80 %).

5.3.2 Runtime of the Clustering Functions

In terms of runtime, the algorithm by Phillips and Sul is way ahead as hierarchical clustering methods are one of the most elaborate methods in theory. Also, in this case, the distance matrix has to be calculated in every step which is tied to a chain of other functions. It is not necessary to include a runtime analysis in the form of a graphic. To get a feeling for the big gap between the two algorithms: The result for one period for the World Panel takes several hours (more than five) for the hierarchical clustering algorithm - for Phillips and Sul's algorithm it just takes a couple of minutes.

5.3.3 Comparison of the t-values

In this section, the t-values of the two algorithms are compared, as well as their mean, minimum and maximum. The algorithm by Phillips and Sul is Algorithm 1, the other one is Algorithm 2.

Table 5.7 shows the descriptive statistics of the World Panel and the two different algorithms. One can see that Algorithm 2 has higher maximum in every period. The high

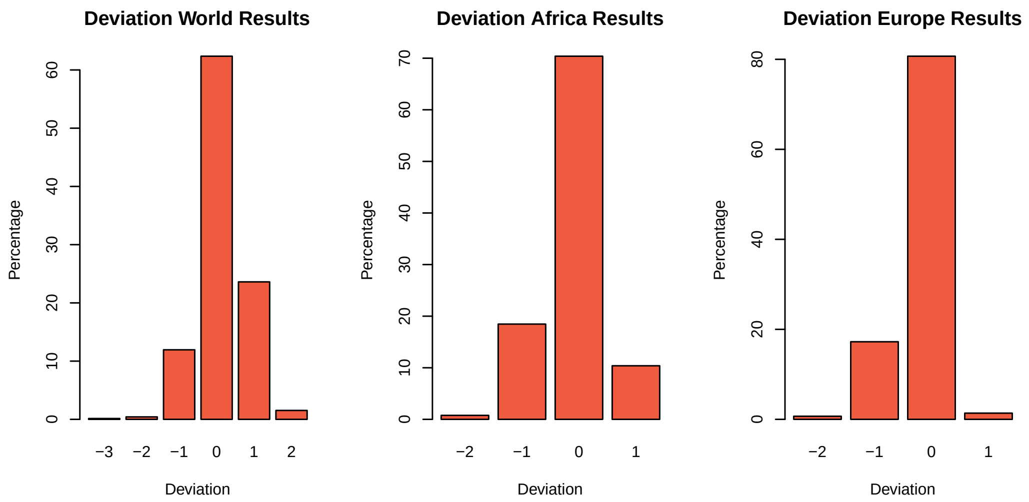

Figure 5.13: The deviation between the two algorithms of the three panels (1) World, (2) Africa, (3) Europe

Table 5.7: Comparison of t-Values - World Panel

	Alg. 1			Alg. 2		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Period 1	0.65	−1.90	3.60	85.86	−6.94	385.20
Period 2	1.97	0.10	7.18	410.33	1.75	1374.54
Period 3	3.53	−6.65	19.12	17379.06	0.07	86035.43
Period 4	24.52	1.76	60.63	34.60	−8.27	170.51
Period 5	4.69	−12.78	29.65	10475.64	−65.04	50284.21

Table 5.8: Comparison of t-Values - Africa Panel

	Alg. 1			Alg. 2		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Period 1	0.43	−0.66	1.44	116.34	0.43	453.90
Period 2	8.01	0.00	30.22	130.77	−2.98	498.03
Period 3	−0.15	−4.33	3.24	3785.32	−1.51	15099.55
Period 4	−0.51	−9.74	4.49	72.17	−3.93	287.60
Period 5	−18.99	−82.90	4.33	10.58	−11.99	38.40

Table 5.9: Comparison of t-Values - Europe Panel

	Alg. 1			Alg. 2		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Period 1	−4.76	−19.01	4.03	−0.26	−19.01	13.16
Period 2	−4.62	−15.77	1.34	−6.63	−19.42	0.90
Period 3	−5.11	−25.20	8.87	−3.43	−11.17	4.12
Period 4	−1.35	−14.51	8.41	−4.36	−11.20	−0.83
Period 5	−0.53	−6.91	3.77	250.05	−5.31	754.51

maximum values lead to higher mean t-values than in Algorithm 1. The distribution of the minimum t-value is not unilateral as both algorithms have the lead in different periods.

Table 5.8 shows the descriptive statistics of the Africa Panel and the two different algorithms. Similar to the World Panel results, Algorithm 2 has higher maximum t-values and also higher mean t-values. Except Period 2, Algorithm 2 has also the higher minimum t-values.

For the Europe Panel, the comparison is more difficult as both algorithms succeed in different periods (see Table 5.9).
In general, Algorithm 2 delivers higher t-values, which is expectable as the algorithm is just based on maximize those values.

5.4 Log Per Capita GDP: Initial vs. Final Period

To highlight the idiosyncratic transitions behave over the different periods for the three panels, Figures 5.14, 5.15 and 5.16 show specific plots. In general, the log per capita income of the initial period is plotted against the log per capita income of the final period. Moreover the clubs[9] are coloured differently. In addition, there is a white 45-degree line in every picture which is used for the interpretation of growth rates: The distance between each point and the line implies the average growth rate over the observed period. Also Phillips & Sul (2009) provided a similar plot for their cluster analysis. As economic level and growth is the main and only input to the clustering analysis, in the Figures 5.14, 5.15 and 5.16, one can see the differently coloured point clouds from top to bottom. Especially in Figure 5.14, the linear relationship in the clubs becomes apparent. The first three clubs show, with some exceptions, positive average growth as most of the points are above the 45-degree line. On the other side, clubs 4 and 5 suffer from negative average growth. From Figure 5.15, unfortunately no more new facts and interpretation can be derived. However, in Figure 5.16, one can see a sort of convergence of the green point cloud (Club 1) over the 5 periods.

[9] Therefore the results of Clustering Algorithm by Phillips and Sul's Algorithm are used.

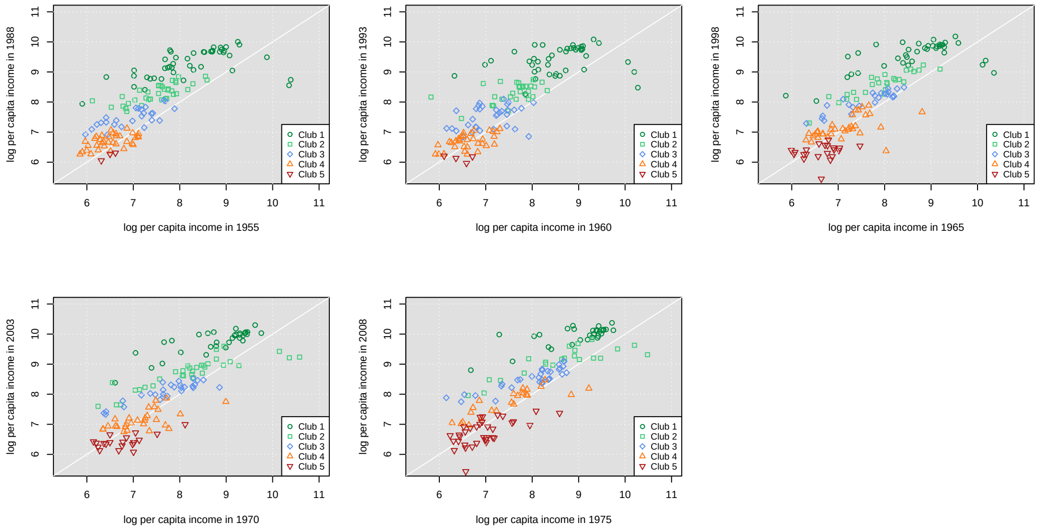

Figure 5.14: World Panel: Log GDP initial vs final period

The cloud, which looks like a line in the first period, transforms to a more dense point cloud around the coordinates (9.5 / 10) in Period 5. This can be seen as a sign for level convergence of the highest developed European countries.

5.5 The β-Convergence Test

Based on Durlauf & Johnson (1995), Canova (2004) and Phillips & Sul (2009) the occurrence of β- Convergence within the various convergence clubs is investigated in this chapter. Following regression is the central point:

$$\frac{\log y_{iT} - \log y_{i1}}{T-1} = a + \beta \log y_{i1} + \varepsilon_i \tag{5.6}$$

On the left-hand side of equation 5.6 is an approximation of the average growth rate over the observed period. Hence, β regulates the influence of the initial per capita income and the average growth rate. In a convergence cluster, from the economic perspective, the estimator for β has to be negative as higher per capita income causes lower average growth rate. In the Figures 5.17, 5.18 and 5.19, one can see the left-hand side of equation 5.6 against the right-hand side. The clubs are coloured differently as the clustering results of the Phillips and Sul Algorithm are used. In the legend, the numbers in parentheses stand for the estimated regression coefficient β for each club in each period. Talking about β, it is not the magnitude of the estimator which affects the interpretation, it is the sign as well as

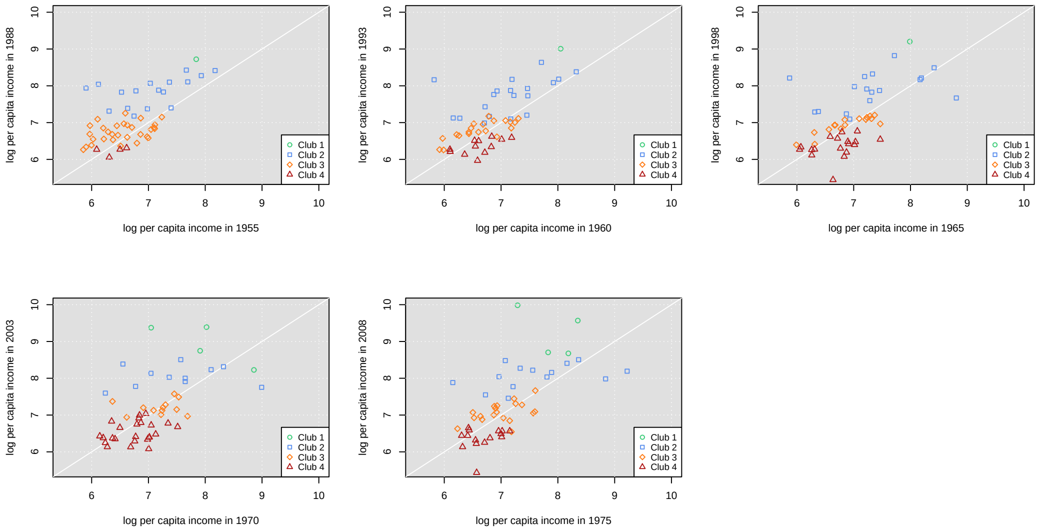

Figure 5.15: Africa Panel: Log GDP initial vs final period

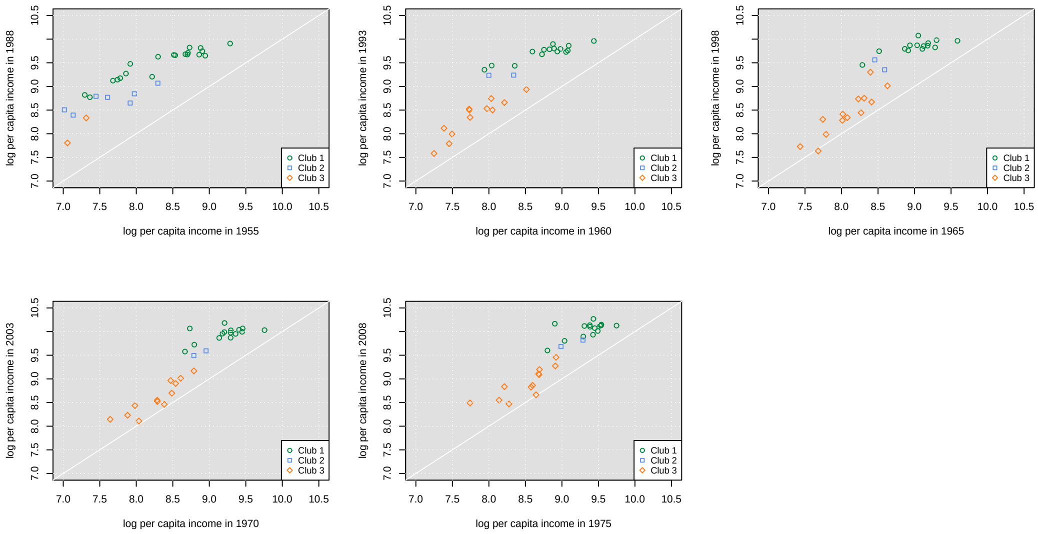

Figure 5.16: Europe Panel: Log GDP initial vs final period

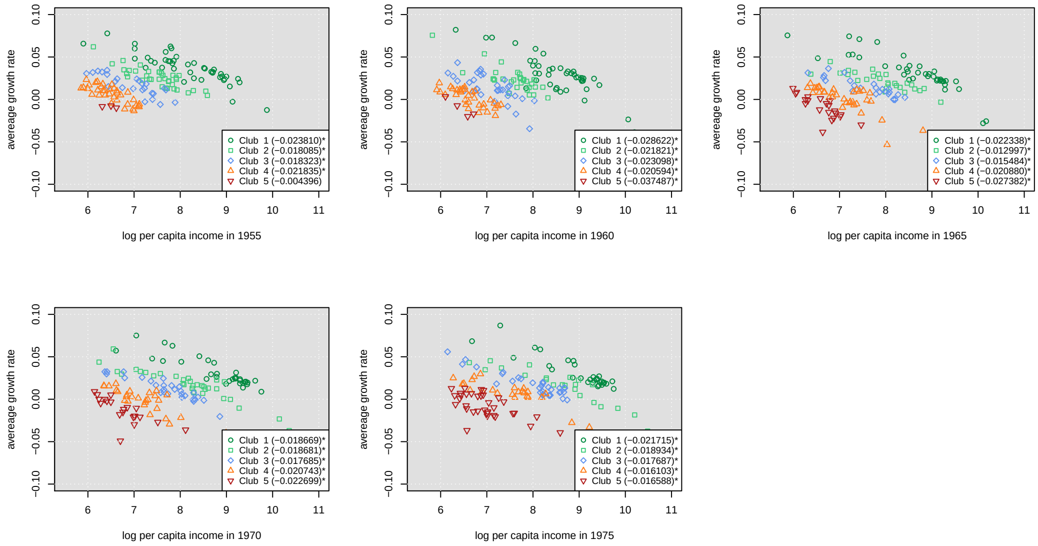

Figure 5.17: World Panel: β-Convergence and convergent clubs. Numbers in parentheses stand for the estimated regression coefficients β on initial period log income. The significance level is 5%

the statistical significance of β.
In Figure 5.17, one can easily see the negative connection between the two plotted variables. The estimators for β are significantly negative for all the convergence clubs[10]. Almost the same interpretation goes for Figures 5.18 and 5.19, with some exceptions at the significance of the estimators. If clubs only contain one country (in case of the Africa panel), β cannot be estimated. In case of two countries, the regression is just a linear interpolation, wherefore no significance has to be proved. However, one conspicuousness is again the sign convergence of the point cloud of Club 1 in the Europe Panel in Figure 5.19.

The concept of β-Convergence is very similar to the concept of the convergence of the idiosyncratic country specific parameter b_{it} which implies relative convergence. However, β-Convergence does not necessarily imply relative convergence of technological progress. An example is provided in Phillips & Sul (2009) on page 1172.
Interpreting the results in Figures 5.17, 5.18 and 5.19, β-Convergence occurs for nearly all clubs in the panel data where all the clubs, except some divergence clubs, show relative convergence. This leads to the speculation that the convergence of $b_{it} \rightarrow b$ implicates β-Convergence.

[10] Convergence Clubs are the clubs 1-4, sometimes also Club 5 forms a convergence club

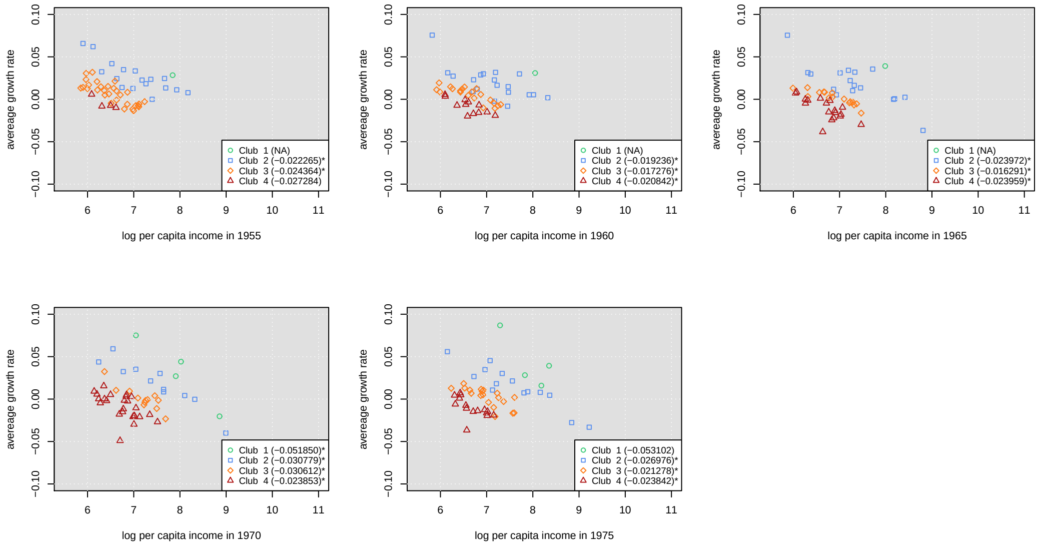

Figure 5.18: Africa Panel: β-Convergence and convergent clubs. Numbers in parentheses stand for the estimated regression coefficients β on initial period log income. The significance level is 5%

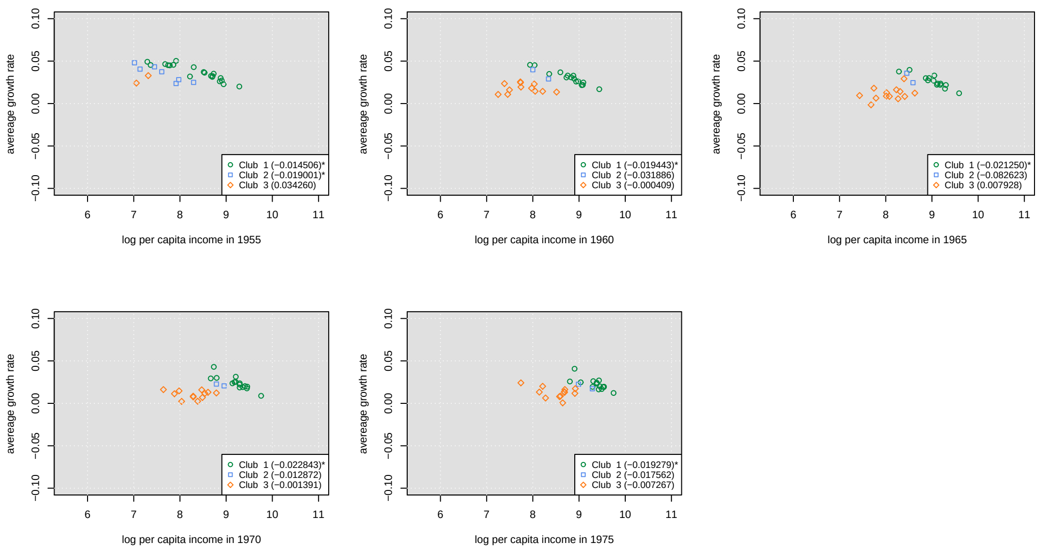

Figure 5.19: Europe Panel: β-Convergence and convergent clubs. Numbers in parentheses stand for the estimated regression coefficients β on initial period log income. The significance level is 5%

5.6 Transition Plots of Panel and Club Data

In Chapter 3, some transition paths of various countries have been illustrated. In the Figures 5.20, 5.21 and 5.20, the transition paths of the whole panels (on the left hand-side) and the mean transition paths of the clubs (on the right-hand side) are plotted. The club classification is taken from the results of Phillips and Sul's Algorithm. The figures should give an impression of how the movement between the clubs takes place as we already derived the movement inside the clubs with the log t convergence test. The used time periods are Period 1, 3 and 5.

In Figure 5.20, the plots on the left-hand side are too full of lines which doesn't make interpretation easy. However, the mean relative transition curves of the 5 clubs in the 3 different periods give an impression of the inequality and its development. The distance between the mean relative transition curves is growing over time, leading to the conclusion that the inequality is transient inside a cluster, but not inside a whole panel.
Regarding Figure 5.21, the interpretation is similar to the one of Figure 5.20 as the distance between the mean relative transition curves is growing.
For the Europe Panel, (see Figure 5.22) the situation is a bit different, which makes sense from the economic perspective. Europe as a panel is closer to a homogeneous set of countries than Africa or the whole world. Hence, in the last plot on the right-hand side, the mean relative transition paths of the three clubs may start to converge as Club 3 starts catching up.

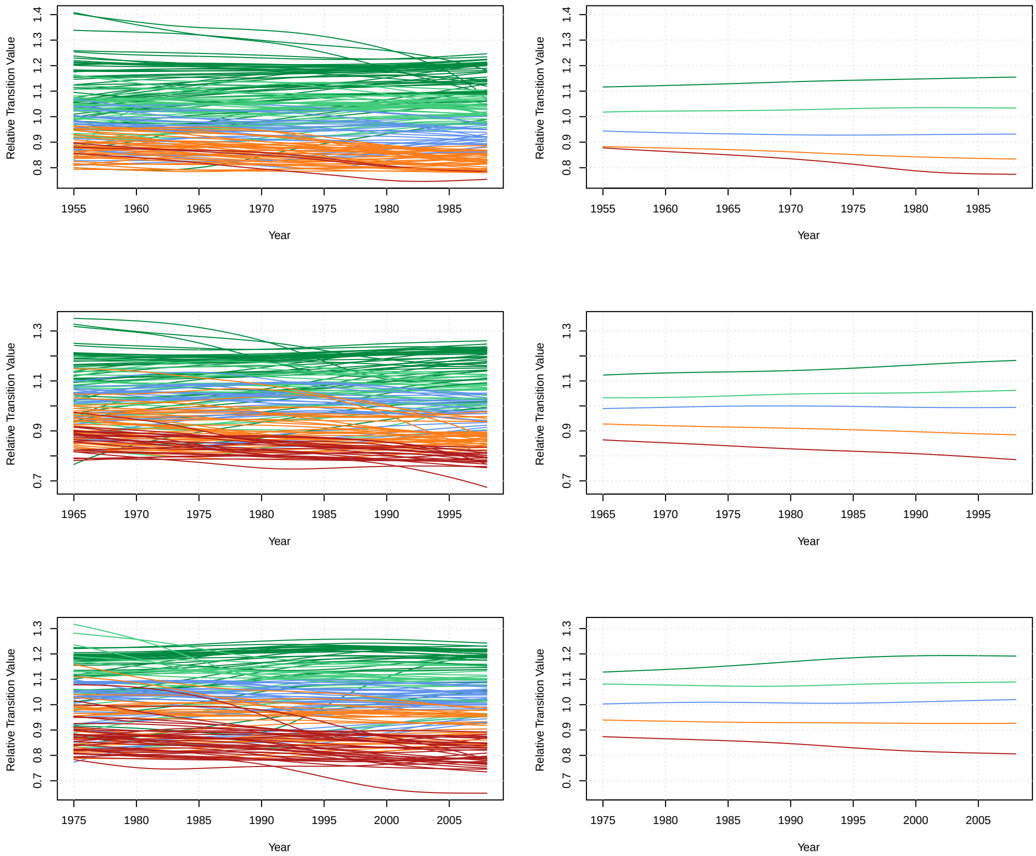

Figure 5.20: World Panel: Transition Curves of Panel and Clubs

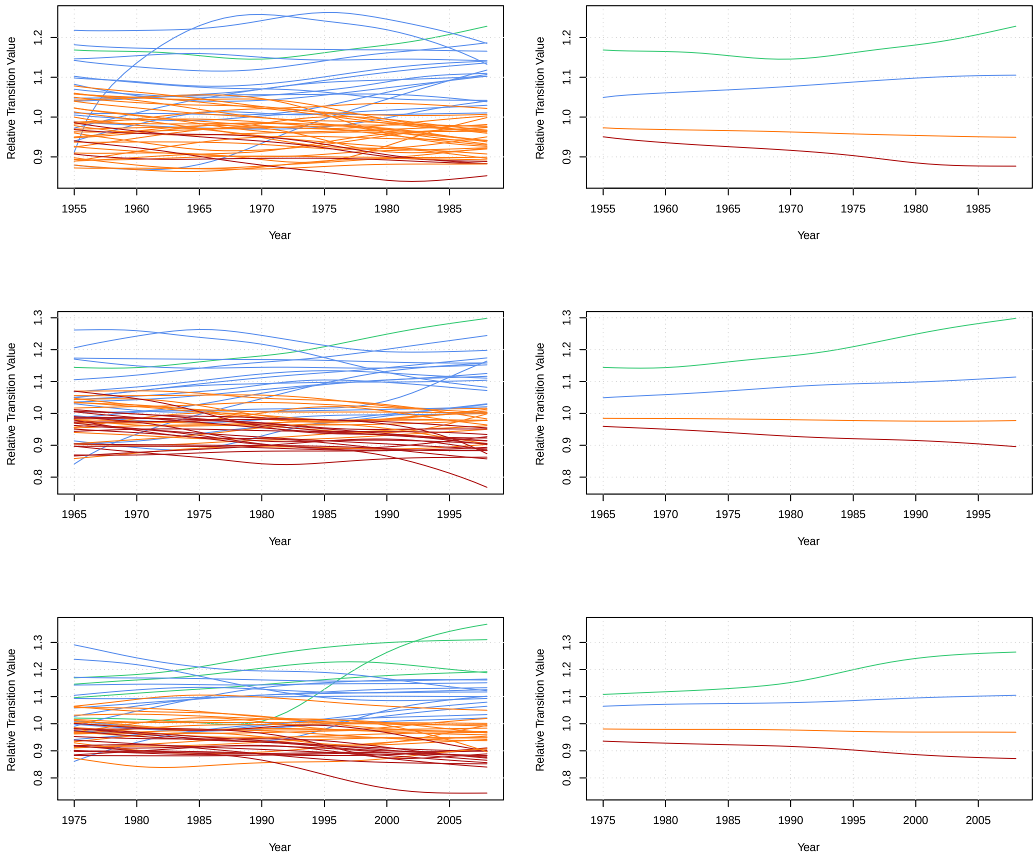

Figure 5.21: Africa Panel: Transition Curves of Panel and Clubs

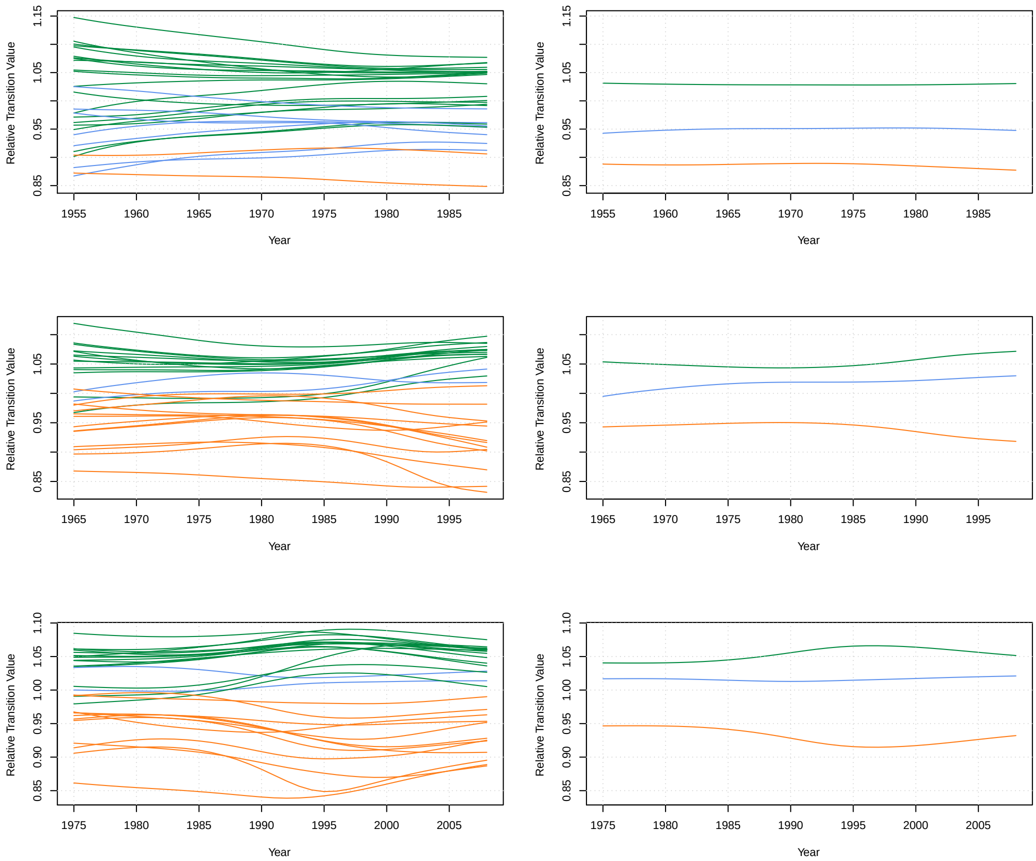

Figure 5.22: Europe Panel: Transition Curves of Panel and Clubs

6 SUMMARY AND DISCUSSION

After explaining the fundamental theoretical basics in Chapter 2 which includes the derivation of the central non-linear factor model as well as the data adjustment and description, the focus was put on transition analysis of big country sets.
After the theoretical introduction to relative transition paths and the different phases, the main emphasis was on showing the dynamics and visualising them. Regarding the OECD countries, one could really get the impression of the convergence signs just through the figures. The benchmark plots of the Asian countries against the 20-country OECD set show the development and strong ongoing growth of many asian economies. In contrast to the Asian economic miracles, the discussion of African and South American countries gives a contrary opinion of the transience of inequality.
For quantifying this imagination, the construction of the log t convergence-test in Chapter 4 is essential. The results in Table 4.1 give an impression of the panel structure and patterns as only the OECD Panel show signs of relative convergence. This table is also an incentive for implementing clustering algorithms to detect the subgroups where convergence patterns occur. The algorithm by Phillips and Sul is a very efficient algorithm with a little a priori influence because of cross section ordering of the data. However, beside this influence, the algorithm is working very fast and stable regarding the sensitivity of changing time frames. To check how and if the cross section ordering is influencing the results, I implemented a second algorithm - without any assumptions and any data ordering - a hierarchical clustering algorithm. The comparison lead to the statement that Phillips and Sul's algorithm has benefits which are not obvious from the beginning. The hierarchical clustering is too time-consuming if it comes to big data analysis. The world table with its 144 countries is a too big data set for this algorithm as it takes hours to generate the clustering results. Regarding the results, the hierarchical clustering indeed delivers the better t-values for convergence clubs, but, as there is no assumption of a minimum t-value in a club, some of the clubs don't show convergence structure which makes interpretation sometimes more difficult. The accordance of the two algorithms gets higher, the smaller the panels get. This could also be justified by a more homogenous group of countries in the smaller panels. However, as the accordance is high (at least 60 % total agreement) both algorithms have justification. The winners and losers are analysed and in many cases it is possible to make a connection to the countries history for explaining up or downgrading (for instance Sudan, Irak, Equatorial Guinea). Also discussing Lucas' statement of the possible transience of inequality in world,

my opinion is that this statement cannot be supported by the results of this thesis. As one can see in the Figures 5.20 and 5.21, the inequality in terms of real GDP per capita seems to increase instead of decrease. There are indeed various selections of countries where inequality is maybe transient but the argument that this happening for the whole world cannot be supported. It seems to be true that many countries, mainly in Asia, caught up with the highly developed countries of the Western World, however, the gap between those countries and the developing countries seems to have been growing over the last decades.
One central question is if those economical miracles will remain on the mean level of the Western OECD or if they will keep their growth rates high and pass the current economic leaders. Until a certain point, the development can look like a convergence pattern but may result in an overtaking manoeuver wherefore it will be interesting feeding the implemented algorithms with the latest data, as the last year of influence for the clustering analysis is 2008. In the next years, it will be interesting to quantify the influence of the financial crisis in 2008 on the transition behavior.

APPENDIX

TABLES - ALGORITHM 1

Table A.1: The Club - Evolution of the Countries of the World Panel

Country	Period 1	Period 2	Period 3	Period 4	Period 5
USA	1	1	1	1	1
Switzerland	1	1	1	1	1
Canada	1	1	1	1	1
Denmark	1	1	1	1	1
Norway	1	1	1	1	1
Sweden	1	1	1	1	1
Japan	1	1	1	1	1
France	1	1	1	1	1
Australia	1	1	1	1	1
Hong Kong	1	1	1	1	1
Belgium	1	1	1	1	1
Germany	1	1	1	1	1
UK	1	1	1	1	1
Finland	1	1	1	1	1
Netherlands	1	1	1	1	1
Austria	1	1	1	1	1
Italy	1	1	1	1	1
New Zealand	1	1	1	1	1
Singapore	1	1	1	1	1
Israel	1	1	1	1	1
UAE	1	1	1	2	2
Slovenia	1	1	1	2	2
Spain	1	1	1	1	1
Ireland	1	1	1	1	1
Portugal	1	1	1	1	2
Puerto Rico	1	1	1	1	1
Greece	1	1	1	2	2
Venezuela	1	1	2	2	2
Croatia	1	2	2	2	2
Trinidad and Tobago	1	1	2	1	1
Taiwan	1	1	1	1	1
Czechoslovakia	1	1	2	2	2
Saudi Arabia	1	1	2	2	2
Qatar	1	1	1	2	2

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Kuwait	1	1	1	2	2
South Korea	1	1	1	1	1
Argentina	2	1	2	2	2
Hungary	2	2	2	2	3
Oman	1	1	1	2	2
Mauritius	2	1	1	1	1
Serbia	1	2	2	3	3
Uruguay	2	1	2	2	2
Bulgaria	1	2	3	2	3
Macedonia	1	2	3	3	3
Syria	1	1	2	2	3
Yugoslavia	1	2	3	2	3
Poland	2	2	2	2	2
Chile	2	1	1	1	1
Mexico	2	2	2	2	3
Brazil	2	2	2	2	3
Turkey	2	2	2	2	2
Jordan	2	2	2	3	3
Seychelles	2	2	2	2	3
Colombia	2	2	2	2	3
Montenegro	1	3	3	3	3
Costa Rica	2	2	2	2	2
Gabon	2	2	3	3	4
Malaysia	1	2	1	1	2
Panama	2	2	2	2	3
Bahrain	2	2	3	2	3
Bosnia	2	3	4	3	3
Romania	2	3	3	3	4
Ecuador	2	2	2	3	3
South Africa	2	2	3	3	3
Thailand	2	2	1	1	1
Peru	2	3	3	3	3
Jamaica	3	1	3	3	4
Libya	2	3	4	4	4
Iran	2	2	3	3	3
Namibia	2	2	3	3	3
Guatemala	2	2	3	3	3
Paraguay	2	2	2	3	4
Tunisia	2	2	2	2	2
Algeria	2	3	3	3	4
Cuba	3	3	4	3	4
Botswana	1	2	1	2	2
Iraq	2	3	4	5	5
North Korea	2	3	4	4	5
Morocco	3	2	3	3	3
Egypt	2	3	2	2	3
Albania	3	3	4	3	3

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Swaziland	2	3	3	3	4
Dominican.Rep.	3	2	3	2	3
Congo (Brazzaville)	2	3	3	4	4
Yemen	2	3	3	3	4
Sri Lanka	3	2	2	2	2
Indonesia	2	3	2	2	3
Bolivia	3	3	4	4	4
El Salvador	3	2	4	3	4
Philippines	3	3	4	4	4
Lebanon	3	3	3	3	3
Honduras	3	3	4	4	4
China	3	3	1	1	1
Djibouti	3	3	4	4	5
Nicaragua	3	3	4	4	5
Côte d Ivoire	3	3	4	4	5
Pakistan	3	2	3	3	4
Equatorial Guinea	3	3	2	1	1
Cameroon	3	3	4	4	5
Mongolia	3	3	4	4	5
Sao Tomé Principe	3	3	4	4	5
Zimbabwe	3	3	4	4	5
Senegal	3	4	4	4	5
India	4	3	3	2	3
Benin	4	3	4	4	5
Cape Verde	3	3	2	2	3
Kenya	4	4	4	4	5
Lesotho	3	3	3	3	4
Mozambique	4	4	4	4	3
Somalia	4	4	4	5	5
Nigeria	4	4	4	4	4
Haïti	4	4	5	5	5
Ghana	4	4	4	4	4
Sierra Leone	4	4	5	5	5
Vietnam	4	4	3	2	2
Mauritania	4	4	4	4	4
Liberia	4	4	4	4	5
Laos	4	4	4	4	4
Cambodia	4	3	4	3	3
Rwanda	3	4	5	5	5
Burkina Faso	4	4	4	4	4
Angola	4	4	5	5	5
Gambia	4	4	5	4	5
Togo	4	4	5	5	5
Guinea.Bissau	4	4	5	5	5
Sudan	4	4	4	3	2
Nepal	4	4	4	4	4
Madagascar	4	4	5	5	5

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Zambia	4	4	5	5	5
Burma	4	4	4	3	3
Comoro Islands	4	4	5	5	5
Burundi	4	4	5	5	5
Mali	4	4	4	4	5
Afghanistan	4	4	5	5	5
Central African Republic	4	4	5	5	5
Ethiopia	4	5	5	5	5
Bangladesh	4	4	4	4	4
Niger	4	5	5	5	5
Uganda	5	4	5	4	4
Congo (Kinshasa)	5	5	5	5	5
Malawi	4	4	5	5	5
Tanzania	4	4	5	5	5
Guinea	4	4	5	5	5
Chad	5	5	5	5	5

Table A.2: The Club - Evolution of the Countries of the Africa Panel

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Mauritius	1	1	1	1	1
Seychelles	2	2	2	1	1
Gabon	2	2	2	1	2
South.Africa	2	2	2	2	2
Libya	2	2	2	2	2
Namibia	2	2	2	2	2
Tunisia	2	2	2	2	1
Algeria	2	2	2	2	2
Botswana	2	2	2	2	2
Morocco	2	2	2	2	2
Egypt	2	2	2	2	2
Swaziland	2	2	2	2	2
Congo...Brazzaville	2	2	2	3	3
Djibouti	2	2	3	3	3
Côte.d.Ivoire	2	2	3	3	3
Equatorial.Guinea	2	2	2	1	1
Cameroon	2	2	3	4	3
Sao.Tomé...Principe	3	2	3	3	3
Zimbabwe	2	3	2	3	3
Senegal	3	3	3	3	3
Benin	3	3	2	3	3
Cape.Verde	3	2	2	2	2
Kenya	3	3	3	4	3
Lesotho	3	2	2	3	2

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Mozambique	3	3	3	3	2
Somalia	3	3	4	4	3
Nigeria	3	3	3	3	3
Ghana	3	3	3	3	2
Sierra.Leone	3	3	4	4	4
Mauritania	3	3	3	4	3
Liberia	3	3	3	4	4
Rwanda	3	3	3	4	3
Burkina.Faso	3	3	3	3	3
Angola	3	4	4	4	3
Gambia	3	3	4	4	3
Togo	3	4	4	4	4
Guinea.Bissau	3	3	4	4	4
Sudan	3	3	3	2	2
Madagascar	3	4	4	4	4
Zambia	3	4	4	4	4
Comoro.Islands	3	4	4	4	4
Burundi	3	3	4	4	4
Mali	3	3	3	4	3
Centr..Afr..Rep.	3	4	4	4	4
Ethiopia	3	4	4	4	4
Niger	3	4	4	4	4
Uganda	4	4	4	4	3
Congo.Kinshasa	4	4	4	4	4
Malawi	3	3	3	4	4
Tanzania	4	4	4	4	4
Guinea	3	3	4	4	4
Chad	4	4	4	4	3

Table A.3: The Club - Evolution of the Countries of the Europe Panel

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Switzerland	1	1	1	1	1
Denmark	1	1	1	1	1
Norway	1	1	1	1	1
Sweden	1	1	1	1	1
France	1	1	1	1	1
Belgium	1	1	1	1	1
Germany	1	1	1	1	1
United.Kingdom	1	1	1	1	1
Finland	1	1	1	1	1
Netherlands	1	1	1	1	1
Austria	1	1	1	1	1
Italy	1	1	1	1	1

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Slovenia	1	2	2	2	2
Spain	1	1	2	1	1
Ireland	1	1	1	1	1
Portugal	1	1	1	1	1
Greece	1	2	3	2	2
Croatia	1	3	3	3	3
Czecho.slovakia	2	3	3	3	3
Hungary	2	3	3	3	3
Serbia	1	3	3	3	3
Bulgaria	2	3	3	3	3
Macedonia	2	3	3	3	3
Yugoslavia	1	3	3	3	3
Poland	2	3	3	3	3
Montenegro	2	3	3	3	3
Bosnia	2	3	3	3	3
Romania	3	3	3	3	3
Albania	3	3	3	3	3

TABLES - ALGORITHM 2

Table A.4: The Club - Evolution of the Countries of the World Panel - Hierarchical Clustering

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Switzerland	1	1	1	1	1
Italy	1	1	1	1	1
Slovenia	1	1	1	2	1
Netherlands	1	1	1	1	1
France	1	1	1	1	1
Finland	1	1	1	2	1
Sweden	1	1	1	1	1
Germany	1	1	1	1	1
Australia	1	1	1	1	1
UK	1	1	1	2	1
Norway	1	1	1	1	1
Canada	1	1	1	2	1
Denmark	1	1	1	1	1
Japan	1	2	1	1	1
Hong.Kong	1	1	1	1	1
Singapore	1	1	1	1	1
Belgium	1	1	1	1	1
Ireland	1	1	1	1	1
Spain	1	1	1	2	1

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Portugal	1	1	1	2	1
New.Zealand	1	2	1	1	1
South.Korea	1	1	1	2	1
Taiwan	2	2	1	2	1
USA	1	1	1	1	2
Macedonia	1	3	2	3	2
Kuwait	1	3	2	3	2
Poland	1	3	2	3	2
Greece	1	2	1	2	2
Qatar	1	2	3	2	2
UAE	1	3	1	2	2
Saudi.Arabia	1	2	1	3	2
Austria	1	1	1	1	2
Oman	1	2	2	3	2
Puerto.Rico	1	1	1	2	2
Croatia	1	3	1	2	2
Israel	1	1	1	2	2
T....Tobago	1	3	2	2	2
Seychelles	1	2	2	3	2
Czecho.slovakia	2	1	1	3	2
Hungary	2	3	3	2	2
Argentina	2	2	2	3	2
Chile	2	2	2	2	2
Venezuela	2	2	2	3	2
Gabon	2	3	2	3	2
Uruguay	2	2	2	3	2
Mauritius	2	2	1	2	2
Malaysia	2	2	2	3	2
Thailand	2	3	2	2	2
China	3	3	2	3	2
Equatorial.Guinea	3	4	2	3	2
Libya	1	4	4	4	3
Turkey	1	2	2	3	3
Yugoslavia	2	3	2	3	3
Syria	2	1	2	3	3
Serbia	2	3	2	3	3
Bulgaria	2	3	2	3	3
Mexico	2	2	2	3	3
Panama	2	3	3	3	3
Botswana	2	2	3	3	3
Bosnia	2	2	4	3	3
Colombia	2	2	2	3	3
Brazil	2	3	3	3	3
Costa.Rica	2	2	2	2	3
Sri.Lanka	2	3	2	2	3
Romania	2	3	3	3	3
Bahrain	2	2	3	3	3

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Montenegro	2	3	3	3	3
Cuba	2	3	4	3	3
Morocco	2	3	3	3	3
Egypt	2	3	3	3	3
Iran	2	4	3	3	3
Indonesia	2	3	2	3	3
Jordan	2	2	3	3	3
South.Africa	2	3	3	3	3
Peru	2	3	3	3	3
Yemen	2	2	3	3	3
Paraguay	2	3	3	3	3
Tunisia	2	3	3	3	3
Algeria	2	3	3	3	3
Guatemala	2	3	3	3	3
Dominican.Rep.	2	3	2	3	3
Ecuador	2	2	2	3	3
Namibia	2	3	3	3	3
Albania	2	3	3	3	3
Lebanon	2	3	3	3	3
Jamaica	2	3	3	3	3
Bolivia	2	3	3	3	3
Swaziland	3	2	4	3	3
Philippines	3	3	3	3	3
El.Salvador	3	3	2	3	3
Honduras	3	2	3	4	3
Pakistan	4	3	2	3	3
Mozambique	4	4	4	4	3
Ghana	4	4	4	4	3
Lesotho	4	4	4	4	3
Laos	4	4	4	4	3
Vietnam	4	4	4	3	3
Cambodia	4	4	4	4	3
India	4	4	4	3	3
Burma	4	4	4	4	3
Cape.Verde	4	4	4	3	3
Sudan	5	5	4	3	3
North.Korea	2	3	2	5	4
Iraq	2	4	5	4	4
Congo..Brazzaville.	2	4	2	4	4
Cameroon	3	4	5	4	4
Côte.d.Ivoire	3	4	4	4	4
Sao.Tomé...Principe	3	4	4	4	4
Djibouti	3	4	4	4	4
Nicaragua	3	4	4	4	4
Mongolia	4	4	3	4	4
Liberia	4	4	4	4	4
Senegal	4	4	4	4	4

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Madagascar	4	5	5	5	4
Gambia	4	4	5	4	4
Togo	4	5	5	5	4
Nigeria	4	4	4	4	4
Tanzania	4	5	5	5	4
Mauritania	4	4	4	4	4
Benin	4	4	4	4	4
Angola	4	5	5	5	4
Somalia	4	4	5	4	4
Burkina.Faso	4	4	4	4	4
Kenya	4	4	3	4	4
Mali	5	5	4	4	4
Guinea	5	5	5	5	4
Uganda	5	5	5	5	4
Niger	5	5	5	5	4
Bangladesh	5	5	4	4	4
Nepal	5	5	4	4	4
Chad	2	5	5	4	5
Zimbabwe	3	4	4	4	5
Malawi	4	5	5	4	5
Zambia	4	5	5	5	5
Centr..Afr..Rep.	4	5	5	5	5
Guinea.Bissau	4	4	5	4	5
Comoro.Islands	4	4	5	4	5
Ethiopia	4	5	5	4	5
Sierra.Leone	4	4	5	5	5
Haïti	4	4	5	5	5
Rwanda	4	4	5	4	5
Afghanistan	5	5	5	4	5
Congo.Kinshasa	5	5	5	5	5
Burundi	5	5	5	4	5

Table A.5: The Club - Evolution of the Countries of the Africa Panel - Hierarchical Clustering

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Mauritius	1	2	1	1	1
Seychelles	1	1	1	2	1
Equatorial.Guinea	2	3	1	1	1
Gabon	1	1	1	2	2
South.Africa	1	1	1	2	2
Swaziland	1	2	2	2	2
Botswana	1	2	1	2	2
Tunisia	1	1	1	2	2
Algeria	1	1	1	2	2

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Morocco	1	2	1	2	2
Namibia	1	1	1	2	2
Congo...Brazzaville	1	2	2	3	2
Egypt	1	2	1	2	2
Sudan	3	3	3	3	2
Lesotho	3	3	3	3	2
Nigeria	3	3	3	3	2
Mozambique	3	3	3	3	2
Cape.Verde	3	3	2	2	2
Liberia	3	3	3	3	3
Libya	1	1	2	3	3
Djibouti	2	3	2	3	3
Senegal	3	3	3	3	3
Rwanda	3	3	2	4	3
Benin	3	3	3	3	3
Mauritania	3	3	3	3	3
Kenya	3	3	2	3	3
Somalia	3	3	2	3	3
Burkina.Faso	3	4	3	3	3
Angola	3	4	4	4	3
Gambia	3	4	3	3	3
Ghana	3	3	3	3	3
Cameroon	3	3	2	3	3
Côte.d.Ivoire	1	2	2	3	3
Sao.Tomé...Principe	2	2	3	3	3
Zimbabwe	2	3	2	3	3
Mali	4	4	3	3	3
Uganda	4	4	4	4	3
Chad	4	4	4	4	3
Malawi	3	4	4	3	4
Madagascar	3	4	4	4	4
Zambia	3	4	4	4	4
Ethiopia	3	4	4	4	4
Sierra.Leone	1	3	4	4	4
Togo	3	4	4	4	4
Comoro.Islands	3	4	4	4	4
Guinea.Bissau	3	4	4	4	4
Centr..Afr..Rep.	3	4	4	4	4
Burundi	4	4	4	4	4
Niger	4	4	4	4	4
Tanzania	4	4	4	4	4
Congo.Kinshasa	4	4	4	4	4
Guinea	4	3	4	4	4

Table A.6: The Club - Evolution of the Countries of the Europe Panel - Hierarchical Clustering

Country	Period 1	Period 2	Period 3	Period 4	Period 5
Switzerland	1	1	1	1	1
Greece	1	2	2	1	1
Italy	1	1	1	1	1
Slovenia	1	1	2	1	1
Spain	1	1	1	1	1
United.Kingdom	1	1	1	1	1
Ireland	1	1	1	1	1
Denmark	1	1	1	1	1
Austria	1	1	1	1	1
France	1	1	1	1	1
Germany	1	1	1	1	1
Netherlands	1	1	1	1	1
Belgium	1	1	1	1	1
Sweden	1	1	1	1	1
Finland	1	1	1	1	1
Portugal	1	1	1	1	1
Norway	1	1	1	1	1
Czecho.slovakia	2	2	2	2	1
Croatia	1	2	2	2	2
Hungary	2	3	2	2	2
Poland	2	3	2	2	2
Yugoslavia	2	3	2	3	3
Serbia	2	3	2	3	3
Macedonia	2	3	2	3	3
Bulgaria	2	3	2	3	3
Montenegro	2	3	2	3	3
Bosnia	2	3	3	3	3
Romania	3	3	3	3	3
Albania	3	3	3	3	3

BIBLIOGRAPHY

CANOVA, F. 2004. Testing for convergence clubs in income per capita: a predictive density approach. *International economic review*, **45**, 49–77.

DURLAUF, SN., & JOHNSON, PA. 1995. Multiple regimes and cross-country growth behavior. *Journal of applied econometrics*, **10**, 365–384.

HODRICK, R. J., & PRESCOTT, E. C. 1997. Postwar u.s business cycles: An empirical investigation. *Journal of money, credit and banking*, **29**(1), 1–16.

HOWITT, P., & MAYER-FOULKES, D. 2005. R&d, implementation and stagnation: a schumpeterian theory of convergence clubs. *Journal of money credit and banking*, **37**, 147–177.

LUCAS, RE. 2002. *The industrial revolution: past and future*. Lectures on Economic Growth. Harvard University Press: Cambridge, MA.

PARENTE, S. L., & PRESCOTT, E. C. 1994. Barriers to technology adoption and developement. *Journal of political economy*, **102**, 298–321.

PHILLIPS, PCB., & SUL, D. 2005. Economic transition and growth. *Cowles foundation discussion paper no. 1514*.

PHILLIPS, PCB., & SUL, D. 2007. Transition modeling and econometric convergence tests. *Econometrica*, **75**, 1771–1855.

PHILLIPS, PCB., & SUL, D. 2009. Economic transition and growth. *Journal of applied econometrics*, **24**, 1153–1185.

SALA-I-MARTIN, X. 1997. I just ran two million regression. *American economic review*, **87**, 178–183.