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Is economic growth a random walk?

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Is Economic Growth a Random Walk ?

by

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Abstract

This paper tests the hypothesis that real per capita income growth rates are random walks against the hypothesis implied by models of endogenous growth that they are stationary. Thereby the influence of the choice of different test statistics as well as the choice of the H_0 on the test results is analysed. As the results show, the overwhelming majority of countries rejects the random walk hypothesis in favour of the stationarity hypothesis, no matter what statistics and H_0 is chosen. Additional tests show that growth rates of most countries significantly differ. Together with the stationarity result, this implies widespread and persistent divergence of real per capita incomes.

Key words: New growth theory, time series analysis, unit root test, autoregressive models, Bayesian econometrics

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1. Introduction¹

Endogenous growth models typically explain real per capita income growth rates by factors that are time invariant. Consequently, following these models, real per capita income growth rates should be time invariant too. Therefore, a very general empirical hypothesis that can be drawn from models of endogenous growth is that real per capita income growth rates are stationary over time.²

In this paper I test this hypothesis within a time series analysis framework. I argue that if time series behaviour of real per capita income growth is best explained by a random walk model, this would seriously question endogenous growth theory.³ If - on the contrary - real per capita income growth is best explained by a mean reverting process, this would be compatible with endogenous growth theory. In this case endogenous growth theory can be interpreted as explaining the mean, around which actual real per capita income growth rates randomly fluctuate.

This paper is organized as follows. Section 2 discusses the factors that determine steady state growth in models of endogenous growth. Section 3 describes the econometric model and discusses some of the problems involved in a test of the stationarity hypothesis. Section 4 presents the test results and section 5 draws the conclusions.

2. Theoretical background

This section briefly sketches the underlying economic relations that determine the steady state real per capita income growth rates of endogenous growth models. Following these models steady state per capita income growth rates are determined by factors such as the structural parameters of the economy (e.g. the rate of time preference, the intertemporal elasticity of substitution of consumption and the production elasticities of inputs); policy parameters (e.g. income taxes and import

¹ I thank Henning Klodt and Karl-Heinz Paqué for valuable comments. Any errors are my responsibility.

² Easterly/Kremer/Pritchett/Summers (1993) emphasize this point.

³ The standard neoclassical growth model also implies that the steady state growth rate should be stationary over time (with a mean equal zero or an exogenously given productivity growth parameter). Therefore, this test is not able to discriminate between neoclassical and endogenous growth models. I do not refer to the neoclassical growth model throughout this paper, because this model does not actually explain steady state growth, but rather postulates steady state growth in a deus-ex-machina manner. Hence, neoclassical growth theory provides no economically meaningful alternative hypothesis to the random walk hypothesis.

tariffs) and the endowment of the economy with non-accumulating production factors. Column 1 of table 1 displays the formulas for per capita steady state growth rates derived from different versions of endogenous growth models.

The "morphological" analogy of the different formulas is evident. In general, the growth rate is inversely related to the intertemporal rate of substitution of consumption (σ) and the rate of time preference (ρ). This morphological analogy of the different growth formulas stems from the fact that nearly all endogenous growth models are built on the assumption that households maximize intertemporal utility - an idea first introduced by Ramsey (1928). Given this assumption the optimal growth rate of consumption (\dot{c}/c) must equal:

$$(1) \quad \frac{\dot{c}}{c} = \sigma^{-1}(r - \rho), \quad \text{with } r = \text{real interest rate.}$$

Hence, increasing interest rates induce a postponement of consumption into the future, in order to equate intertemporal marginal utilities. As the steady state solution of most models implies that all income aggregates grow with the same steady state rate, the growth rate of per capita consumption can be equalized to the growth rate of per capita income. The underlying economic rationale of this procedure stems from the fact that a higher rate of consumption growth induced by higher interest rates, can only be achieved by higher savings. Higher savings, however, allow for a higher rate of accumulation of (all kinds of) capital. Yet, a higher rate of capital accumulation leads to higher per capita income growth. Consequently, a higher real interest rate leads to higher per capita growth.

Given this nearly identical way of modelling intertemporal consumption behaviour, the differences of the growth formulas in table 1 can only arise from the different ways the interest rate is determined in the different versions of endogenous growth models. The way the real interest rate is determined depends on the technologies and the production sectors of the economy. As it turns out in models of endogenous growth, the sector production function that includes an accumulating production factor (such as physical capital, human capital or technological capital) which displays the property of non-diminishing marginal returns is most important in determining the real interest rate.

Table 1 - Steady state growth rates of selected endogenous growth models (a)

Steady state growth rate	Critical production function	Type of model
$g = \sigma^{-1}(A - \rho)$	$Y = A K$	Universal capital model, Rebelo (1990)
$g = \sigma^{-1}(\beta L^{(1-\beta)} - \rho)$	$Y = K^\beta L^{(1-\beta)} \theta^\gamma$ where $\beta + \gamma = 1$	Learning by doing model, Romer (1986)
$g = \sigma^{-1}(\beta A^{1/\beta} (1-\tau) \tau^{(1-\beta)/\beta} - \rho)$	$Y = A K^\beta G^{(1-\beta)}$	Fiscal spending model, Barro (1990)
$g = \sigma^{-1}(\Gamma H^\alpha L^\beta - \rho)$ where $\Gamma = (\alpha + \beta)^{(\alpha+\beta)} (1-\alpha-\beta)^{(2-\alpha-\beta)}$	$\dot{A} = H_A^\alpha L_A^\beta A \bar{x}^{(1-\alpha-\beta)}$	Lab equipment R&D model, Rivera-Batiz/Romer (1991b)
$g_k = \sigma^{-1} \left[\Gamma \left(\sum_t^n H_t^\alpha L_t^\beta \bar{x}_t^{-1} \right)^{\alpha+\beta} - \rho \right]$ where $\Gamma = (\alpha + \beta)^{(\alpha+\beta)} (1-\alpha-\beta)^{(1-\alpha-\beta)}$	$\dot{A}_t = H_{t,A}^\alpha L_{t,A}^\beta \left(\sum_t^n A_k \right) \bar{x}^{(1-\alpha-\beta)}$	n-country version of the lab equipment model, Rivera-Batiz/Romer (1991b)
$g = (1 + \Lambda \sigma)^{-1} (\delta H - \Lambda \rho)$ where $\Lambda = \alpha / (1 - \alpha - \beta) (\alpha + \beta)$	$\dot{A} = \delta A H$	Knowledge capital R&D model, Rivera-Batiz/ Romer (1991a, b), similar: Grossman/ Helpman (1991)
$g = \bar{\sigma}^{-1} (\delta - \rho)$ where $\bar{\sigma}^{-1} = (1 + \psi - \beta) / (\sigma(1 + \psi - \beta) - \psi)$	$\dot{h} = \delta h (1 - u)$	Human capital model Lucas (1988)
$g = \left(\Omega \delta L - \frac{\beta}{1-\beta} s^{-1} \right)$ where $\Omega = (1 - \alpha - \beta) / (1 - \beta)$	$\dot{A} = \delta A L_A$	Knowledge capital R&D model with constant savings rate "s" (see appendix 2)
(a) Definition of variables see text.		

The second column of table 1 displays these critical production functions. The first three models have only one production sector. In the universal capital model of Rebelo (1990) the aggregate production function includes a broad measure of capital (K) as an accumulating production factor with non-diminishing marginal returns. As this model contains no other production factors, the real interest rate equals $Y_k = A$. The learning by doing model of Romer (1986) has a similar structure. As knowledge capital (θ) is set equal to the physical capital stock (K), the real interest rate equals $Y_k = \beta L^{(1-\beta)}$. This model shows what happens to the growth formula, if the critical production function includes a non-accumulating production factor like raw labor (L): As the real interest rate depends positively on the endowment of the economy with this non-accumulating production factor, the growth rate itself depends positively on this production factor. The fiscal spending model of Barro (1990) is built on an aggregate production function that is similar to the Rebelo (1990) production function with the exception that the capital stock is split into privately accumulated capital (K) and governmentally accumulated capital (G). As the aggregate production function includes no non-accumulatable production factors, the real interest rate - and hence the growth rate - does not depend on the resource endowment of the economy. However, as the ability of the government to accumulate capital (G) depends on the tax income of the government, the income tax rate (τ) enters the growth formula. The lab equipment R&D model of Rivera-Batiz/Romer (1991b) is a three sector model, where all three sectors work on the basis of the same production technology. The accumulating production factor of this model is knowledge capital (A) that is measured as the number of patents for special types of production machinery (\bar{x}). As the critical production function includes two kinds of non-accumulating production factors (H and L), the real interest rate and hence the growth rate depends on the endowment of the economy with these production factors. Rivera-Batiz/Romer (1991b) interpret these non-accumulating production factors as human capital (H) and raw labor (L). However, they could also be interpreted as any other production factors that are non-accumulating (at least by private market forces alone) and necessary in the production of new technological knowledge. For example, they could be institutional capital such as a stable legal framework, an effective protection of property rights, efficient education institutions, and efficient conditions for the establishment of research

networks.⁴ The n-country version⁵ of the Rivera-Batiz/Romer (1991b) lab equipment model reveals that in open economies the growth rate of country k may also depend on the resource endowment and the import tariffs (τ) of the rest of the world ($\sum_l^n (H_l^\alpha L_l^\beta \tau^{-1})^{\frac{1}{\alpha+\beta}}$).

The knowledge capital R&D model of Rivera-Batiz/Romer (1991a) and (1991b) has a R&D sector that uses only human capital (H) and accumulated technological knowledge as input. Again, the endowment of the economy with human capital (or any other non-accumulating production factor necessary for the production of technological knowledge) appears in the growth formula as a positive argument.

The models described so far all assume that human capital can not be accumulated - at least over a certain maximum level. Romer (1990a) argues that this assumption is justified by the empirical observation that the capacity of human beings to accumulate knowledge and abilities is finite. Therefore he strictly distinguishes between human capital, that is non-accumulating over a certain level and technological knowledge that can infinitely be accumulated. However, other authors such as Lucas (1988) and Mulligan/Sala-i-Martin (1993) base their models on the assumption that human capital can infinitely be accumulated. As the human capital model of Lucas (1988) shows (see line 8, table 1), the production function of human capital plays in these model the same role as the production function of technological capital in R&D models á la Romer. Hence their influence on the arguments of the steady state growth formula is the same.

To sum up, this "morphological" discussion of growth formulas of different versions of endogenous growth models shows that - given the way these models interpret the world - real per capital income growth rates depend on arguments that are time invariant. Given the fact that certain production factors, whose accumulation is not or not solely performed by market forces, enter some formulas, growth rates may display a long run trend, if the endowment with these production factors changes, driven by non-market forces. Yet, as none of the ingredients of the growth formulas can be interpreted to display a random walk behaviour I draw the conclusion that endogenous

⁴ See appendix 2 for a further discussion of the interpretation of non-accumulating production factors.

⁵ As all sectors of the lab equipment model of Rivera-Batiz/Romer (1991b) work with the same production technologies, no specialization of countries on certain sectors according to their comparative advantages will appear and the model can straightforward be extended for the n-country case.

growth models generally predict that real per capita income growth rates are stationary over time.

However, one important argument against this stationarity-hypothesis can be made. As the formulas given in table 1 refer to steady state growth rates only, one might argue that out of steady state endogenous growth models predict time variant growth rates, such that a falsification of endogenous growth models based on empirical observations of time variant growth rates is not possible. However, as the analysis of the transitional dynamics in two-sector endogenous growth models by Mulligan/Sala-i-Martin (1993) shows, these models display an out of steady state behaviour that corresponds to a time trend, along which growth rates move smoothly to their steady state level. Hence, even out of steady state endogenous growth models do not predict random walk behaviour of growth rates, but rather a trend stationary behaviour. Therefore, a straightforward way to discriminate between out of steady state behaviour and mere random walk behaviour is to test whether a random walk model performs better than a trend stationary model.⁶ If the random walk model performs better, this can be taken as evidence against endogenous growth models.⁷

⁶ As shown by Christiano/Eichenbaum (1990), it is hard to distinguish between random walk processes and trend stationary processes (see the discussion in the next section). Fortunately, the real per capita income growth rates of most countries display a stationary behaviour. Consequently, it is not necessary to discriminate between both kinds of processes.

⁷ One might also argue that endogenous growth models are already falsified, because a cornerstone of these models - the intertemporal utility maximization assumption as expressed in equation (1) - is already falsified by empirical tests. Indeed, the relation between real interest rates and real consumption growth, as described by equation (1), has been subject to several tests. Many of them come to the conclusion that there is no significant positive relation between real interest rates and the real growth rate of per capita income growth or real savings, especially when the level of real per capita income is added as a competing explanatory variable (Carrol/Lawrence/Summers (1991), Campbell/Mankiw (1989), Giovannini (1983) and (1985)). Earlier empirical studies (Feldstein (1970), McKinnon (1973), Fry (1980) and (1978), Abe et al (1977) could not reject the hypothesis of a positive relation between real savings and the real interest rate. However, although equation (1) provides some comfort in solving endogenous growth models it is no necessary ingredient. Given the way endogenous growth models work, it should be no problem to modify them based on the alternative assumption that savings are a constant fraction of income. As the last row of table 1 shows for a knowledge capital R&D model, the way the parameters and resource endowments enter the steady state growth rate is not essentially influenced by this alternative assumption - with the exception that now the exogenous savings quota enters the growth rate (see appendix 2 for a derivation of the steady state growth rate in R&D models under different assumptions of savings behaviour).

3. The econometric model

This section gives a description of the econometric model used to test the stationarity hypothesis and discusses some of the problems involved in such a test. If real per capita growth rates are stationary they should display a time series behaviour where random shocks do not influence the time series mean. The equilibrium forces behind the time series process should always revert the equilibrium mean within a span of time. Hence, as time passes by a random shock should become more and more unimportant. In other words: the time series of growth rates should have no long term memory concerning random shocks of their past.

Stationary real per capita income growth rates should display such a time series behaviour independent from the time series behaviour of real per capita income. It is an open question, whether real per capita income is trend stationary or difference stationary. As Christiano/Eichenbaum (1990) argue, it is hardly possible to empirically discriminate between both types of time series behaviour. The only difference between both types of both types of time series behaviour is the time series behaviour of the error terms, as is revealed by taking first differences. Taking first differences the trend stationary model equals:

$$(2) \quad y_t = \gamma t + \varepsilon_t + \sum_{j=1}^L \alpha_j \varepsilon_{t+j} \Leftrightarrow \hat{y}_t = \gamma + \left(\varepsilon_t - \varepsilon_{t-1} + \sum_{j=1}^L \alpha_j (\varepsilon_{t-1-j} - \varepsilon_{t-2-j}) \right)$$

Taking the first differences the difference stationary model equals:

$$(3) \quad y_t = \mu + y_{t-1} + \varepsilon_t + \sum_{j=1}^L \alpha_j \varepsilon_{t+j} \Leftrightarrow \hat{y}_t = \mu + \left(\varepsilon_t + \sum_{j=1}^L \alpha_j \varepsilon_{t-j} \right)$$

I interpret endogenous growth models only to explain the constant term in these equations (γ or μ). I do not see that endogenous growth models imply any restrictions, whether this constant term is the shift parameter of a difference stationary time series of real per capita income or the trend parameter of a trend stationary time series of real per capita income.⁸

To test for stationarity of real per capita growth rates, I use a model of the following autoregressive type:

⁸ As it turns out, the real per capita income growth rates of most countries are stationary. Consequently, I do fortunately not have to cope with the identification problem revealed by Christiano/Eichenbaum (1990).

$$(4) \hat{y}_t = \mu + \rho \hat{y}_{t-1} + \varepsilon_t,$$

where \hat{y}_t is the realization of the real per capita growth rate in period t , μ and ρ are constant parameters and ε_t is white noise. If the time series of real per capita growth rates are mean reverting processes and random shocks become more and more unimportant as time passes by, an estimation of equation (4) should yield a parameter estimate of $|\rho| < 1$. If - on the contrary - time series of real per capita growth rates are random walks, an estimation of equation (4) should yield a parameter estimate of $\rho = 1$. In this case the solution of the characteristic equation of (4) possess at least one unit root. Therefore a test of $\rho = 1$ is often called a unit root test. To see more intuitively the crucial importance of the absolute magnitude of ρ note that if \bar{y} is the intertemporal equilibrium solution (i.e. the particular integral) of equation (4) the following equation holds:

$$(5) \bar{y} = E(y_t) = E(y_{t+1}),$$

where $E(\cdot)$ is the expectations operator. Taking expectations from equation (4) and inserting equation (5) yields:

$$(6) \bar{y} = \mu / (1 - \rho)$$

Solving for μ , inserting this into equation (4) and subtracting $\hat{y}_{t-1} - \bar{y}$ from both sides yields:

$$(7) \hat{y}_t - \hat{y}_{t-1} = (\rho - 1)(\hat{y}_{t-1} - \bar{y}) + \varepsilon_t$$

Consequently, if $|\rho| < 1$ a positive deviation of \hat{y}_{t-1} from the intertemporal equilibrium value \bar{y} is followed in the next period by an $\hat{y}_t < \hat{y}_{t-1}$, such that after a random shock a correction toward the intertemporal equilibrium value takes place until \hat{y}_t equals again \bar{y} . Hence, for $|\rho| < 1$ equation (7) is a simple error correction model. If however $\rho = 1$, no correction for a deviation of \hat{y}_{t-1} from the intertemporal equilibrium value \bar{y} takes place and equation (7) equals a random walk model:

$$(8) \hat{y}_t = \hat{y}_{t-1} + \varepsilon_t$$

Hence, the conditional expectation value for \hat{y}_{t+k} given \hat{y}_{t-1} equals $E_{t-1}(\hat{y}_{t+k} | \hat{y}_{t-1}) = \hat{y}_{t-1} \quad \forall k$. This implies that a random shock is transmitted into all future periods, such that the conditional mean of \hat{y}_t changes. The time series displays long term memory concerning the random shocks of its past. Consequently, the time series behaviour of \hat{y}_t is driven by random shocks and no equilibrium value \bar{y} that could be explained by endogenous growth models exists (see equation (6)).

However, the autoregressive model given by equation (4) allows only for first order autocorrelation and may hence be too restrictive for a test of the null hypothesis that \hat{y}_t follows a random walk. If for example the true time series process were a second order autocorrelative random walk, an estimation of equation (4) would yield a downward biased estimate of the autoregression coefficient ($\hat{\rho}$), such that $|\hat{\rho}| < 1$ although the true parameter value would equal $\rho=1$.⁹ Therefore, in order to be fair to the random walk hypothesis, a test should be based on a higher order autocorrelative equation. As can be shown, an autoregressive process of order p (AR(p)) can be written as:

$$(9) \hat{y}_t = \mu + \sum_{i=1}^p \alpha_i \hat{y}_{t-i} + \varepsilon_t \iff \hat{y}_t = \mu + \rho \hat{y}_{t-1} + \sum_{i=1}^p \gamma_i d\hat{y}_{t-i} + \varepsilon_t$$

with $\rho=1$, if \hat{y}_t follows a random walk (Dickey/Fuller (1981), p. 1065). However, even equation (9) may be too restrictive, if for example the true error process displays autocorrelative behaviour too. In this case the appropriate estimation model would be an ARIMA($p,1,q$) model that allows for an autocorrelative moving average of the error process of order q . Unfortunately the estimation of such a highly parameterized model reduces the degrees of freedom by $p+q+1$. Given the fact that the longest appropriate annual time series data enclose about 40 observations the quality of the test may be seriously deteriorated. However, Said/Dickey (1984) showed that any ARIMA($p,1,q$) process can be adequately approximated by an ARIMA($p,0,0$) = AR(p) process, if p is chosen large enough.

The problem with this approach is however that the appropriate magnitude of p is unknown. As Schwert (1989) has shown, this problem can seriously influence the test result. Based on a Monte-Carlo-Study Schwert shows that if the true time series process is ARIMA(0,1,1) and hence $\rho=1$, but is estimated with a AR(1), ARIMA(1,0,1), AR(int(4(T/100)^{0.25})) or AR(int(12(T/100)^{0.25})) model¹⁰, the size of the test for small samples ($T=25$ or $T=50$) is typically larger than indicated by the Dickey/Fuller distributions for a t-test and a K-test¹¹ of the H_0 that $\rho=1$ (Dickey/Fuller

⁹ Following a common inconsistency of notation a parameter with a hat " ^ " represents the estimator of this parameter, while a variable with a hat " ^ " represents the growth rate resp. the first difference of the variable.

¹⁰ T is the sample size.

¹¹ See section 4 for a definition of the various test statistics.

(1981) and Fuller (1976)).¹² Consequently, the actual probability that H_0 is rejected although H_0 is true is larger than suggested by the Dickey/Fuller distributions. However, if p is chosen to equal $\text{int}(4(T/100)^{0.25})$ or $\text{int}(12(T/100)^{0.25})$ a t-test based on an AR(p) model leads to a size of test that is approximately compatible with the Dickey/Fuller distributions. Nevertheless, a K-test typically leads to a size of test that is larger than indicated by the Dickey/Fuller distributions no matter what p is chosen.

To cope with these problems I perform two kinds of model specification tests. *First*, I estimate several AR(p) models with $p \in \{0,1,4,6\}$ and chose the minimum p where a Breusch-Godfrey test (BG-test) for autocorrelation of the error process of order six is not rejected. I argue that this way the biasing influences of a moving average error process is minimized. *Second*, if the AR(p) model that passes the BG-test is rejected by a modified Plosser-Schwert-White differencing test¹³ (PSW-test), I chose the next minimum p that passes the PSW-test too. As it turns out the higher p the better the AR(p) model passes the BG- and PSW-test. Indeed out of a sample of 111 countries there exists for each country an AR(p) specification with $p \in \{0,1,4,6\}$ that passes both tests.

While the Monte-Carlo-Study of Schwert (1989) shows that unit root test based on an AR(p) model are often biased in favour of a rejection of the H_0 that $\rho=1$, Bayesian criticism as stated in Sims (1988) and Sims/Uhlig (1991) argues that unit roots tests tend to be biased in favour of an acceptance of the H_0 that $\rho=1$. To understand this criticism one has to take into consideration the principles of classical inference. Classical inference typically rejects the H_0 only if there is overwhelming evidence against it. That is to say that the H_0 is only rejected if the probability of rejecting H_0 , while the H_0 is true, is smaller than a significance level of $\alpha = 1\%$ or $\alpha = 5\%$. This is a very conservative behaviour towards the H_0 . It implies a rather critical attitude against the H_1 that growth rates are stationary. The advantage of this procedure is that a rejection of H_0 is strong evidence in favour of the H_1 that growth rates are stationary. Bayesians, however claim that such a behaviour implies an implicit prior in favour of the H_0 . In case of a test for unit roots they even emphasise their criticism, because given the H_0 that $\rho=1$, its estimator $\hat{\rho}$ has not the standard symmetrical student

¹² An ARIMA(0,1,1) model equals: $\hat{y}_t = \mu + \hat{y}_{t-1} + e_t + \theta e_{t-1}$. Schwert (1989) chooses θ to take different values. A high value (0.5 or 0.8) for θ typically leads to a higher size of test, whereas a low value (0 or -0.5 or -0.8) typically leads to a lower size of the test than indicated by the Dickey/Fuller distribution tables (for t-test as well as for K-tests).

¹³ In order to be applied for autoregressions the PSW-test has to be modified to avoid an a priori correlation of dependent variables with the error term (e.g. Maddala (1988), p. 513).

distribution around $\rho=1$, but is asymmetrically distributed around $\rho=1$ with a concentration of probability in favour of $\hat{\rho}<1$ (see figure 1, probability density function $f(\hat{\rho}|\rho=1)$).¹⁴ However, for any H_0 that $\hat{\rho}$ takes a value smaller than unity the estimator $\hat{\rho}$ has the standard symmetrical student distribution around ρ (see figure 1, probability density function $f(\hat{\rho}|\rho=0.9)$). This implies that for $\hat{\rho}<1$ a much higher t-value is needed to reject H_0 that $\rho=1$ than the H_0 that $\rho=\hat{\rho}-(1-\hat{\rho})$, although $|\hat{\rho}-\rho|=|\hat{\rho}-\rho'|$. This discontinuity of classical asymptotic theory in the case of unit root test is drafted in figure 1. If for example an OLS estimation yields a $\hat{\rho}=0.95$ the H_0 that $\rho=0.9$ can be rejected with a p-value of α , whilst the H_0 that $\rho=1$ can only be rejected with a p-value of $\beta>\alpha$, though the absolute difference of $\hat{\rho}=0.95$ from $\rho=0.9$ equals that from $\rho=1$. The Bayesian approach to avoid these kind of problems is to base the test conclusions not on the likelihood density function of the test (i.e. $f(\hat{\rho}|\rho)$) but on the posterior probability function $f(\rho|\hat{\rho})$. As the posterior probability function $f(\rho|\hat{\rho})$ is symmetrical around $\hat{\rho}$ the discontinuity of classical asymptotic theory in case of unit root tests does not emerge ((see the posterior probability function $f(\rho|\hat{\rho}=0.95)$ in figure 1).¹⁵ For example, suppose an OLS estimation provides a $\hat{\rho}=0.95$. Then, given the posterior probability function, the probability that the true $\rho \geq 1$ equals γ (see figure 1).

However, there is a price to pay for this comfort. A data sample only provides sufficient information for determining the likelihood density function of the test $f(\hat{\rho}|\rho)$. Yet, to derive the posterior probability function $f(\rho|\hat{\rho})$, the knowledge of the unconditional probability of ρ , i.e. $f(\rho)$, and the knowledge of the unconditional probability of the data, i.e. $f(\hat{\rho})$, has to be given.¹⁶ As the unconditional probability of ρ is the probability of ρ before the world came into being¹⁷ the unconditional probability of ρ (and $\hat{\rho}$ as well) is unknown. To cope with this problem real Bayesians

¹⁴ For an analytical derivation see Fuller (1976), for a Monte-Carlo simulation see Sims/Uhlig (1991).

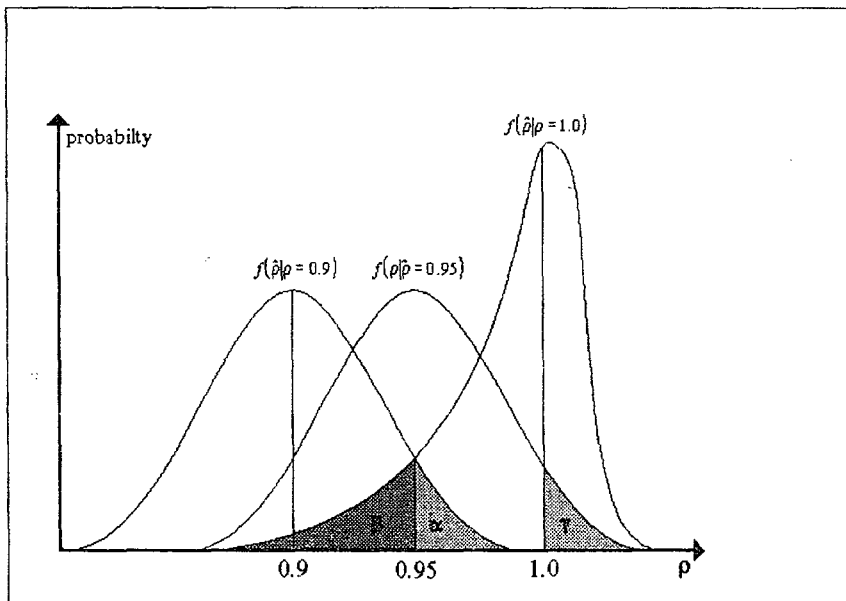
¹⁵ This is shown by the Monte-Carlo simulation of Sims/Uhlig (1991).

¹⁶ Given the definition of conditional probability the following relation holds:
 $f(\rho|\hat{\rho}) = f(\hat{\rho}|\rho) f(\rho) / f(\hat{\rho})$.

¹⁷ Since the point in time the world came into being all its parameters are determined. Hence one may argue that after this point in time the unconditional probability of a certain ρ is either zero or unity.

substitute the unconditional probability of ρ by their own beliefs about $f(\rho)$.¹⁸ Researchers, who have no own beliefs, or who are not keen enough to substitute them for the unconditional probability of ρ , must follow other strategies.

Figure 1 - Probability density functions for $\hat{\rho}$ under $\rho = 0.9$ and $\rho = 1$ and posterior probability density for ρ under $\hat{\rho} = 0.95$



One such strategy is possible if - metaphorically spoken - the shape of the posterior probability function approximately equals the shape likelihood density function. In this case by the sake of symmetry the p-value of the likelihood probability function for an estimate of $\hat{\rho} = 0.95$ under the H_0 that $\rho = 1$ equals the probability that the true $\rho \geq 1$ given an estimate of $\hat{\rho} = 0.95$. This can be seen by drawing the standard student

¹⁸ This procedure is based on the Bayesian conviction that the more tests a theory passes the higher becomes the probability that it is the true theory. Therefore, the beliefs of a researcher, which should reflect this probability, is an appropriate substitute for the unconditional probability $f(d)$. However, whether a theory can become the more probable the more tests it passes, has been intensively discussed among science theorists. Popper (1989), appendix XVII provides a proof, which - based on the entropy assumption of Jaynes/Khinchin/Carnap - shows that if in the beginning all theories have the same probability (given the information of the researcher) the probability conditional on the test result stays always the same for all non-rejected theories and can not grow above 0.5 no matter how many tests are performed.

distribution as the likelihood density function for $f(\hat{\rho}|\rho=1)$ in figure 1 (see appendix figure A1, where $\beta=\gamma$). Hence, the p-value of a t-test of the H_0 that $\rho=1$ based on the standard student distribution around $\rho=1$ equals the probability that the true $\rho \geq 1$.¹⁹ However, as shown by the Monte-Carlo- Study by Sims/Uhlig (1991) posterior probability function is more dispersed than the standard student distribution. The degree of dispersion is the higher the lower $\hat{\rho}$. Nevertheless, it should be clear from this discussion that the p-value of a t-test of the H_0 that $\rho=1$ based on the standard student distribution provides valuable information. Therefore, I report not only the p-values of the asymmetrical distribution of $f(\hat{\rho}|\rho=1)$, as tabulated in Dickey/Fuller (1981) and Fuller (1976), but also the p-values based on the student distribution.

Another strategy of avoiding a Bayesian mixture of personal priors and objective data is to determine the prior probability in favour of a unit root necessary to equal the posterior probability of a unit root with the posterior probability of no unit root.²⁰ As the definition of conditional probability²¹ shows, this can be done by solving the following equation for ω :

$$(10) \frac{f(\rho=1|\hat{\rho})}{f(\rho < 1|\hat{\rho})} = \frac{f(\hat{\rho}|\rho=1)}{f(\hat{\rho}|\rho < 1)} \frac{\omega}{1-\omega} = 1$$

I report these ω -values based on a test statistic derived by Sims (1988) and use it for diagnostic checks.

¹⁹ Pratt (1965) considers conditions, where p-values and posterior probabilities will approximately coincide. In general the one-tailed p-values and posterior probabilities will coincide, if the prior probabilities used to derive the posterior probability are equally distributed over the regression parameters and over the log of the residual variance. The Monte-Carlo simulation of Sims/Uhlig (1991) is based on the assumption that the prior probability of all $\rho \in [0.8, 1.1]$, which are used to construct the time series is equally distributed. Hence, they implicitly assume that the realization of each type of world out of the interval $[0.8, 1.1]$ occurs with equal probability. This is the reason, why their posterior probability function (as drafted in figure 1) is symmetrically. However, as the unconditional probability of a certain ρ before the world existed was probably not equally distributed over all $\rho \in [0.8, 1.1]$ (for example: explosive values ($\rho > 1$) may have been less likely), the true posterior probability function of ρ may not be symmetrical either. I neglect this argument in the following.

²⁰ Of course this is a rather sublime seduction of the reader to get involved into Bayesian subjective prior inference, because given the value of this "critical prior probability" every one will ask himself whether the "critical prior probability" in favour of a unit root is too high to accept the unit root hypothesis.

²¹ See footnote 10 or e.g. Maddala (1989), p. 503.

4. The test results

This section describes the data and provides the results of the econometric tests described in section 3. I use two different data sets, the growth rate of per capita GDP in prices of 1985 of 16 industrialized countries based on Maddison (1991), tables A8 and B4, and the per worker GDP data in 1985 US relative prices of the Penn World Tables (Mark 5) of Summers/Heston (1991), series 19 (RGDPW).²² I restrict the Maddison sample to the period 1950-1989, to exclude the structural shifts following World War Two. The Penn World Tables provide sample periods of different length from 1950-1988 for 138 countries. I present the test results for all countries that have a minimum sample period of 20 years after the model selection procedure described in section 3 is executed.²³ This restriction leaves 111 countries with sample periods varying from 20-38 years. I do *not* control for structural breaks neither for the Maddison sample nor for the Penn World Table sample.²⁴

I test several versions of the H_0 that $\rho=1$. Table 2 surveys these tests and the test statistics used for each one. As shown by the Monte-Carlo-Study of Dickey/Fuller (1981) these test statistics have the highest power (i.e. lowest probability of a type two error for a given probability of a type one error) for the combinations of H_0 and H_1 hypotheses listed in table 2.

²² I chose the real per worker GDP growth rate, because this is the growth rate explained by the growth models discussed in section 2 and to achieve comparability with the results of Easterly/Kremer/Pritchett (1993). However, I run the tests with other growth aggregates of the Summers/Heston (1991) data, such as real per capita GDP (series 1 and series 6) too. These data provided similar test results. The results are available upon request.

²³ As this selection procedure chooses between models with a maximum lag of six years, the sample periods provided by the Penn World Table are cut by a maximum of six years.

²⁴ This implies a rather critical behaviour against the H_1 , because structural breaks (as the broke down of Bretton Woods and the oil shocks of the seventies) typically reduce the prediction power of the sample mean and enhance the prediction power of the lag (see the description of the test statistics).

Table 2 - Tested hypotheses and test statistics

H₀	H₁	test statistic (a)
H ₀ : (μ, ρ) = (0, 1)	H ₁ : (μ, ρ) = (0, ρ < 1)	$d = \frac{\sum_{t=1}^T (\hat{y}_t - \hat{y}_{t-1})^2}{\sum_{t=1}^T (\hat{y}_t - \bar{\hat{y}})^2}$
H ₀ : (μ, ρ) = (μ, 1)	H ₁ : (μ, ρ) = (μ, ρ < 1)	$t = \frac{\hat{\rho} - 1}{\sigma_{\hat{\rho}}}$
H ₀ : (μ, ρ) = (0, 1)	H ₁ : (μ, ρ) = (μ, ρ ≠ 1)	$K = T(\hat{\rho} - 1) \text{ and } t = \frac{\hat{\alpha}}{\sigma_{\hat{\alpha}}}$
(a) $\bar{\hat{y}}$ is the sample mean that may diverge from the intertemporal equilibrium solution \bar{y} of equation (6).		

The first test statistic is the von Neumann ratio. According to Dickey/Fuller (1981) it has the highest power for a test of the H₀ of a simple random walk without a drift, H₀: (μ, ρ) = (0, 1), against the H₁ of a mean reverting process, H₁: (μ, ρ) = (0, |ρ| < 1).²⁵ If the time series properties of a variable is best described by a simple random walk, last year's realization of the variable is the best forecast of this year's growth rate. If, on the contrary, the time series properties of a variable is best described by a mean reverting process, the best forecast for this year's growth rate is the sample mean. Hence, if the H₀ of a simple random walk were true, the squared deviations of this year's growth rate from last year's growth rates should be smaller than the sample variance. The critical values for a rejection of the H₀ at a significance level of 5% and 1% are given by its cumulative probability function displayed in table 1 of Sargan/Bhargava (1983). For a sample size of 25 resp. 38 years these values are 0,879 resp. 0,612 for a significance level of 5% and 1,475 resp. 0,839 for a significance level of 1%.²⁶ As column 6 of

²⁵ The von Neumann ratio is the only test statistic I use that is not estimated by allowing for a higher order autocorrelation of the growth process. Hence, the number of lags given in column 2 of table 3 and 4 do not refer to the von Neumann ratio test statistics.

²⁶ It is somehow astonishing that these values for the rejection of the H₀ are that low. However, this stems from the fact that this test allows for a certain degree of autocorrelation of the time series with |ρ| < 1. Given this degree of autocorrelation the squared deviations of this year's growth rate from last year's growth rate may be smaller than the squared deviations of this year's growth rate from the sample mean, even if the time series follows not a random walk.

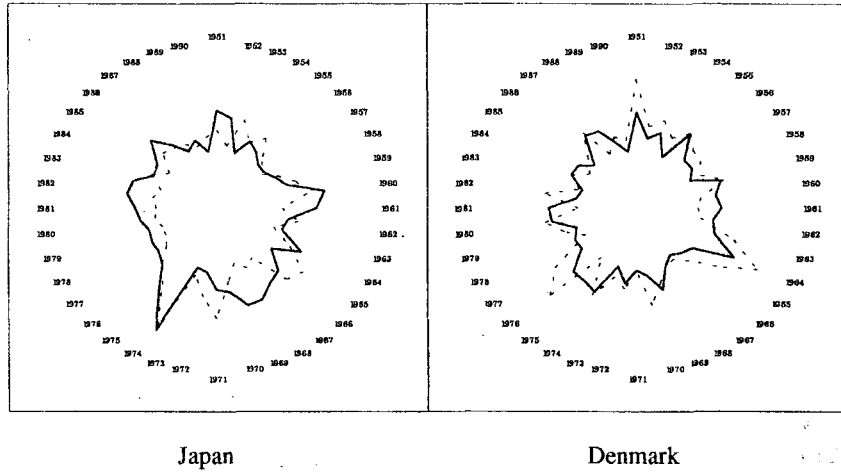
appendix table A1 displays, the H_0 can be rejected for all countries of the Maddison sample with a level of significance of 5% and for all countries but France and Japan with a level of significance of 1%. Column 6 of appendix table A2 displays that the H_0 can be rejected for all but two countries (Algeria and Papua New Guinea) of the 115 countries of the Summers/Heston sample at a significance level of 5% and for all but twelve countries with at a significance level of 1%. Consequently, the rejection of the H_0 based on the von Neumann ratio is overwhelming. Figures 2 and 3 give a visual impression of the von Neumann ratio for the country with the highest and the lowest von Neumann ratio in the Maddison sample (Denmark ($d=1,91$) and Japan ($d=0,72$)).²⁷

Figure 2 shows the prediction error spots of the sample mean and the one year lag of the real per capita growth rate. The dotted line give the deviation of the of this year's growth rate from last year's growth rate the bold line gives the deviation of the growth rates from the sample mean. The distance from the center of the circle to each line equalizes this deviation plus one. Figure 2 reveals that most of the time for the Danish growth process these deviations are significantly larger for last year's growth rate than for the sample mean but not so for the Japanese growth process.

Figure 3 shows that a positive deviation from the sample mean in the Danish growth process was typically followed by a negative deviation within a couple of years. Consequently, the equilibrium forces of the growth process led to a reversion of the sample mean. Contrary to Denmark, positive (negative) deviations from the sample mean of the Japanese growth process were followed by positive (negative) deviations over periods up to twelve years.

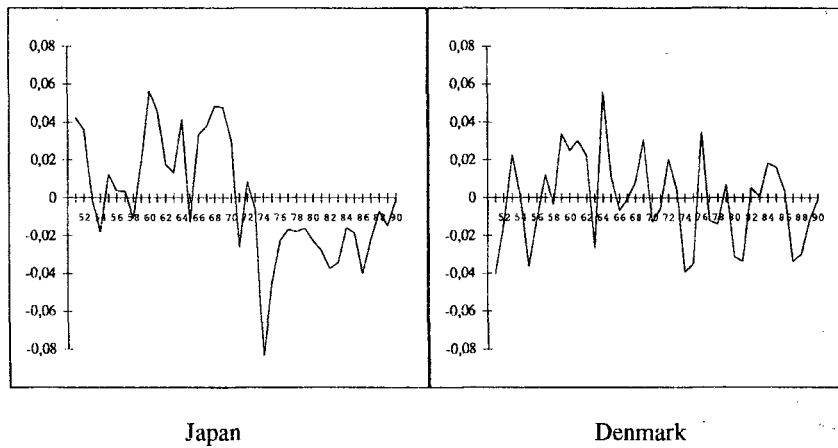
²⁷ For the other countries of the Maddison sample see appendix figures A2 and A3.

Figure 2 - Prediction error spots of sample mean and one year lag for the real per capita growth rate of Denmark and Japan 1951-1990 (a)



(a) The dotted line give the deviation of the of this year's growth rate from last year's growth rate the bold line gives the deviation of the growth rates from the sample mean. The distance of the lines from the center of the circle equalize the deviations plus one.

Figure 3 - Deviation of real per capita growth rates from sample mean for Denmark and Japan 1951-1990



However, as the large and persistent positive deviations at the beginning of the sample period and the large and persistent negative deviations at the end of the sample period indicate, this time series pattern of the Japanese growth process seems to be generated by a declining time trend of Japanese growth rates but not by a random walk process. This is indeed the result of a test of the H_0 of the absence of a time trend based on the test statistic Φ_2 (equation (12)). The results of this test will be presented at the end of this chapter.²⁸

To sum up, based on the von Neumann ratio all countries of the Maddison sample as well as the overwhelming majority the countries of the Summers/Heston sample do reject the H_0 of a random walk against the H_1 of a stationary mean reverting process. Consequently, the results based on the von Neumann ratio significantly favour the stationarity hypotheses, which is implied by models of endogenous growth.

However, this unequivocal picture changes if a test is based on the t-statistic. Dickey/Fuller (1981) present the cumulative probability distribution of the t-statistic under the H_0 $\rho=1$. According to this distribution the H_0 is rejected at a significance level of 1% resp. 5% if the t-statistic reaches a level of -3,75 resp. -3,0 for a sample size of $T=25$ and a level of -3,58 resp. -2,93 for a sample size of $T=50$. Dickey/Fuller (1981) show that the t-statistic is the most powerful test among their statistics for a test of the $H_0: (\mu, \rho) = (\mu, 1)$ against the $H_1: (\mu, \rho) = (\mu, \rho < 1)$. I estimate ρ based on the regression model of equation (7). As described by the selection procedure in section 3, I allow for higher order autoregression whenever necessary to pass the PSW- and BG-test. Column 9 of appendix table A1 and A2 display the results of the t-test. The H_0 cannot be rejected at a significance level of 5% for 6 out of the 16 countries of the Maddison sample and for 45 out of the 115 countries of the Summers/Heston sample. Nine countries of the Maddison sample and 52 countries of the Summers/Heston sample reject the H_0 at significance level of 1%.²⁹ Consequently, although the majority of countries rejects the H_0 a large group does not reject the H_0 .

²⁸ Of course, the time series behaviour of Japanese real per capita growth rates may have been caused by a structural break around the early seventies. I do not test for this.

²⁹ According to Bayesian arguments discussed in section 3, the cumulative student distribution can be used to estimate the probability that the true parameter ρ is equal or larger than unity given the estimate $\hat{\rho}$, if one assumes that the shape of the posterior probability function approximately equals the shape likelihood density function. Given this assumption, the probability that the true parameter ρ is equal or larger than unity is equal or smaller than 5% in 96 countries of the Summers/Heston sample and 15 countries of the Maddison sample (see the underlined t-test values).

However, this picture changes ones again if one makes the non-parametric correction of the t-test statistic proposed by Phillips/Perron (1988). As a Monte- Carlo-Study of Handa/Ma (1989) shows, if the errors of the regression equation are autocorrelated (as indicated by the BG-tests) the Phillips/Perron t-test has a higher power than the Dickey/Fuller t-test. The price one has to pay for this higher performance of the Phillips/Perron t-test in the presence of autocorrelated errors is according to Handa/Ma (1989) its relative poor small sample performance. As columns 8 and 12 of appendix table A2 display,³⁰ based on the Phillips/Perron t-test only 6 countries of the Summers/Heston do not reject the H_0 (Cameroon, Ecuador, Mozambique, Papua New Guinea, Philippines, Trinidad and Tobago). Nine countries reject the H_0 only at the 5% significance level. All other countries reject the H_0 at the 1% level. The countries of the Maddison sample reject the H_0 at a level of significance of 1% with the exception of Japan that does not reject the H_0 . Consequently, if the low small sample performance of the Phillips/Perron t-test does not seriously bias the test results, the overwhelming majority of countries rejects the H_0 .

The third test statistic, the K-test: $K = T(\hat{\rho} - 1)$, provides a similar result. As shown by Dickey/Fuller (1981) this test has the highest power of their statistics, if the H_1 equals $\rho \neq 1$. According to the cumulative probability distribution presented by Dickey/Fuller (1981) the H_0 is rejected at a significance level of 1% resp. 5% if the K-statistic reaches a level of -17,2 resp. -12,5 for a sample size of $T=25$ and a level of -18,9 resp. -13,3 for a sample size of $T=50$. Column 10 of appendix table A1 and A2 display the results of the K-test. The H_0 cannot be rejected at a significance level of 5% for 4 out of the 16 countries of the Maddison sample and for 12 out of the 115 countries of the Summers/Heston sample. Four countries of the Maddison sample and 14 countries of the Summers/Heston sample reject the H_0 at significance level of 1%. If the Dickey/Fuller K-test is corrected by the non-parametric method of Phillips/Perron the test result changes only slightly in favour of a rejection of the H_0 (column 10 and 11 of appendix table A1 and A2): The H_0 cannot be rejected at a significance level of 5% for none of the countries of the Maddison sample and for 3 countries (Cameroon, Jamaica, Papua New Guinea) of the Summers/Heston sample. Nine countries of the Maddison sample and 99 countries of the Summers/Heston sample reject the H_0 at significance level of 1%. Consequently, based on the K-test the overwhelming majority of the countries rejects the H_0 .

³⁰ The Phillips/Perron t-test equals the Dickey/Fuller t-test, if the regression model is AR(0).

To sum up, the tests based on the different test statistics envisaged so far reveal that for 69 of the 115 countries of the Summers/Heston sample the H_0 is rejected by all test statistics (i.e. von Neumann ratio, Dickey/Fuller t-test, Phillips/Perron t-test, Dickey/Fuller K-test and Phillips/Perron K-test), while 46 countries at least one test does not reject the H_0 (these countries are marked with a curl " ° " in table (4) at a significance level of 5%. The countries of the Maddison sample display roughly the same ratios: For 10 countries out of the 16 countries of the Maddison sample the H_0 is rejected by all statistics, while for 6 countries at least one test does not reject the H_0 at a significance level of 5%. Counting only the results for countries with at least 30 observations roughly the same ratios show up: for 23 of the 64 countries with at least 30 observations of the Summers/Heston sample the H_0 is not rejected by any test statistic. This is 36% compared to 40% of the entire sample. Hence, one might conclude, if there is any bias caused by small time series it works in favour of the H_0 .

These test results are confirmed by Sims' prior ω . As column 13 displays, the prior probability in favour of a unit root has to be at least 95% for 92 countries in order to equalize the posterior probability of a unit root with the posterior probability of no unit root. Only 4 countries (Algeria, Austria, Bolivia, Sweden) reach an equalization of the posterior probabilities with a prior probability in favour of a unit root lower than 60% (but still higher than 50%). Hence, a Bayesian researcher, who wants to interpret the test results in favour of the H_0 , needs strong subjective priors in favour of the H_0 .

The high priors necessary to equalize the posterior probabilities indicate that the problems arising from the discontinuity of classical asymptotic theory in the case of unit root tests may be serious. Thus the choice of the H_0 that $\rho=1$ may have critically influenced the test results (see the discussion in section 3). To check this, I present a test of the H_0 that real per capita growth rates are stationary against the H_1 that $\rho=1$. This test is based on a statistic developed by Kahn/Ogaki (1991). It uses the fact that a weakly stationary time series implies $E(\hat{y}_t^2) = E(\hat{y}_{t-1}^2)$.³¹ If this condition holds the best linear unbiased estimator of β equals $\hat{\beta} = 0,5$. To see this, note that a necessary condition for $\hat{\beta}$ to be the best linear unbiased estimator of β is $E(\epsilon_t(\hat{y}_t - \hat{y}_{t-1})) = 0$ with $\epsilon_t = \hat{y}_t - \hat{\beta}(\hat{y}_t - \hat{y}_{t-1})$.³² This orthogonality condition can be written:

³¹ Note that under the assumptions of a weakly stationary process $E(\hat{y}_t) = E(\hat{y}_{t-k}) = \mu$ and $\sigma_{\hat{y}} - E(\hat{y}_t)^2 = \sigma_{\hat{y}} - E(\hat{y}_{t-k})^2 = E(\hat{y}_t^2) = E(\hat{y}_{t-k}^2)$.

³² Note that the OLS estimator of β is given by the following formula:

$$\hat{\beta} = \text{cov}(\hat{y}_t, (\hat{y}_t - \hat{y}_{t-1})) / \text{var}(\hat{y}_t) = \beta + (E(\epsilon_t(\hat{y}_t - \hat{y}_{t-1})) - E(\epsilon_t)E(\hat{y}_t - \hat{y}_{t-1})) / \text{var}(\hat{y}_t).$$

$E(\varepsilon_t(\hat{y}_t - \hat{y}_{t-1})) = (1 - \hat{\beta})E(\hat{y}_t^2) - (1 - 2\hat{\beta})E(\hat{y}_t\hat{y}_{t-1}) - \hat{\beta}E(\hat{y}_{t-1}^2)$. As follows from this, if $E(\hat{y}_t^2) = E(\hat{y}_{t-1}^2)$, the orthogonality condition holds if $\hat{\beta} = 0,5$. Hence, if a time series is actually weakly stationary, such that $E(\hat{y}_t^2) = E(\hat{y}_{t-1}^2)$ holds, an OLS estimation of $\hat{\beta}$ should yield an estimate close to 0,5. The statistic Kahn/Ogaki (1991) propose, to test for this, equals

$$(11) K_T = 4(1 - \rho)T(\hat{\beta} - 0,5),$$

where ρ can, roughly spoken, be estimated by an OLS regression of the type $\hat{y}_t = \mu + \rho\hat{y}_{t-1} + \varepsilon_t$. This test statistic converges in distribution to a random variable that is the difference between two independent chi-square variates with one degree of freedom, whose density function is derived in Miller (1964). Kahn/Ogaki (1991) estimate the critical value at the 5% significance level for K_T to be 3,2. I provide the test results for K_T for the Summers/Heston sample only. As is displayed in column 13 of table 4, only 5 countries (Cameroon, Chad, Congo, Fiji, India) reject the H_0 of stationarity at the 5% significance level. However, it is somehow surprising that three of these countries (Chad, Congo, India) do reject all tests of the H_0 of non-stationarity too. Possibly, this has to be explained with the different finite sample properties of the tests. Nevertheless, the K_T -test of Kahn/Ogaki (1991) supports the view that the growth rates of per worker GDP are stationary for the overwhelming majority of countries.

So far only test results concerning the question of stationarity were reported. Now I turn to the results concerning the estimates of the intertemporal equilibrium solution, equation (6) $\bar{y} = \mu/(1 - \rho)$. To test the $H_0: \mu = 0$, I use two t-tests. The first is the t-test of the H_0 under the assumption of non-stationarity, $\rho = 1$. Dickey/Fuller (1981), table 1, provide the cumulative probability distribution for this case. According to this distribution the H_0 is rejected at a significance level of 1% resp. 5% if the t-statistic reaches a level of 3,41 resp. 2,61 for a sample size of $T=25$ and a level of 3,28 resp. 2,56 for a sample size of $T=50$. As displayed in tables 5 and 6, column 2, the H_0 is rejected by 11 countries of the Maddison sample at a significance level of 5% and by 7 countries at a significance level of 1%, whilst 26 countries of the Summers/Heston sample reject the H_0 at a significance level of 5% and 9 countries at a significance level of 1%. Hence, based on the assumption of non-stationarity, $\rho = 1$, the overwhelming majority of countries rejects the $H_0: \mu = 0$. However, as the H_0 of non-stationarity, $\rho = 1$, is rejected by most of the data, a test of the $H_0: \mu = 0$ should be based on the assumption of stationarity $\rho < 1$. The cumulative probability distribution of a t-test based on this assumption corresponds to the student distribution. Based on the student distribution the H_0 is rejected at a significance level of 1% resp. 5% if the t-

statistic reaches a level of 2,48 resp. 1,71 for a sample size of $T=25$ and a level of 2,40 resp. 1,68 for a sample size of $T=50$. Given these critical values, the H_0 is rejected by 13 countries of the Maddison sample at a significance level of 5% and by 12 countries at a significance level of 1%, whilst 53 countries of the Summers/Heston reject the H_0 at a significance level of 5% and 29 countries at a significance level of 1%. Consequently, under the assumption of stationarity much more countries display a constant $\mu > 0$. Nevertheless, the majority of the Summers/Heston countries does not reject the $H_0: \mu = 0$. As follows from equation (6) $\bar{y} = \mu / (1 - \rho)$, this implies that hypothesis that the intertemporal equilibrium solution of the real per worker growth rate is zero cannot be rejected for the majority of countries. However, all this implies is that the majority of countries had neither a significantly good nor a significantly bad growth performance within the sample periods. As the countries in appendix table A3 are ranked according to their compound growth rate of real per worker GDP (column 4), it is apparent that countries with a high growth performance tend to have a significant constant μ .

As revealed by columns 3 and 4 of tables 5 and 6, the value of the intertemporal equilibrium solution, \bar{y} , is always close to the compound growth rate, \hat{y} . Indeed, a t-test based on the variance of the compound growth rate, does reject the $H_0: \hat{y} = \bar{y}$, only for one country (Ivory Coast). Consequently, cross country regressions, such as Schatz (1974), Heitger (1987), Barro (1990), Barro/Sala-i-Martin (1991), Levine/Renelt (1992), Gundlach (1994), that use the compound growth rate as dependent variable, use a good proxy for the intertemporal equilibrium solution, around which growth rates fluctuate (see equation (6)). Simple averaging across growth rates eliminates most of their autocorrelated fluctuations.

So far the empirical analysis did not deliver much evidence against the hypothesis that real per worker growth rates are stationary, as implied by model of endogenous growth. However, the discussion in section 2 has shown that under certain circumstances endogenous growth models may also predict trend stationarity. According to endogenous growth models, trend stationarity may occur out of steady state as well as in cases where the endowment with non-accumulating production factors changes, driven by exogenous non-market forces. Therefore, it may be interesting to check, in how far such conditions were prevailing. To do this, I use the following test statistic, which corresponds to a F-test if the time series are stationary:

$$(12) \quad \Phi_4 = \frac{\left(\sum_{t=1}^T \left(\hat{y}_t - \left(\mu + \hat{\rho} \hat{y}_{t-1} + \sum_{i=1}^p \gamma_i \hat{d}y_{t-i} \right) \right)^2 \right) - \left(\sum_{t=1}^T \left(\hat{y}_t - \left(\mu + \hat{\rho} \hat{y}_{t-1} + \sum_{i=1}^p \gamma_i \hat{d}y_{t-i} + \lambda t \right) \right)^2 \right)}{\left(\frac{2}{T-4} \right) \sum_{t=1}^T \left(\hat{y}_t - \left(\mu + \hat{\rho} \hat{y}_{t-1} + \sum_{i=1}^p \gamma_i \hat{d}y_{t-i} + \lambda t \right) \right)^2 (T-p-2)}$$

This statistic tests the autoregressive model of equation (9) against the same model plus a time trend, λt . According to the cumulative probability distribution of the F-statistic the H_0 of the absence of a time trend is rejected at a significance level of 1% resp. 5% if Φ_4 reaches a level of 8,09 resp. 4,35 for a sample size of $T=25$ and a level of 7,31 resp. 4,08 for a sample size of $T=40$. As column 13 of appendix table A1 displays, the H_0 cannot be rejected at the 5% significance level for all countries of the Maddison sample but France, Italy and Japan and for all but 16 countries of the Summers/Heston sample.³³ Consequently, the overwhelming majority of countries seems to display a steady state behaviour, where real per capita growth rates are stationary and non-trending. Given that real per capita growth rates differs between countries this implies that the level per capita income *diverges* between countries.

Therefore, a test of the hypothesis that real per capita growth rates differ may be of interest. Although the test of the $H_0: \mu=0$ has already shown that some countries have growth rates significantly different from zero, while others have not, I explicitly test the H_0 that the average deviation of all countries' growth rates from all other countries' growth rates is zero, $H_0: \Delta \bar{y}_i = \frac{\sum_{j=1}^J (\bar{y}_i - \bar{y}_j)}{J-1} = 0 \quad \forall i \in J$. As it turns out, this is equivalent to a test of the $H_0: \Delta \bar{y}_i = \left(\bar{y}_i - J^{-1} \sum_j \bar{y}_j \right) (J/(J-1)) = 0 \quad \forall i \in J$. The t-test statistic equals: $t = (J^{0.5} \Delta \bar{y}_i) / \sigma_{\Delta \bar{y}}$. As such a test implies a comparison of growth rates across countries, the Summers/Heston sample has to be restricted to countries with approximately the same sample period. I base the test on all countries with a sample period from 1951/2-1987/8. This leaves a sample of 31 countries. A test of the H_0 that the per capita growth rates of all 31 countries do not differ is a multivariate test over 31 t-statistics. Consequently, the test cannot be based on the standard critical t-value for a rejection of the H_0 at significance level of 5%. As follows from the Bonferroni inequality, if the probability of a type one error at a certain critical t-value is 5%, the probability of a type one error, if one or more of 31 t-statistics is higher than this

³³ These countries are: Denmark, Finland, France, Gambia, Germany, Ghana, Greece, Italy, Ivory Coast, Liberia, Mexico, New Zealand, Panama, Trinidad and Tobago, Tunisia and Yugoslavia.

critical t-value, is smaller or equal 31 times 5%.³⁴ Consequently, the probability of a type one error would be much to high. Therefore, in order to restrict the probability of a type one error at 5%, the H_0 has to be rejected only if one or more t-statistics are larger than the standard t-statistic of a test at the 5/31% level. The critical value for the t-test statistic that corresponds to this is 2,95. Hence if at least one of the 31 t-test statistics reaches a level of at least 2,95, the H_0 can be rejected at the 5% level. The corresponding t-test statistic at the 1% level equals 3,35%.³⁵ As the columns 6, 7, 13 and 14 of appendix table A4 show, these values are at large exceeded by the t-test statistics of many countries based on the intertemporal equilibrium solution of equation (6), $\Delta\hat{y}$, as well as on the compound rate, $\Delta\hat{y}$. Consequently, the H_0 that the average deviation of all countries' growth rates from all other countries growth rates is zero can easily be rejected at the 1% significance level. The same is true for the countries of the Maddison sample (column 6 and 7 of appendix table A3).

5. Conclusions

All in all the test results of section 4 show that real per capita and per worker growth rates of most countries are *stationary, non-trending* and *differ*. These findings give rise to some conclusions and several questions:

First, the stationarity or persistence of real per capita GDP growth rates is in accordance with a very general implication of endogenous growth models. The approach of endogenous growth models, to explain steady state per capita income growth with factors that are time invariant, seems to be right. It seems not to be necessary to formulate growth models, which explain the second or higher order differences of real per capita income. Somehow surprising is the fact that growth rates of most countries are not only stationary but actually non-trending. Within the framework of endogenous growth models this implies that not only the parameters determining the steady state growth rates (see table 1) but although the non-accumulating production factors determining the steady state growth rates are non-

³⁴ The Bonferroni inequality follows from the lemma $P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$, where $P(A)$ is the unconditional probability of event A. Hence, if A and B are stochastically independent events, the Bonferroni inequality becomes an equality. See Fama (1984) for tests based on the Bonferroni inequality.

³⁵ As the lowest tabulated significance level of the student distribution is 1%, I derive the critical values for the t-test statistics from the standard normal distribution, which delivers values down to a probability level of 0,0001%. This approximation may be justified by the fact that the student distribution converges to the normal distribution as $J \rightarrow \infty$. Given the extremely high t-test statistics of table 6, this approximation does not influence the test results.

trending. As the discussion in section 2 and appendix 2 pointed out, production factors, such as human capital, institutional capital, public infrastructure, efficient supply of public goods and the labor force, are typically non-accumulating by market forces alone. But this does not mean that they are not accumulated by non-market forces. Indeed, in most countries at least the supply of public infrastructure and of course the labor force have grown since the Second World War. Given this were the case, endogenous growth models predict trending growth rates. Hence, in so far the empirical findings of section 4 are not in accordance with the predictions of endogenous growth models. The empirical findings suggest instead, that growth rates have to be explained by factors that are neither non-stationary nor trending.

However, I would not conclude that the test results do imply that there have been no structural breaks in the time series behaviour of real per capita growth rates. Many countries faced strong shocks either caused by changes of the institutional framework (e.g. break down of Bretton Woods, change of macroeconomic policies, trade regime shifts) or by changes of prices of natural resources. Tests for the incidence of these breaks on the process of real per capita growth must be based on test statistics more sensitive for structural breaks than the statistics used in this paper.

Second, within the framework of endogenous growth models stationary and non-trending growth rates are steady state growth rates. However, models of endogenous growth typically imply that in steady state no structural change takes place. Instead, all GDP aggregates - either consumption or production aggregates - grow with the same rate. This, however, contradicts with the well known stylized fact, that the structure of GDP changes typically changes with the level of per capita income. Figure 4 summarizes the results of the large scale cross country analysis of Chenery/Syrquin (1989). This study was based on the following regression equation:

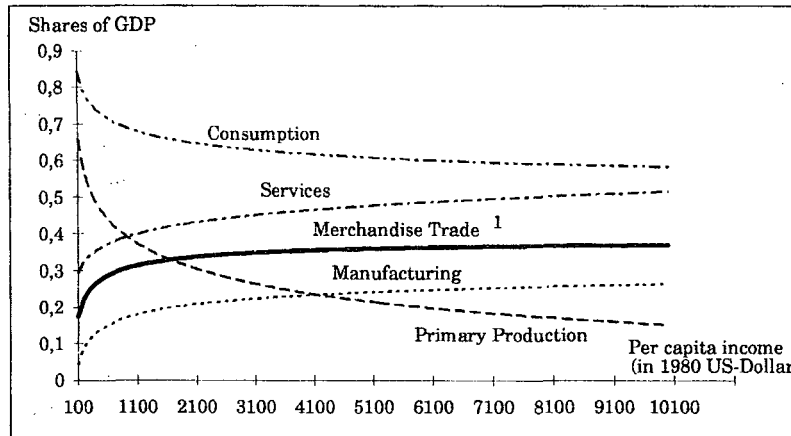
$$(21) \quad \frac{Z}{Y} = \beta_0 + \beta_1 \ln(y) + \beta_2 (\ln(y))^2 + \beta_3 \ln(P) + \beta_4 (\ln(P))^2 + \sum_j^4 D_j$$

where Z/Y equals a certain component of GDP, y equals per capita GDP, P equals population and D_j equals a time dummy.³⁶ Chenery/Syrquin estimate this equation for a pooled cross country sample of about 100 countries over the period 1950-1983. They obtain significant coefficients of per capita GDP and population size for the share of

³⁶ $D_1=1$ if $t \geq 1960$; $D_2=1$ if $t \geq 1967$; $D_3=1$ if $t \geq 1973$; $D_4=1$ if $t \geq 1979$. The semilogarithmic formulation of the regression equation has the comfortable algebraic property that the shares of the estimated GDP components add up to 1, if the shares of the actual GDP components add up to 1.

consumption, government consumption, investment, merchandise exports, merchandise imports, primary production, industry and services in GDP. Figure 4 displays the average shares of these components in GDP dependent on per capita GDP, for a normalized population size of 20 million, corresponding to the regression results of Chenery/Syrquin. As figure 4 shows, in the course of per capita income growth the structure of GDP composition significantly changes, based on the demand side as well as based on the production side. These empirical findings rise the question, how a stationary and non-trending per capita growth rate can be explained within models that allow for structural change in a way indicated by figure 4.

Figure 4 - Average GDP-composition dependent on per real capita GDP 1950-1983



¹ Share of merchandise exports plus imports in GDP.

Source: Chenery/Syrquin (1989); own calculations

Third, the significant indication that real per capita growth rates differ between many countries, can be explained within the framework of endogenous growth models under certain assumptions. One such assumption is the existence of imperfect capital markets. Given imperfect capital markets, interest rates between countries may differ and hence - as discussed in section 2 - growth rates may differ too. As the existence of imperfect capital markets between countries seems to be indicated by the empirical findings of Feldstein/Horioka (1980), imperfect capital markets may indeed be a good explanation for differing growth rates. An alternative explanation for differing growth rates within the framework of endogenous growth models are differing parameters of time preference and intertemporal substitution of consumption. Together with the

assumption of perfect international capital markets, this would imply that some countries (with a low rate of time preference) bear a permanently growing net creditor position, while other countries (with a high rate of time preference) bear a permanently growing net debtor position. As there are many countries with very high creditor and very high debtor positions, this may be a good explanation for differing growth rates too. An alternative explanation for differing growth rates offer models of trade hysteresis as presented by Grossman/Helpman (1991).³⁷ These models show that given the assumption of international immobility of technological knowledge, it is possible that international trade induces some countries to specialize - according to their comparative advantage - on traditional production sectors with low productivity growth. Given a set of further assumptions concerning demand of traditional goods and factor price equalization, per capita income of the country specialized on traditional goods will grow with a lower rate than per capita income of countries specialized on "high tech" goods. It is however controversial, in how far the cornerstone of trade hysteresis models, the assumption of international immobility of technological knowledge, is in accordance with the facts. Nevertheless, less than perfectly mobile technological knowledge may be an explanation for differing growth rates too.

Fourth, the finding that real per capita growth rates are stationary, non-trending and differ between countries implies that the level of per capita and per worker income between countries diverges. This corroborates the findings of Quah (1994), based on a stochastic kernel analysis of the dynamic evolution of the distribution of cross country income levels, that the income level of many countries diverges rather than converges.

The existence of persistent divergence of per capita income between many countries is no satisfactory perspective for future development. A better understanding of the reasons for divergence and the empirics of the process of per capita growth seems to be desirable. As the per capita growth rates of most countries display a stationary time series behaviour, standard cross country regressions appear to be in fact a viable econometric approach towards this aim.

³⁷ For an early version of a trade hysteresis model see Krugman (1981).

Appendix 1: Tables and Figures



Table A1 - Test results for the 16 countries of Maddison (1991) (a)

Country (b)	Lag	Obs.	PSW-Test (c)	BG-Test (d)	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/Perron)	K (Dickey/Fuller)	K (Phillips/Perron)	Sims' prior ω	Φ_4
Australia°	4	35	0,38	6,14	0,637	1,23**	-1,51	-4,19**	-6,8	-19,2**	0,81	0,18
Austria°	6	33	0,06	2,12	0,505	1,37**	<u>-2,19</u>	-4,96**	-8,8	-26,5**	0,87	2,70
Belgium	1	38	3,04	11,31	0,231	1,71**	<u>-3,57*</u>	-5,43**	-26,0**	-32,2**	1,00	0,09
Canada°	4	35	1,00	12,\$	0,012	1,88**	<u>-2,59</u>	-5,89**	-33,7**	33,3**	0,99	0,06
Denmark	1	38	0,80	9,00	-0,055	1,91**	<u>-4,85**</u>	-6,00**	-50,0	-37,9**	1,00	2,94
Finland	4	35	0,82	10,28	0,041	1,67**	<u>-2,62</u>	-5,27**	-50,5*	-26,7**	1,00	0,37
France	0	39	0,34	9,32	0,435	1,15**	<u>-4,07**</u>		-22,1*		1,00	4,71*
Germany°	6	33	0,14	5,48	0,356	0,96*	<u>-2,82</u>	-4,13**	-7,8	-17,0*	0,98	1,74
Italy	0	39	0,58	8,79	0,367	1,28**	<u>-4,24**</u>		-24,7*		1,00	7,61**
Japan°	0	39	1,56	7,00	0,64	0,72*	<u>-2,86</u>		-14,0*		0,95	4,17*
Netherlands	0	39	0,78	12,13	0,211	1,58**	<u>-4,90**</u>		-30,8*		1,00	2,93
Norway	0	39	0,95	5,31	0,023	1,93**	<u>-5,87**</u>		-38,1**		1,00	0,49
Sweden	0	39	0,24	6,26	0,291	1,42**	<u>-4,53**</u>		-27,7*		1,00	1,64
Switzerland	1	38	1,08	9,25	0,039	1,59**	<u>-4,79**</u>		-44,9*		1,00	2,48
UK	1	38	1,06	8,98	-0,234	1,78**	<u>-5,93**</u>	-5,59**	-76,3**	-35,3**	1,00	0,00
USA	1	38	0,49	10,07	0,006	1,69**	<u>-5,07**</u>	-5,41**	-41,8*	-30,7**	1,00	0,45

(a) One asterisk " * " indicates a 5% significance level for the rejection of the H_0 based on Dickey/Fuller (1981). Two asterisks " ** " indicate a 1% significance level for the rejection of the H_0 . Underlined numbers indicate a 5% significance level based on the standard student distribution.

(b) One curl " ° " indicates that at least one test cannot reject the H_0 of non-stationarity. (c) 5% significance level for the rejection of the H_0 of misspecification: 0 lag: $F(1,39)=4,12$; 1 lag: $F(2,38)=3,25$; 4lags: $F(4,35)=2,65$; 6 lags: $F(6,33)=2,39$. (d) significance level for the rejection of the H_0 of autocorrelated errors: $\chi^2=12,6$.

Table A2 - Test results for 115 countries of the Penn World Table 1950-1988 (a)

Country	Lag	Obs.	PSW-Test	BG-Test	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/ Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/ Perron)	K (Dickey/ Fuller)	K (Phillips/ Perron)	Sims' prior ω	K _T Kahn/ Ogaki	Φ_4
Afghanistan°	4	20	1,26	5,57	-0,355	1,41*	-2,46	-3,61*	-27,1**	-13,38*	0,997	-0,001	0,00
Algeria°	6	21	0,45	6,26	1,525	0,62	1,43	-5,82**	11,0	-27,6**	0,585	-0,998	4,15
Angola°	0	24	1,16	3,30	0,356	1,28*	-3,21*		-15,5*		0,988	0,255	0,24
Argentina°	4	33	0,02	10,24	0,256	2,16**	-1,70	-6,62**	-24,6**	-38,4**	0,917	0,538	2,67
Australia°	4	33	0,09	5,71	0,363	1,95**	-1,64	-5,98**	-21,0**	-28,1**	0,989	-0,526	0,05
Austria°	4	33	0,97	7,82	0,744	0,86*	-1,42	-3,81**	-8,45	-22,1**	0,532	-1,285	2,83
Bangladesh	0	25	0,14	2,99	-0,175	2,36**	-5,76**		-29,4**		1	-0,478	0,00
Barbados°	1	23	0,49	12,32	0,558	1,08*	-1,86	-2,93*	-10,2	-12,6*	0,961	0,539	3,67
Belgium	0	37	2,24	8,49	0,23	1,11**	-4,65**		-28,5**		1	0,810	3,06
Benin°	4	24	1,44	12,39	-0,229	1,76**	-2,25	-4,73**	-29,5**	-20,2**	0,981	-2,879	0,33
Bolivia°	4	33	0,01	4,53	0,75	1,53**	-1,20	-4,84**	-8,3	-35,6**	0,513	-2,110	2,34
Botswana	0	25	0,08	9,95	-0,071	1,91**	-4,56**		-26,8**		1	0,886	0,25
Brazil	0	36	0,01	2,58	0,147	1,72**	-5,07**		-30,7**		1	-0,029	1,85
Burma	0	34	0,33	10,64	-0,244	2,52**	-7,34**		-42,3**		1	-1,444	0,04
Burundi°	6	21	0,30	6,73	-0,736	1,77**	-2,72	-4,63**	-36,5**	-23,9**	0,982	0,200	0,53
Cameroon°	6	21	1,19	12,25	-0,186	1,1*	-1,36	-2,48	-24,9**	-10,9	0,878	3,558*	0,45
Canada	4	33	1,26	5,51	-0,554	2,52**	-3,56*	-7,93**	-51,3**	-46,0**	0,961	-0,227	0,84
Cape Verde°	4	20	0,12	4,43	-0,112	1,57**	-2,42	-3,93**	-22,2**	-18,8**	0,994	0,225	0,18
Central Afr.	0	27	1,04	8,19	-0,104	2,24**	-5,64**		-29,8**		1	-0,905	0,02
Chad	0	24	0,24	8,76	-0,15	1,84**	-4,33**		-27,6**		1	8,787*	0,07
Chile	1	29	0,87	11,39	0,194	1,39**	-3,31*	-4,28**	-23,4**	-23,3**	1	0,637	1,14
China	4	23	1,16	8,28	-1,009	1,93**	-3,40*	-5,83**	-46,2**	-16,6*	1	-12,27	0,76
Colombia°	4	33	0,16	5,11	0,251	1,75**	-2,12	-5,37**	-24,7**	-35,1**	0,999	0,001	1,19
Congo	0	25	0,42	9,27	0,094	1,55**	-3,53*		-22,6**		0,997	4,375*	0,01
Costa Rica°	6	31	0,03	2,68	0,701	1,72**	-1,11	-5,29**	-9,3	-36,2**	0,746	-0,089	2,75

Table A2 (continued) - Test results for 115 countries of the Penn World Table 1950-1988

Country (b)	Lag	Obs.	PSW-Test (c)	BG-Test (d)	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/ Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/ Perron)	K (Dickey/ Fuller)	K (Phillips/ Perron)	Sims' prior ω	K _T Kahn/ Ogaki	Φ_4
Cyprus	0	37	0,67	8,81	0,063	1,53**	-5,55**		-34,7**		1	0,324	0,09
Denmark	0	37	0,69	8,36	0,094	1,87**	-5,61**		-33,5**		1	-0,862	4,74 *
Dominica	0	37	0,17	6,34	-0,115	2,32**	-6,87**		-41,3**		1	-28,00	2,84
Ecuador	0	37	2,02	6,29	0,38	1,24**	-3,96**	1,87	-22,9**	15,7*	1	0,249	0,98
Egypt	0	37	0,02	3,37	0,179	1,62**	-4,84**		-30,4**		1	0,443	0,00
El Salvador	0	37	0,92	3,90	0,543	0,91**	-3,21*		-16,9*		0,984	-0,128	3,36
Ethopia°	4	31	1,42	7,86	-0,023	2,59**	-2,14	-7,52**	-31,7**	-33,6**	0,956	-14,34	0,68
Fiji°	4	22	0,48	6,65	0,461	2,06**	-1,05	-5,28**	-11,9	-35,2**	0,79	3,239*	2,57
Finland°	6	31	0,03	7,85	-0,373	1,88**	-2,68	-5,32**	-42,6**	-22,2**	0,986	-4,124	8,82**
France°	0	37	2,27	9,06	0,619	0,75*	-2,96*		-14,1*		0,963	-1,968	5,80**
Gabon°	4	20	0,18	3,43	0,251	2,16**	-1,43	-5,30**	-15,0*	-24,1**	0,999	-0,663	0,41
Gambia°	4	20	0,29	6,11	-0,938	2,87**	-2,63	-8,13**	-38,7**	-31,3**	1	0,818	4,58*
Germany°	4	33	0,04	11,46	0,488	1,04**	-2,50	-3,72**	-16,9*	-17,4**	0,731	-2,111	5,83*
Ghana	4	28	0,18	5,08	-0,276	2,02**	-3,15*	-5,70**	-35,7**	-31,4**	0,915	0,143	4,68*
Greece°	1	36	2,10	12,16	0,401	1,77**	-2,71	-5,41**	-21,6**	-32,3**	1	-0,808	6,84*
Guatemala°	4	33	1,30	10,21	0,494	0,79*	-2,53	-3,10*	-16,7*	-15,9*	0,756	-0,071	3,06
Guayana	0	37	1,49	9,34	0,162	1,68**	-5,05**		-31,0**		1	-0,211	2,26
Haiti	0	27	0,84	4,50	-0,019	0,08**	-5,21**		-27,5**		1	-1,110	0,35
Honduras	4	33	0,39	3,76	0,08	1,48**	-3,02*	-4,57**	-30,4**	-28,1**	0,969	3,46	0,48
Hong Kong	4	23	0,29	5,92	-1,116	1,87**	-3,96**	-4,88**	-48,7**	-21,7**	0,986	0,201	0,53
Iceland	4	33	0,59	8,32	-0,185	1,43**	-2,96*	-4,56**	-39,1**	-20,3**	0,999	-0,181	1,63
India	0	37	0,35	4,67	-0,231	2,36**	-7,19**		-45,6**		1	3,21*	0,06
Indonesien	0	25	0,83	3,23	0,342	1,39**	-3,82**		-16,5*		0,998	-1,836	0,43
Iran	0	29	0,87	10,57	0,364	1,27**	-3,56*		-18,4**		0,996	0,0139	0,32
Iraq	6	25	0,51	7,28	-2,297	1,62**	-4,04**	-4,65**	-82,4**	-19,2*	0,973	-2,181	0,03

Table A2 (continued) - Test results for 115 countries of the Penn World Table 1950-1988

Country (b)	Lag	Obs.	PSW- Test (c)	BG -Test (d)	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/ Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/ Perron)	K (Dickey/ Fuller)	K (Phillips/ Perron)	Sims' prior ω	K _T Kahn/ Ogaki	Φ_4
Ireland	0	37	0,28	11,88	0,469	1,06**	-3,53*		-19,7**		0,995	-1,104	2,94
Israel	0	34	0,23	4,26	0,331	1,38**	-4,27**		-22,8**		1	-6,652	3,76
Italy°	4	33	1,18	7,06	0,285	1,44**	-2,34	-4,61**	-23,6**	-27,0**	0,902	-1,841	16,84**
Ivory Coast°	6	21	0,80	8,81	1,043	1,46**	0,09	-3,81**	0,9	-26,3**	0,636	1,147	8,94**
Jamaica°	1	32	0,43	9,45	0,71	0,77*	-1,97	-3,01*	-9,3	-10,9	0,959	-3,105	2,07
Japan	0	37	0,02	6,17	0,467	1,07*	-3,82**		-19,7**		0,998	-3,843	3,60
Jordan°	4	29	0,98	7,29	0,514	2,29**	-1,37	-6,66**	-14,1*	-49,6*	0,705	-0,711	0,39
Kenya	0	37	4,01	8,84	0,059	1,98**	-5,89**		-34,8**		1	-4,526	0,22
South Korea°	4	30	1,07	11,20	0,436	1,78**	-1,49	-5,22**	-16,9*	-31,9*	0,936	1,577	0,22
Kuwait	0	25	0,30	8,69	0,006	1,96**	-4,70**		-24,9**		1	0,041	3,83
Lesotho	0	24	1,75	10,13	-0,096	2,13**	-5,03**		-26,3**		1	0,270	0,47
Liberia°	4	21	0,24	5,93	0,598	1,28**	-1,05	-3,83**	-8,4	-12,6*	0,705	-6,627	5,47*
Luxemburg	1	36	0,21	9,88	-0,135	2,73**	-5,08**	-8,07**	-40,9**	-39,7**	1	-7,252	0,50
Madagascar	0	27	0,05	2,26	0,093	1,8**	-4,51**		-24,5**		1	1,116	2,35
Malawi	1	32	1,03	10,81	-0,204	1,84**	-5,07**	-5,30**	-38,5**	-30,4**	1	-0,510	2,41
Malaysia	1	31	0,52	12,44	0,127	1,37**	-4,02**	-4,01**	-27,1**	-23,6**	0,999	2,188	1,05
Mali°	4	23	0,71	6,13	0,341	2,24**	-1,71	-5,88**	-15,2*	-33,3**	0,986	-0,016	1,12
Malta	4	29	0,51	8,81	0,181	1,11**	-3,20*	-3,58**	-23,8**	-19,5**	0,985	1,951	0,14
Mauretania°	4	23	0,34	3,21	0,003	1,49**	-2,13	-5,67**	-22,9**	-28,9**	0,952	-0,106	1,36
Mauritius°	1	36	0,23	12,30	0,422	1,63**	-2,61	-5,03**	-20,8**	-29,4**	1	0,816	1,07
Mexico°	4	33	1,06	10,89	0,675	1,23**	-1,21	-4,12**	-10,7	-23,6**	0,766	-3,037	5,52*
Morocco	0	37	0,70	8,78	0,272	1,46**	-4,49**		-26,9**		1	0,285	0,40
Mozambique°	0	27	0,66	3,33	0,479	1,04*	-2,92		-14,1**		0,97	0,357	0,65
Nepal	0	24	0,29	12,76	-0,139	2,28**	-5,39**		-27,4**		1	-0,017	0,02
Netherlands°	6	31	1,63	8,67	0,672	1,29**	-1,11	-4,23**	-10,2**	-27,8**	0,693	0,184	1,29

Table A2 (continued) - Test results for 115 countries of the Penn World Table 1950-1988

Country (b)	Lag	Obs.	PSW- Test (c)	BG -Test (d)	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/ Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/ Perron)	K (Dickey/ Fuller)	K (Phillips/ Perron)	Sims' prior ω	K _T Kahn/ Ogaki	Φ_4
New Zealand	0	37	0,23	7,11	0,093	1,88**	-5,60**		-33,6**		1	-2,111	5,24*
Nicaragua	0	35	2,64	8,79	-0,098	2,21**	-6,37**		-38,4**		1	-0,546	4,12
Niger	6	21	0,16	4,48	-1,091	1,93**	-3,61*	-5,02**	-43,9**	-25,7**	0,98	0,098	1,73
Nigeria	0	37	0,86	9,89	0,395	1,21**	-3,91**		-22,4**		0,999	-0,391	1,17
Norway	4	33	0,55	4,16	-0,291	1,79**	-3,06*	-5,50**	-42,6**	-31,1**	0,999	0,230	1,79
Pakistan°	4	33	1,23	10,22	0,567	1,19**	-1,98	-3,89**	-14,3*	-25,5**	0,86	1,477	0,13
Panama	0	35	3,76	11,54	0,098	1,88**	-5,48**		-31,6**		1	-1,147	5,59*
Papua Guinea°	6	21	0,16	1,30	0,693	0,84	-1,04	-2,74	-6,5	-9,42	0,766	-1,226	0,40
Paraguay	0	37	0,67	8,51	0,171	1,67**	-5,04**		-30,7**		1	-0,234	0,13
Peru°	4	33	0,14	6,95	0,552	1,38**	-1,35	-4,20**	-14,8*	-20,9**	0,935	2,509	3,70
Philippines	1	36	0,68	4,97	0,484	0,77*	-3,59*	-2,89	-18,8**	-16,3**	0,947	1,452	2,90
Portugal	0	37	0,14	8,37	0,254	1,52**	-4,72**		-27,6**		1	-2,468	3,21
Ruanda°	6	21	0,05	6,22	-0,845	1,61**	-2,84	-4,28**	-38,8**	-16,1*	0,961	-0,175	1,27
Senegal	0	27	2,15	6,08	-0,235	2,48**	-6,39**		-33,4**		1	-0,235	0,02
Sierra Leone°	6	20	0,08	8,45	0,816	1,6**	-0,29	-4,16**	-3,7	-20,2**	0,783	0,037	11,17
Somalia°	0	27	0,61	5,05	-0,407	2,81**	-7,69**		-38,0**		1	0,069	0,01
South Africa°	0	37	2,08	5,92	0,051	1,91**	-5,67**		-35,1**		1	-1,168	2,39
Spain°	6	31	1,18	14,63	0,719	1,49**	-1,09	-4,92**	-8,7	-30,1**	0,724	-6,381	1,07
Sri Lanka	0	36	1,08	6,85	-0,363	2,79**	-8,71**		-49,1**		1	-2,051	0,76
Sudan	0	32	1,79	8,97	0,012	1,96**	-5,36**		-31,6**		1	0,356	1,26
Suriname	0	24	2,93	11,65	0,312	1,36**	-3,28*		-16,5*		0,991	0,650	2,42
Sweden°	6	31	0,17	6,29	0,57	1,44**	-1,56	-4,58**	-13,3*	-29,8**	0,596	0,362	1,72
Switzerland	0	37	3,17	6,79	0,184	1,66**	-5,02**		-30,2**		1	-2,051	0,57
Syria	0	27	2,67	10,30	-0,051	2,1**	-5,27**		-28,4**		1	-0,053	3,35
Taiwan	1	36	0,44	10,48	0,253	1,35**	-3,84**	-4,35**	-26,9**	-24,5**	1	-1,754	1,13

Table A2 (continued) - Test results for 115 countries of the Penn World Table 1950-1988

Country (b)	Lag	Obs.	PSW-Test (c)	BG-Test (d)	$\hat{\rho}$	d	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Dickey/ Fuller)	$t = \frac{\hat{\rho}-1}{\sigma_{\hat{\rho}}}$ (Phillips/ Perron)	K (Dickey/ Fuller)	K (Phillips/ Perron)	Sims' prior ω	K _T Kahn/ Ogaki	Φ_4
Tanzania ^o	4	23	0,20	8,62	-0,238	2,61**	<u>-1,94</u>	-7,01**	-28,5**	-31,0**	0,991	-0,411	4,03
Thailand	4	33	0,22	6,17	-0,439	1,99**	<u>-5,20**</u>	-6,04**	-47,5**	-36,5**	0,974	2,457	0,91
Togo ^o	4	23	0,01	3,36	0,161	1,92**	<u>-2,37</u>	-4,98**	-19,3**	-29,5**	0,872	-0,009	3,84
Trinidad & T. ^o	0	37	0,25	4,83	0,643	0,74*	<u>-2,61</u>		-13,2*		0,911	1,153	4,55*
Tunesia	0	27	2,94	10,59	0,156	1,65**	<u>-4,13**</u>		-22,8**		1	-0,793	5,52*
Turkey	6	31	0,07	3,45	-0,041	2,15**	<u>-3,21*</u>	-6,53**	-32,3**	-32,1**	0,76	-8,772	1,41
U.K.	0	37	4,81	11,26	0,121	1,74**	<u>-5,18**</u>		-32,5**		1	1,053	0,03
U.S.A.	0	37	0,21	6,78	0,058	1,9**	<u>-5,63**</u>		-34,9**		1	-0,828	0,07
Uganda	0	34	0,20	11,24	0,057	1,87**	<u>-5,30**</u>		-32,1**		1	0,517	0,58
Uruguay ^o	6	31	0,91	10,67	-0,486	2,02**	<u>-2,79</u>	-6,23**	-46,1**	-28,4**	0,934	-9,27	0,11
Venezuela	0	36	1,92	6,83	0,205	1,59**	<u>-4,73**</u>		-28,6**		1	-1,073	4,01
Yugoslavia	0	26	0,00	11,59	0,111	1,73**	<u>-4,25**</u>		-23,1**		1	-0,313	7,25*
Zaire	0	37	0,90	8,62	0,109	1,85**	<u>-5,52**</u>		-33,0**		1	-3,556	1,31
Zambia ^o	4	28	0,02	4,41	0,344	2,16**	<u>-1,68</u>	-6,11**	-18,4**	-34,0**	0,915	-0,845	1,04
Zimbabwe	0	33	2,07	12,35	-0,128	2,27**	<u>-6,37**</u>		-37,2**		1	-0,585	0,28

(a) One asterisk " * " indicates a 5% significance level for the rejection of the H_0 based on Dickey/Fuller (1981). Two asterisks " ** " indicate a 1% significance level for the rejection of the H_0 . Underlined numbers indicate a 5% significance level based on the standard student distribution. (b) One curl " ° " indicates that at least one test cannot reject the H_0 of non-stationarity. (c) 5% significance level for the rejection of the H_0 of misspecification: 0 lag: $F(1,39)=4,12$; 1 lag: $F(2,38)=3,25$; 4lags: $F(4,35)=2,65$; 6 lags: $F(6,33)=2,39$. (d) significance level for the rejection of the H_0 of autocorrelated errors: $\chi^2=12,6$.

Table A3 - Equilibrium solution and compound growth rate for the 16 countries of Maddison (1991)

Country (a)	$\frac{\mu}{\sigma_{\mu}}$	$\hat{y} = \frac{\mu}{1-\rho}$	\hat{y}	$\frac{\tilde{y} - \hat{y}}{\sigma_{\tilde{y}} T^{0.5}}$	$\frac{\Delta \hat{y}_j}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta \tilde{y}_j}{\sigma_{\Delta} T^{0.5}}$
Australia°	1,525	0,023	0,022	-0,113	-2,86	-3,82
Austria°	1,61	0,03	0,04	0,379	0,41	3,77
Belgium	<u>3,049*</u>	0,028	0,029	0,063	-0,53	-0,87
Canada°	<u>2,591*</u>	0,029	0,028	-0,038	-0,06	-1,29
Denmark	<u>4,033**</u>	0,026	0,025	-0,018	-1,46	-2,56
Finland	<u>2,482</u>	0,035	0,035	0,029	2,75	1,66
France	<u>3,423*</u>	0,03	0,032	0,092	0,41	0,40
Germany°	1,908	0,024	0,039	0,506	-2,40	3,35
Italy	<u>3,511**</u>	0,038	0,04	0,06	4,15	3,77
Japan°	2,42	0,056	0,058	0,069	12,56	11,35
Netherlands	<u>3,655**</u>	0,026	0,025	-0,011	-1,46	-2,56
Norway	<u>5,29**</u>	0,033	0,033	0,016	1,81	0,82
Sweden	<u>3,57**</u>	0,026	0,027	0,039	-1,46	-1,71
Switzerland	<u>3,195*</u>	0,022	0,022	0,016	-3,33	-3,82
UK	<u>4,941**</u>	0,022	0,022	0,025	-3,33	-3,82
USA	<u>3,243*</u>	0,018	0,02	0,103	-5,20	-4,66

(a) One curl "°" indicates that at least one test cannot reject the H₀ of non-stationarity.

Table A4 - Equilibrium solution of equation (4) and compound growth rate for 115 countries of the Penn World Table, 1950-1988

Country (a)	$\frac{\mu}{\sigma_{\mu}}$	$\bar{y} = \frac{\mu}{1-\rho}$	\hat{y}	$\frac{\hat{y}-\bar{y}}{\sigma_{\hat{y}} T^{0.5}}$	$\frac{\Delta\hat{y}_j}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta\hat{y}_j}{\sigma_{\Delta} T^{0.5}}$	Country	$\frac{\mu}{\sigma_{\mu}}$	$\bar{y} = \frac{\mu}{1-\rho}$	\hat{y}	$\frac{\hat{y}-\bar{y}}{\sigma_{\hat{y}} T^{0.5}}$	$\frac{\Delta\hat{y}_j}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta\hat{y}_j}{\sigma_{\Delta} T^{0.5}}$
Gabon°	1,147	0,073	0,069	-0,028			Gambia°	2,109	0,034	0,033	-0,014		
Botswana	3,046*	0,069	0,068	-0,012			Indonesia	2,545	0,039	0,033	-0,126		
Lesotho	2,953*	0,059	0,057	-0,033			France°	2,34	0,03	0,032	0,093	3,27	3,76
Taiwan	3,379**	0,054	0,057	0,099	13,12	14,19	Jordan°	0,141	0,006	0,032	0,266		
Japan	3,098*	0,053	0,056	0,109	12,71	13,77	Malaysia	2,727*	0,033	0,031	-0,039		
Hong Kong	3,688**	0,046	0,051	0,128			Thailand	5,101**	0,039	0,031	-0,183		
South Korea°	1,525	0,053	0,049	-0,099			Panama	3,692**	0,033	0,03	-0,071		
Greece°	2,251	0,043	0,043	-0,01	8,61	8,35	Burma	3,344**	0,028	0,029	0,019		
Italy°	2,011	0,039	0,042	0,111			Norway	2,936*	0,028	0,029	0,067		
Austria°	0,714	0,024	0,041	0,607			Iran	0,982	0,029	0,027	-0,022		
Cyprus	2,151*	0,041	0,041	-0,002	7,79	7,51	Netherlands°	0,151	0,004	0,027	0,738		
Malta	2,899*	0,044	0,041	-0,067			Philippines	2,088	0,024	0,027	0,068	0,81	1,67
Portugal	3,343	0,038	0,04	0,053			Belgium	3,435**	0,026	0,026	-0,002	1,63	1,25
Turkey	2,57	0,032	0,039	0,12			Pakistan°	1,701	0,03	0,026	-0,111		
Brazil	2,598*	0,04	0,038	-0,025	7,38	6,26	Tanzania°	1,441	0,024	0,026	0,036		
Cameroon°	1,166	0,044	0,038	-0,115			Ecuador	1,96	0,025	0,025	-0,001	1,22	0,83
Spain°	0,642	0,027	0,038	0,256			Ireland	2,055	0,023	0,025	0,049	0,40	0,83
Yugoslavia	2,698*	0,037	0,037	0,005			Iceland	2,236	0,023	0,024	0,033		
China	3,125*	0,048	0,036	-0,123			Algeria°	-2,195	0,086	0,023	-0,55		
Congo	1,792	0,036	0,036	0,003			Denmark	3,465**	0,024	0,023	-0,053	0,81	0,00
Egypt	2,76*	0,038	0,036	-0,025	6,56	5,43	Dominican R.	2,186	0,021	0,023	0,04	-0,42	0,00
Germany°	1,499	0,024	0,036	0,392			Luxemburg	3,727**	0,026	0,023	-0,068	1,63	0,00
Finland°	2,52*	0,034	0,035	0,046			Togo°	0,49	0,009	0,023	0,242		
Israel	2,179*	0,03	0,035	0,119			Morocco	1,817	0,023	0,022	-0,017	0,40	-0,42
Syria	1,614	0,033	0,034	0,006			Suriname	0,817	0,02	0,022	0,025		

Table A4 (continued) - Equilibrium solution of equation (4) and compound growth rate for 115 countries of the Penn World Table, 1950-1988

Country (a)	$\frac{\mu}{\sigma_{\mu}}$	$\bar{y} = \frac{\mu}{1-\rho}$	\tilde{y}	$\frac{\tilde{y} - \bar{y}}{\sigma_{\tilde{y}} T^{0.5}}$	$\frac{\Delta \tilde{y}_j}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta \tilde{y}_j}{\sigma_{\Delta} T^{0.5}}$	Country	$\frac{\mu}{\sigma_{\mu}}$	$\bar{y} = \frac{\mu}{1-\rho}$	\tilde{y}	$\frac{\tilde{y} - \bar{y}}{\sigma_{\tilde{y}} T^{0.5}}$	$\frac{\Delta \tilde{y}_j}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta \tilde{y}_j}{\sigma_{\Delta} T^{0.5}}$
Tunisia	2,132	0,021	0,022	0,039			Barbados°	0,322	0,008	0,014	0,103		
U.K.	3,856**	0,022	0,022	0,005	-0,01	-0,42	Honduras	2,024	0,016	0,014	-0,063		
Colombia°	1,579	0,019	0,021	0,1			Kenya	0,995	0,01	0,014	0,056	-4,94	-3,76
Ivory Coast°	-0,529	0,252	0,021	-4,437			Peru	0,124	0,003	0,014	0,213		
Sweden°	1,316	0,02	0,021	0,089			Sri Lanka	2,352	0,013	0,014	0,021	-3,71	-3,76
Switzerland	2,537*	0,02	0,021	0,039	-0,83	-0,83	Zaire	0,856	0,01	0,014	0,052	-4,94	-3,76
Trinidad & T.°	0,316	0,01	0,021	0,125	-4,94	-0,83	Bangladesh	0,852	0,012	0,013	0,017		
Costa Rica°	0,039	0,001	0,02	0,451			Argentina°	0,722	0,009	0,011	0,045		
Iraq	2,809	0,034	0,02	-0,092			Burundi°	2,268	0,031	0,011	-0,254		
Malawi	2,087	0,018	0,02	0,029			Ruanda°	1,607	0,019	0,011	-0,085		
Mexico°	0,368	0,01	0,019	0,233			Sierra Leone°	-0,9	-0,079	0,011	1,505		
Papua Guinea°	-0,181	-0,006	0,019	0,474			Mauritius°	0,807	0,013	0,01	-0,056	-3,71	-5,43
Australia°	1,331	0,017	0,018	0,029			New Zealand	1,631	0,012	0,01	-0,053	-4,12	-5,43
Jamaica°	0,04	0,001	0,018	0,275			Uruguay	0,713	0,005	0,01	0,085		
Paraguay	1,948	0,019	0,018	-0,031	-1,24	-2,09	Nicaragua	0,347	0,006	0,009	0,022		
South Africa°	2,059	0,017	0,018	0,023	-2,07	-2,09	Benin°	0,48	0,004	0,008	0,071		
Venezuela	1,146	0,015	0,018	0,042	-2,89	-2,09	Chile	0,69	0,01	0,008	-0,026		
Canada	2,927*	0,016	0,016	0,026			El Salvador	0,497	0,007	0,008	0,027	-6,17	-6,26
Cap Verde°	0,85	0,019	0,016	-0,033			Nigeria	0,251	0,005	0,007	0,026	-6,99	-6,68
Ethiopia°	1,619	0,013	0,016	0,131			Fiji°	0,127	0,003	0,006	0,055		
India	3,121*	0,016	0,016	0,021	-2,48	-2,92	Niger	0,133	0,001	0,006	0,069		
Nepal	1,959	0,016	0,016	0,002			Uganda	0,208	0,004	0,006	0,02		
U.S.A.	2,934*	0,016	0,016	0,029	-2,48	-2,92	Afghanistan°	0,695	0,005	0,005	-0,013		
Guatemala°	1,805	0,019	0,015	-0,156			Bolivia°	0,099	0,003	0,005	0,047		
Zimbabwe	1,446	0,014	0,015	0,017			Mauretania°	-0,347	-0,006	0,004	0,129		

Table A4 (continued) - Equilibrium solution of equation (4) and compound growth rate for 115 countries of the Penn World Table, 1950-1988

Country (a)	$\frac{\mu}{\sigma_{\mu}}$	$\bar{y} = \frac{\mu}{1-\rho}$	\tilde{y}	$\frac{\bar{y} - \tilde{y}}{\sigma_{\tilde{y}} T^{0.5}}$	$\frac{\Delta \tilde{y}_t}{\sigma_{\Delta} T^{0.5}}$	$\frac{\Delta \tilde{y}_t}{\sigma_{\Delta} T^{0.5}}$
Sudan	0,178	0,002	0,004	0,031		
Central Afr.	0,182	0,001	0,002	0,03		
Haiti	0,477	0,004	0,002	-0,046		
Ghana	-0,294	-0,002	0,001	0,054		
Liberia°	-0,47	-0,011	0,001	0,177		
Somalia°	0,032	0,001	0,001	0,006		
Mali°	0,648	0,009	-0,001	-0,184		
Senegal	-0,304	-0,002	-0,001	0,024		
Guyana°	-0,693	-0,013	-0,011	0,02	-14,38	-14,19
Zambia°	-0,629	-0,014	-0,011	0,034		
Madagascar	-1,532	-0,012	-0,012	0,013		
Angola°	-0,438	-0,014	-0,013	0,005		
Chad	-0,971	-0,015	-0,013	0,031		
Mozambique°	-0,532	-0,014	-0,015	-0,015		
Kuwait	-2,807	-0,078	-0,075	0,023		

(a) One curl " ° " indicates that at least one test cannot reject the H_0 of non-stationarity.

Figure A1 - Probability density functions for $\hat{\rho}$ under $\rho = 0.9$ and posterior probability density for ρ under $\hat{\rho} = 0.95$

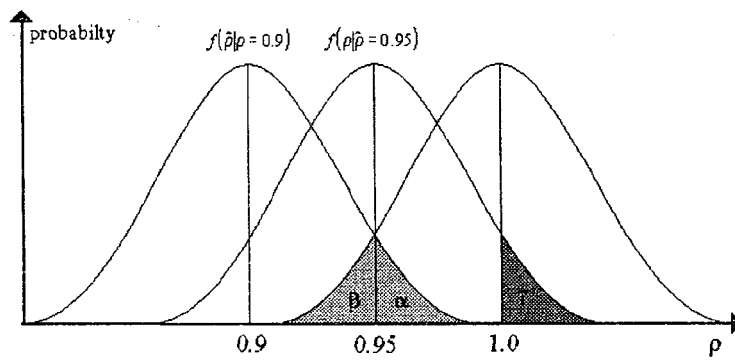
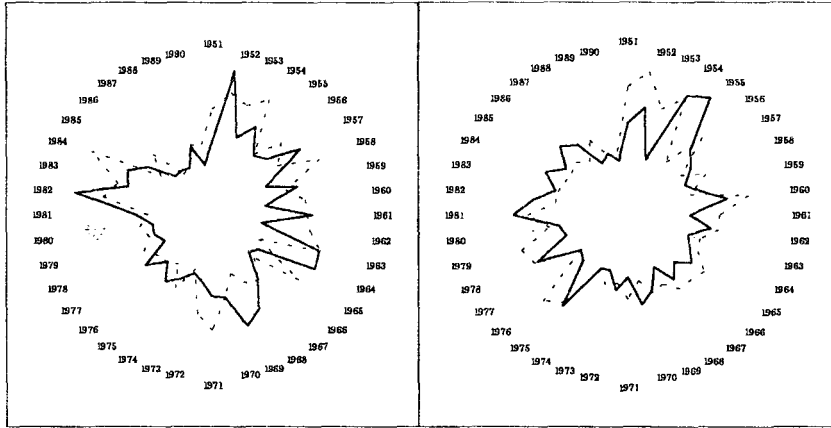
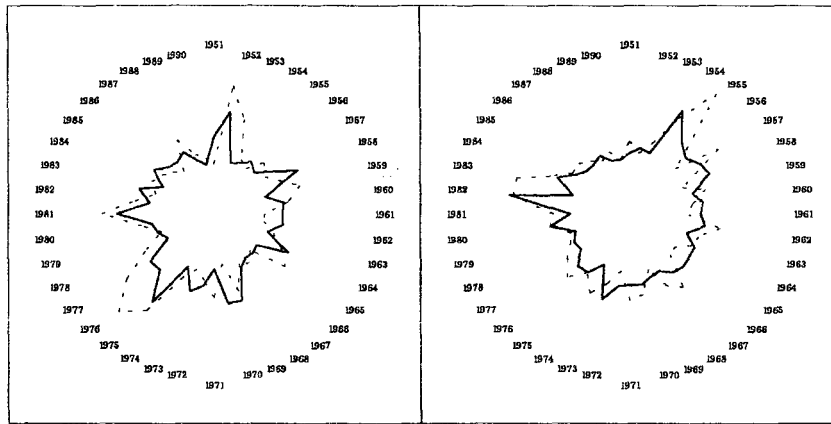


Figure A2 - Prediction error spots of sample mean and one year lag for the real per capita growth rate of the Maddison sample countries 1951-1990 (a)



Australia

Austria

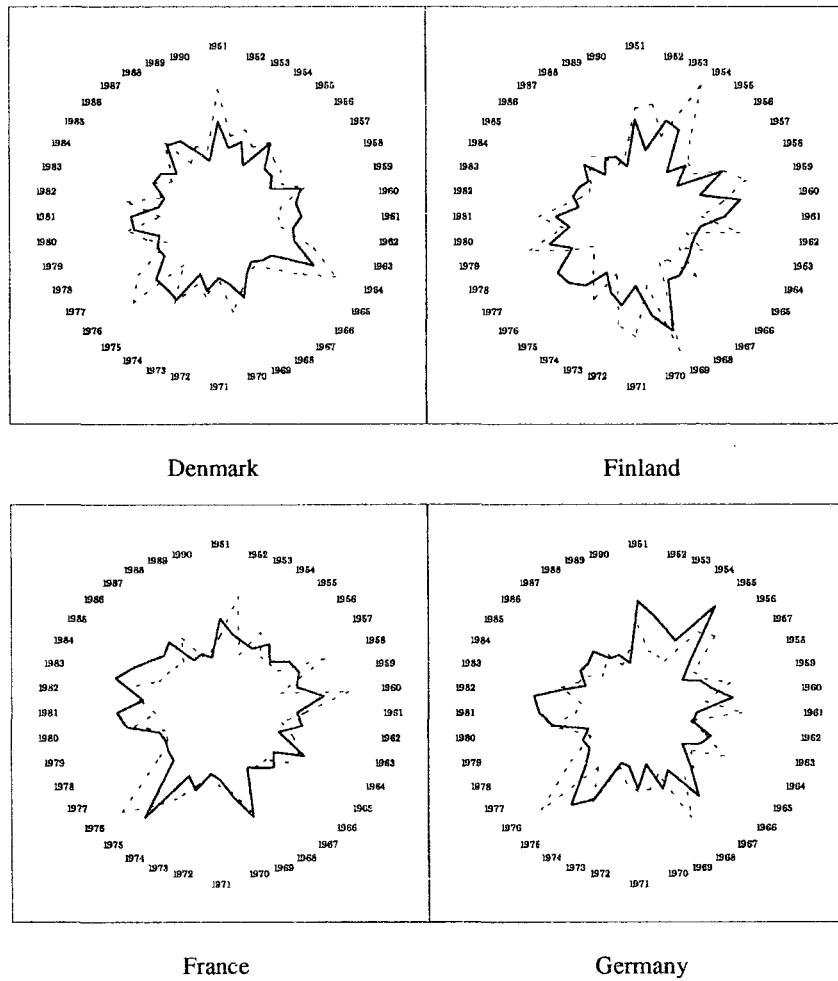


Belgium

Canada

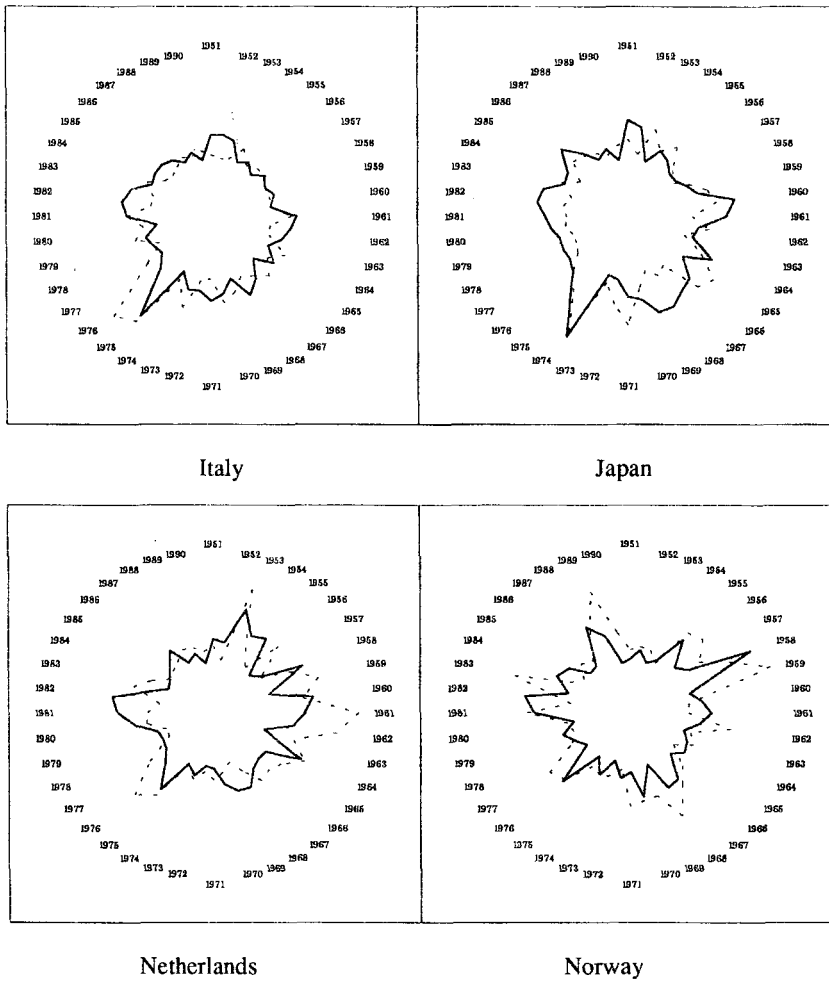
(a) The dotted line gives the deviation of the of this year's growth rate from last year's growth rate. The bold line gives the deviation of the growth rates from the sample mean. The distance of the lines from the center of the circle equalize the deviations plus one.

Figure A2 (continued) - Prediction error spots of sample mean and one year lag for the real per capita growth rate of the Maddison sample countries 1951-1990 (a)



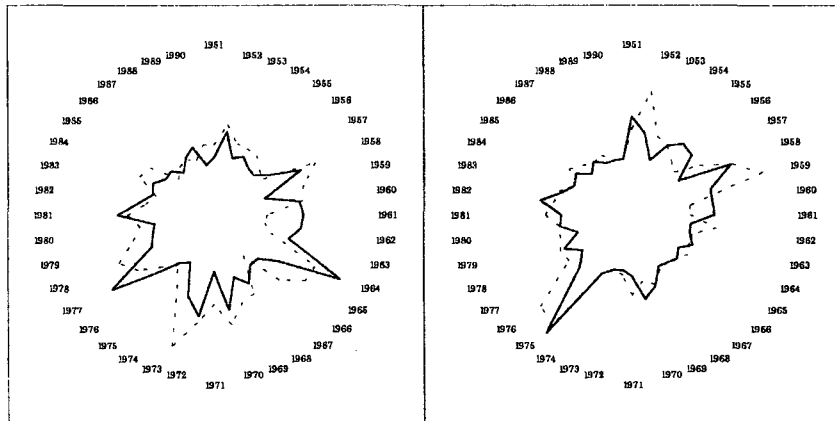
(a) The dotted line gives the deviation of the of this year's growth rate from last year's growth rate. The bold line gives the deviation of the growth rates from the sample mean. The distance of the lines from the center of the circle equalize the deviations plus one.

Figure A2 (continued) - Prediction error spots of sample mean and one year lag for the real per capita growth rate of the Maddison sample countries 1951-1990 (a)



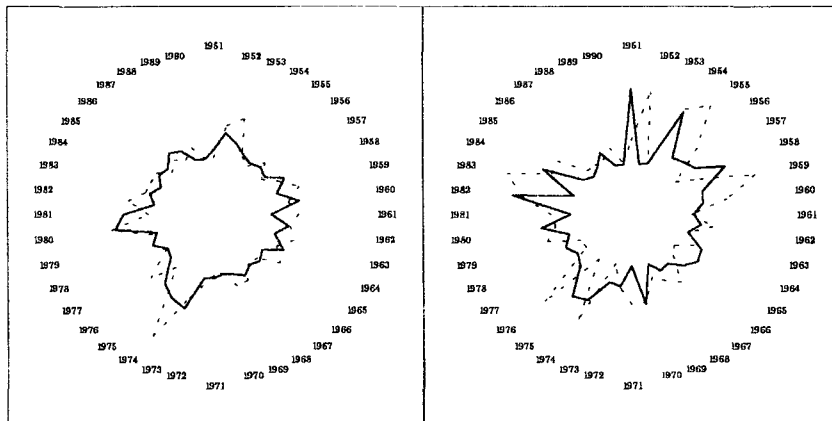
(a) The dotted line gives the deviation of the of this year's growth rate from last year's growth rate. The bold line gives the deviation of the growth rates from the sample mean. The distance of the lines from the center of the circle equalize the deviations plus one.

Figure A2 (continued) - Prediction error spots of sample mean and one year lag for the real per capita growth rate of the Maddison sample countries 1951-1990 (a)



Sweden

Switzerland

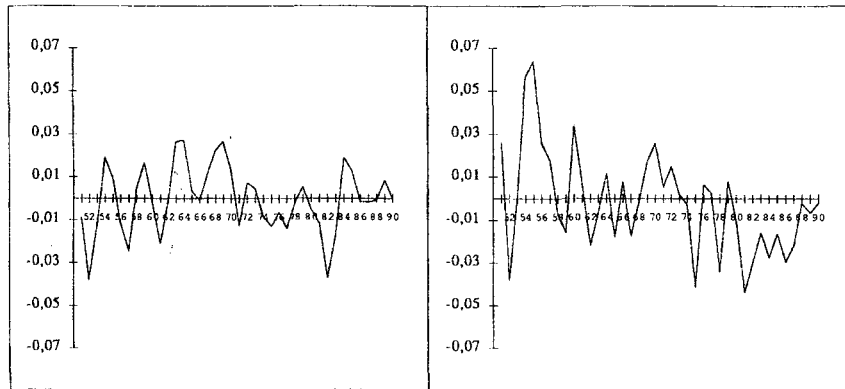


United Kingdom

United States

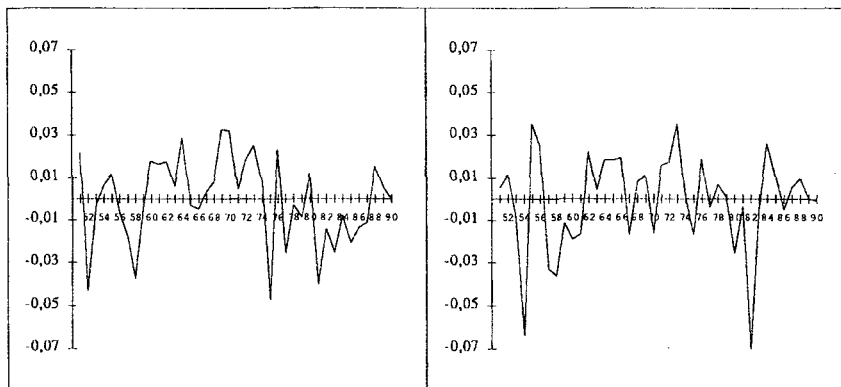
(a) The dotted line gives the deviation of the of this year's growth rate from last year's growth rate. The bold line gives the deviation of the growth rates from the sample mean. The distance of the lines from the center of the circle equalize the deviations plus one.

Figure A3 - Deviation of real per capita growth rates from sample mean for the Maddison sample countries 1951-1990



Australia

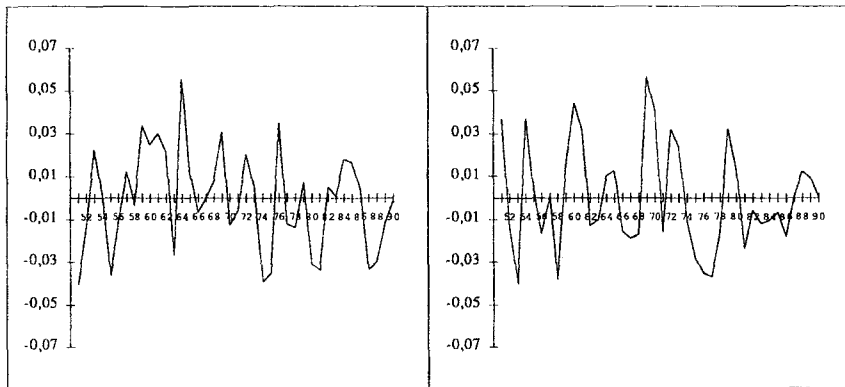
Austria



Belgium

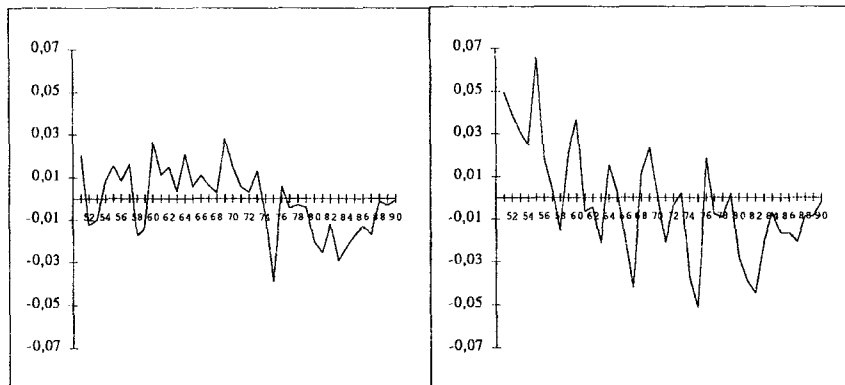
Canada

Figure A3 (continued) - Deviation of real per capita growth rates from sample mean for the Maddison sample countries 1951-1990



Denmark

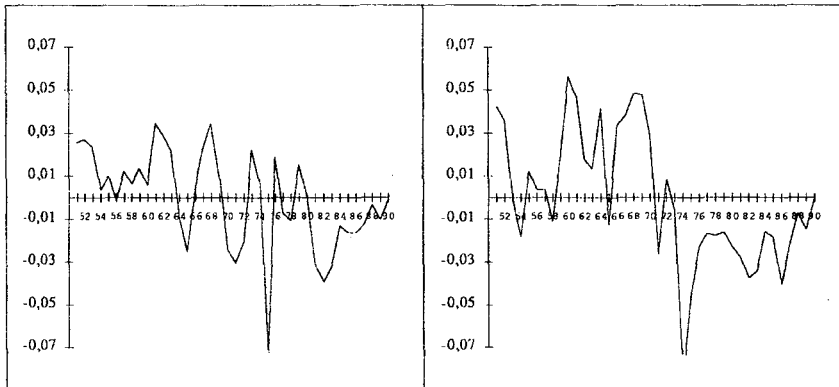
Finland



France

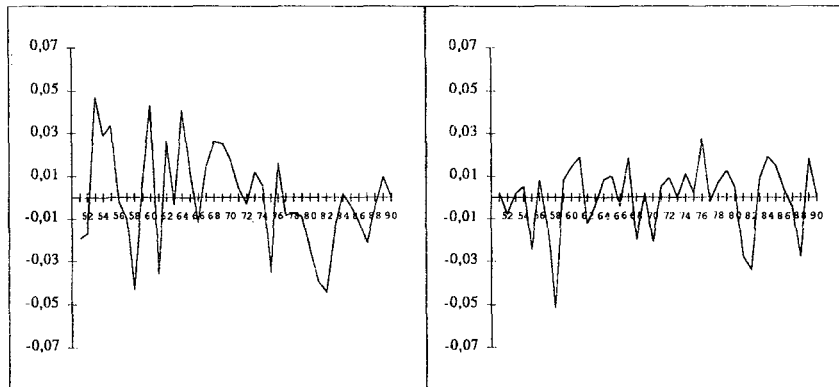
Germany

Figure A3 (continued) - Deviation of real per capita growth rates from sample mean for the Maddison sample countries 1951-1990



Italien

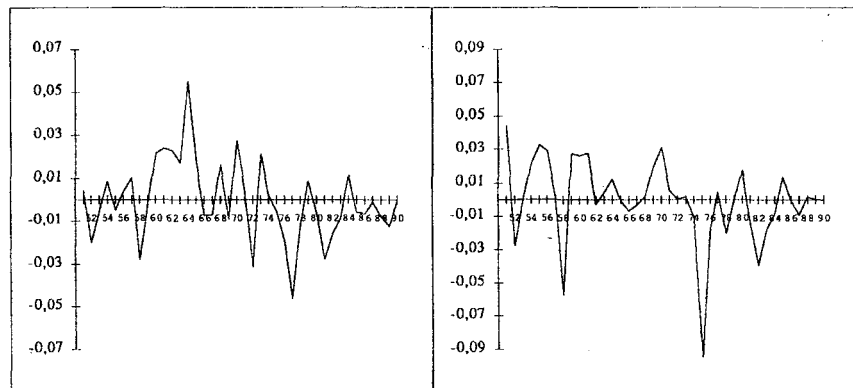
Japan



Netherlands

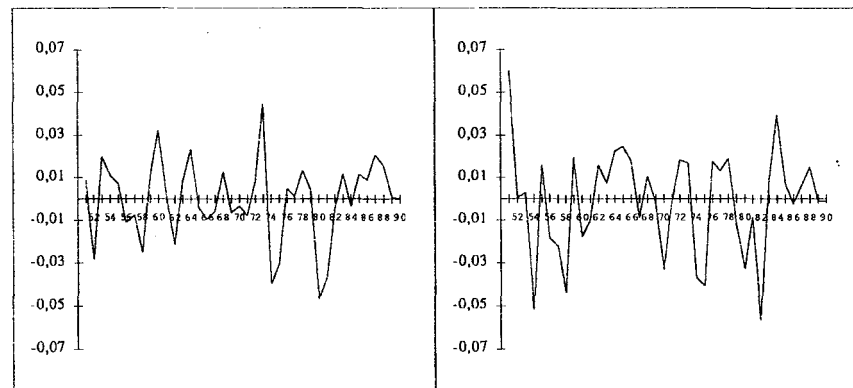
Norway

Figure A3 (continued) - Deviation of real per capita growth rates from sample mean for the Maddison sample countries 1951-1990



Sweden

Switzerland



United Kingdom

United States

Appendix 2 - A simple R&D-model of endogenous growth under different assumptions of saving behaviour.

Consider an economy with two production sectors, one for the productions of the neoclassical universal good (Y), which can be consumed as well as invested for physical capital, and one for the production of new technological knowledge (A), which can be used to intensify the division of labor in the production of the universal good. The sector for the production of new technological knowledge is called the R&D-sector, the sector for the production of the universal good is called the universal good sector. There are three production factors: The first is a non-accumulating factor L, which is called labor and which represents all those production factors that can not and not fully be accumulated by market forces for *technical* (free riders can not be excluded from consumption: light houses, dikes, legal and public security, defence; asymmetrical information: human capital; physical limitations: land, natural resources, human capital) *legal* (state licensed monopolies: infrastructure, telecommunication, education) and *behavioural* (non-economic production factors influence the accumulation: human capital, children, hence quantity and quality of the labor force) reasons.³⁸ The second production factor is an accumulating production factor K, which is called capital and which represents all those production factors which can be perfectly accumulated by market forces (machines, buildings, and up to a certain extend natural resources). However, one accumulating production factor is not represented by K: Technological knowledge (A). Technological knowledge is measured by the number of blueprints. Each blueprint allows to add one additional production step to the production function of the universal good sector. The production function of the universal good sector is described by the following equation:

$$(1) Y = \sum_{i=1}^A y_i = \sum_{i=1}^A L_{y,i}^\alpha K_i^\beta, \quad 0 < \alpha, \beta < 1,$$

where y_i is the output of production step $i=1,2,3,\dots,A$, which adds up to the universal good, Y. As the technologies of all production steps are equal, each production step uses the same amount of L and K, hence equation (1) can be rewritten:

$$(6) Y = \sum_{i=1}^A \left(\frac{L_y}{A} \right)^\alpha \left(\frac{K}{A} \right)^\beta = A^{1-\alpha-\beta} L_y^\alpha K^\beta,$$

where, L_y is the amount of labor, which is used in the production of the universal good. From equation (6) follows immediately that productivity of labor and capital

³⁸ This list is neither complete nor in a rather systematic order. It is just a kind of loose definition.

grows as the number of production steps increases. This reflects the idea that division of labor increases productivity by allowing for learning effects of specialization (Smith (1994)).³⁹ The production function of technological knowledge is given by:

$$(6) \dot{A} = \delta A^\psi L_A, \text{ with } \psi = 1,$$

where δ is a productivity parameter, A is the number of accumulated blueprints, \dot{A} is the number of new blueprints per time unit and L_A is the quantity of labor used for the production of blueprints. L_A and L_Y add up to L , the endowment of the economy with labor. Production function (6) has two implications:

First, it implies that accumulated technological knowledge joins the production function of new technological knowledge with non-diminishing marginal returns ($\psi = 1$). Consequently, it is an accumulating production factor with non-diminishing marginal returns. This is the critical assumption necessary to generate endogenous growth (Romer (1990, p.80). If technological knowledge had decreasing marginal returns ($0 < \psi < 1$), the marginal return of investments in technological knowledge would decrease as the stock of technological knowledge increased and the incentives to invest in the production of technological knowledge would shrink, such that the accumulation of technological knowledge, and hence productivity growth, would come to a standstill.

Second, it production function (6) implies that accumulated technological knowledge can be used nonrival and without payment for the production of technological knowledge. This assumption seems plausible given the nature of technological knowledge and provides some comfort in solving the model. However, it is neither necessary nor sufficient to generate endogenous growth.

To solve the model, first the allocation of labour between the universal good sector and the R&D sector has to be determined. This is done by equating the wage rates of both sectors, as a market equilibrium implies the absence of arbitrage possibilities. The wage rate of the universal good sector is given by:

$$(6) w_Y = \alpha A^{1-\alpha-\beta} L^{\alpha-1} K^\beta = \alpha Y L_Y^{-1}$$

The wage rate of the R&D sector is given by:

³⁹ "The greatest improvement in the productive powers of labour and the greater part of the skill, dexterity and judgement, with which it is anywhere directed, or applied seems to have been the effects of the division of labour" (Smith (1994), p.3). The production function given in equation (2) is a simplification of a production function used by Romer/Rivera-Batiz (1991 a,b).

$$(6) \quad w_A = \delta A \frac{P_A}{r}$$

As infinite termed patents are legally guaranteed for each new blueprint, the value of a blueprint equals the present value of its period leasing charge, p_A . As there is free entry to the market for technological knowledge, there is no leeway for monopoly profits and p_A equals the marginal productivity of a blueprint in the production of the universal good:

$$(6) \quad p_A = (1 - \alpha - \beta) A^{1-\alpha-\beta} L_Y^\alpha K^\beta$$

Inserting (6) in (6) yields

$$(7) \quad w_A = \delta (1 - \alpha - \beta) Y r^{-1}$$

Hence, equalization of wage rates implies:

$$(8) \quad w_Y = w_A \Leftrightarrow L_Y = \Lambda r, \quad \text{where } \Lambda = \alpha / \delta (1 - \alpha - \beta)$$

Inserting (8) into (6) yields:

$$(9) \quad \frac{\dot{A}}{A} = \delta (L - \Lambda r)$$

This implies, the higher the interest rate, r , the lower the present value of a blueprint, p_A/r , the lower the productivity of labor in the R&D sector, the lower the growth rate of technological knowledge \dot{A}/A . To determine the equilibrium interest rate, capital demand K^D and capital supply K^S have to be balanced. To determine capital demand, note that a profit maximum implies that marginal productivity of capital equals the interest rate. hence, from equation (6) follows:

$$\frac{\delta Y}{\delta K} = \beta A^{1-\alpha-\beta} L_Y^\alpha K^{\beta-1} = r \Leftrightarrow$$

$$(10) \quad K^D = r^{1/(\beta-1)} (\beta A^{1-\alpha-\beta} L_Y^\alpha)^{1/(1-\beta)}$$

For the sake of simplicity assume that the capital stock is completely consumed within one production period, such that K equals the demand for new capital K^D . As capital supply, K^S depends on saving behaviour, the model can be solved under different assumptions of saving behaviour.

1. Intertemporal utility maximization

The idea that savings behaviour of economic agents is determined by their efforts to maximize their intertemporal utility, was first formulated by Ramsey (1928). If one assumes that a representative household maximizes an intertemporal utility function of the following type

$$(11) \quad U_0 = \int_{t=0}^{\infty} e^{-\rho t} \frac{c_t^{1-\sigma}}{1-\sigma} dt,$$

where ρ is the rate of time preference, σ^{-1} is the intertemporal marginal rate of substitution of consumption and c_t is consumption per period, subject to a budget constraint of the following type

$$(12) \quad \dot{d} = r d_t + w l + c_t,$$

where $r d_t$ is capital income, $w l$ is labor income and \dot{d} is the change of the net wealth position of the household. The necessary condition for an intertemporal utility maximum imply:

$$(13) \quad \frac{\dot{c}}{c} = \sigma^{-1} (r - \rho)$$

Consequently, the growth rate of consumption, i.e. the amount of consumption postponed into the future, i.e. the level of savings per period is the higher, the higher the return from savings, i.e. the interest rate r . The growth rate of consumption is the lower the higher rate of time preference and the lower the intertemporal rate of substitution of consumption. As the steady state solution implies that the consumption quota and hence the savings quota and hence investment quota stay constant, the growth rate of consumption must equal the growth rate of the universal good sector output. Consequently, the following relation holds in steady state:

$$(14) \quad \frac{\dot{c}}{c} = \frac{\dot{Y}}{Y}$$

From the first derivation of equation (6) with respect to time follows

$$(15) \quad \frac{\dot{Y}}{Y} = (1 - \alpha - \beta) \frac{\dot{A}}{A} + \beta \frac{\dot{K}}{K}$$

To determine \dot{K}/K , take the first derivation with respect to time from the capital demand equation (10):

$$(16) \quad \dot{K} = r^{1/(\beta-1)} \frac{1}{1-\beta} (\beta A^{1-\alpha-\beta} L_T^\alpha)^{\frac{1}{1-\beta}} \beta L_T^\alpha (1-\alpha-\beta) A^{-\alpha-\beta} \dot{A}$$

Dividing (16) by (10) yields:

$$(17) \quad \frac{\dot{K}}{K} = \left(\frac{1-\alpha-\beta}{1-\beta} \right) \frac{\dot{A}}{A}$$

Inserting (17) into (15) yields:

$$(18) \quad \frac{\dot{Y}}{Y} = \Omega \frac{\dot{A}}{A}, \text{ where } \Omega = \left(\frac{1-\alpha-\beta}{1-\beta} \right)$$

Inserting (18) into (14) and (13), solving for the interest rate and inserting this into (9) yields the steady state growth rate dependent on the structural parameters of the economy and the exogenous endowment with the non-accumulating production factors L:

$$(19) \quad \frac{\dot{Y}}{Y} = \frac{L - \Lambda \rho}{\Lambda \sigma + \Omega^{-1} \delta^{-1}}$$

As equation (14) was used to derive the steady state solution, it has to be shown, that (14) holds in steady state. The universal good is used for consumption as well as for investment. Hence, the following relation holds:

$$(20) \quad C = Y - K \Leftrightarrow \frac{C}{Y} = 1 - \frac{K}{Y}$$

As equation (17) and (18) show, K/Y is constant in steady state, consequently C/Y is constant too.

2. Constant savings quota

Although theoretically less appealing, empirically savings behaviour is much better described by a constant savings quota as by intertemporal utility maximization.⁴⁰ Under the assumption of a constant savings quota, s , capital supply per period equals:

$$(21) \quad K^s = s Y$$

As follows from equation (10), capital demand can be written in the following way:

$$(22) \quad K^D = \beta Y r^{-1}$$

Hence, in market equilibrium the real interest rate equals:

$$(23) \quad r = \frac{\beta}{s}$$

Consequently, the interest rate is the higher, the higher capital productivity, as measured by the production elasticity, β , and the lower the savings quota, s . Given equation (23), the growth rate of technological knowledge - as follows from equation (9) - equals:

$$(24) \quad \frac{\dot{A}}{A} = \delta \left(L - \Lambda \frac{\beta}{s} \right)$$

Therefore, as follows from equation (18), the steady state growth rate of the universal goods sector equals now:

$$(25) \quad \frac{\dot{Y}}{Y} = \Omega \delta \left(L - \Lambda \frac{\beta}{s} \right) = \frac{1 - \alpha - \beta}{1 - \beta} \delta L - \frac{\beta}{1 - \beta} s^{-1}$$

⁴⁰ See the empirical literature listed in section 2. The neoclassical idea that people maximize their intertemporal utility by equalizing marginal levels of utility across time was born under historical circumstances, where per capita income in the leading industrialized countries reached enormous levels compared to earlier periods of human history. Hence, for a growing part of the population consumption was no longer a question of survival but of pleasure. However, during the longest part of human history per capita income was enormously low and consumption was primarily a question of survival. Hence, during the longest part of history human beings might have not been engaged in maximising their utility but their probability of survival. Given that human behaviour was shaped under these circumstances, the hypothesis that humans have inherited a pattern of behaviour that leads them to save always a certain fraction of their income in order to reduce future income risk may be a much better explanation for real savings behaviour than the hypothesis of intertemporal utility maximization.

Hence, steady state growth is the higher, the higher the endowment of the economy with non-accumulating production factors, L , the higher the savings quota, and the lower capital productivity in the universal goods sector as measured by production elasticity β . The latter effect stems from the fact that a higher β increases i.a. productivity of labor in the universal good sector and consequently leads to a reallocation of labor out of the R&D sector into the universal good sector.

3. Concave savings function

Although a constant marginal savings quota fits much better the data than the assumption of intertemporal utility maximization, it is not in accordance with the fact that empirical savings quotas grow with the level of per capita income (see the declining consumption quota in figure 4). Of course, this can be explained by out of steady state behaviour. However, a growing savings quota is also displayed by many countries that show a stationary per capita income growth rate. Yet, a stationary per capita income growth rate is a typical steady state property. As an attempt to model a steady state with a growing savings quota assume the following relation between per capita income and savings quota:

$$(26) \quad s = \theta - \frac{\Psi}{Y}, \quad \text{with } 0 < \theta < 1 \text{ and } \frac{\Psi}{\theta} < Y$$

Hence, the savings quota grows with per capita income, but converges asymptotically to θ . Following (26) capital supply equals:

$$(27) \quad K' = \theta Y - \Psi$$

Now the steady state interest rate equals:

$$(28) \quad r = \frac{\beta}{\theta - \Psi/Y}$$

Substituting equation (28) in equations (9) and (18) yields:

$$(29) \quad \frac{\dot{Y}}{Y} = \Omega \delta \left(L - \Lambda \frac{\beta}{\theta - \Psi/Y} \right)$$

Consequently, under the assumption of equation (26) the steady state growth rate converges asymptotically to the steady state growth rate with a constant savings quota (equation (25)). Hence, the price one has to pay within this model for a growing steady state savings quota is a declining steady state per capita growth rate.

References

- ABE, S.; M.J. FRY; B. KYUN MIN; P. VONGVIPANOND; TEH-PEI YU, 1977, Financial Liberalisation and Domestic Saving in Economic Development: an Empirical Test for Six Countries, *Pakistan Development Review*, Vol. 16. 298-308.
- BARRO, Robert, 1991, Economic Growth in a Cross Section of Countries, *The Quarterly Journal of Economics*, Vol. 106, p. 407-443.
- BARRO, Robert; Xavier SALA-I-MARTIN (1991), Convergence across states and regions, *Brookings Papers on Economic Activity* 1, 107-182, April.
- CAMPBELL, John; MANKIW Gregory, 1989, Consumption, Income, and Interest Rates: Reinterpreting the Time Series Evidence, NBER Working Paper No. 2924.
- CARROL, Christopher D.; SUMMERS, Lawrence; 1991, Consumption Growth parallels Income Growth: Some new Evidence, in *National Saving and Economic Performance*, edited by B. Douglas BERNHEIM; John B. SHOVEN.
- CHENERY, Hollis B.; SYRQUIN, Moshe, 1989, Patterns of Development, 1950 to 1983, *World Bank Discussion Papers* No. 41.
- CHRISTIANO, Lawrence J., EICHENBAUM, Martin, 1990, Unit Roots in Real GNP: Do We Know, and Do We Care?, *Carnegie-Rochester Conference Series on Public Policy* 32, p. 7-62.
- DICKEY, David A., FULLER Wayne A., 1981, Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root., *Econometrica*, Vol. 49, No. 4.
- EASTERLY, William, Michael KREMER, Lant PRITCHETT, Lawrence H. SUMMERS, 1993, Good Policy or Good Luck? Country Growth Performance and Temporary Shocks, NBER Working Paper No. 4474.
- FAMA, Eugen, 1984, Term Premiums in Bond Returns, *Journal of Financial Economics* 13, p. 529-546.
- FELDSTEIN, Martin, 1970, Inflation, Specification Bias and the Impact of Interest Rates, *Journal of Political Economy*, Vol. 78, 1325-1339.
- FELDSTEIN, Martin, Charles HORIOKA, 1980, Domestic Saving and International Capital Flows, *Economic Journal*, Vol. 90, p. 314-329.
-

FRY, M.J., 1980, Saving, Investment, Growth and the Cost of Financial Repression, *World Development*, Vol. 8, p. 317-327.

FRY, M.J., 1978, Money and Capital or Financial Deepening in Economic Development?, *Journal of Money, Credit and Banking*, Vol. 10, 464-475.

FULLER, W.A., 1976, *Introduction to Statistical Time Series*, New York, John Wiley and Sons.

GIOVANNINI, A., 1983, The Interest Elasticity of Savings in Developing Countries: the Existing Evidence, *World Development*, Vol. 11, 464-475.

GIOVANNINI, A., 1985, Saving and the Real Rate of Interest in LDCs, *Journal of Development Economics*, Vol. 18, 197-217.

GROSSMAN, Gene M., Elhanan HELPMAN, 1991, *Innovation and Growth in the Global Economy*, The MIT Press, Cambridge Massachusetts.

GUNDLACH, Erich, 1994, The Role of Human Capital in Economic Growth: New Results and Alternative Interpretations, Kiel Working Paper No. 659.

HANDA, J., B.K., MA, 1989, Four Tests for the Random Walk Hypothesis: Power versus Robustness, *Economics Letters*, 29, 141-5.

HEITGER, Bernard, 1987, Corporatism, Technological Gaps and growth in OECD Countries, *Weltwirtschaftliches Archiv*, Vol. 123, Tübingen, S. 463-473.

KAHN, James A., MASAO, Ogaki, 1990, A Chi-Square Test for a Unit Root, *Economics Letters*, Vol. 34, p. 37-42, North-Holland.

KAHN, James A., MASAO, Ogaki, 1992, A Consistent Test for the Null of Stationarity against the Alternative of a Unit Root, *Economics Letters*, Vol. 39, p. 7-11, North-Holland.

KRUGMAN, Paul, 1981, Trade, accumulation and uneven development, *Journal of Development Economics* Vol 8, p. 149-161.

LEVINE, Ross, David Renelt, 1992, A sensitivity analysis of cross-country growth regressions, *American Economic Review*, Vol. 82, 942-963.

LUCAS, Robert, 1988, On the mechanics of economic development, *Journal of Monetary Economics*, Vol. 22, 4-42.

MADDALA, G.S., 1988, Introduction to Econometrics, New York, Maxwell Macmillan Canada.

MADDISON, Angus, 1991, Dynamic Forces in Capitalist Development, A long-run Comparative View, Oxford, New York, Oxford University Press.

McKINNON, R.I., 1973, Money and Capital in Economic Development, Brookings Institution.

MILLER, Kenneth S., 1964, Multivariate Distributions, Robert E. Krieger Publishing Company, Huntington, New York.

MULLIGAN, Casey B., Xavier, SALA-I-MARTIN, 1992, Transitional dynamics in two-sector models of endogenous growth, NBER Working Paper No. 3986

PHILLIPS, P.; PERRON P., 1988, Testing for a Unit Root in Time Series Regression, Biometrika, Vol 75, p. 335-46.

POPPER, Karl R., 1989, Logik der Forschung, neunte verbesserte Auflage, Tübingen (1st edition 1934).

PRATT, John, 1965, Bayesian Interpretation of Classical Inference Statements, Journal of the Royal Statistical Society, Series B., p. 169-192.

QUAH, Danny, 1994, Convergence Empirics across Economies with (Some) Capital Mobility, Suntory-Toyota International Centre for Economics and Related Disciplines, London School of Economics, Discussion Paper No. EM/94/275.

RAMSEY, F.P., 1928, A mathematical theory of saving, Economic Journal, 38, p. 543-559.

REBELO, S., 1990, Long Run Policy Analysis and Long Run Growth, NBER Working Paper, April.

RIVERA-BATIZ, L., Paul Romer, 1991a, International trade with endogenous technological change, European Economic Review 35.

RIVERA-BATIZ, L., Paul Romer, 1991b, Economic integration and endogenous growth, Quarterly Journal of Economics, Vol. 106, 531-550.

ROMER, Paul, 1986, Increasing returns and long-run growth, Journal of Political Economy, Vol. 94, 1002-1037.

ROMER, Paul, 1990, Endogenous technological change, *Journal of Political Economy*, Vol. 98, No.5, 71-102.

SAID, S.E.; DICKEY, D.A., 1984, Testing for Unit Roots in Autoregressive-Moving Average Models of Unknown Order, *Biometrika*, Vol. 71, p. 599-607.

SARGAN, J.D.; BHARGAVA, Alok, 1983, Testing Residuals from Least Squares Regression for being Generated by the Gaussian Random Walk, *Econometrica*, Vol. 51, No. 1.

SCHATZ, Klaus-Werner, 1974, Wachstum und Strukturwandel der westdeutschen Wirtschaft im internationalen Verbund, *Analyse und Prognosen*, Kieler Studie Nr. 128, J.B.C. Mohr, Tübingen.

SCHWERT, William G., 1989, Test for Unit Roots: A Monte Carlo Investigation, *Journal of Business and Economic Statistics*, Vol. 7, No. 2, p. 147-159.

Shaw, E.S.; 1973, *Financial Deepening in Economic Development*, Oxford University Press.

SIMS, Christopher A., 1988, Bayesian Skepticism on Unit Root Econometrics, *Journal of Economic Dynamics and Control*, Vol. 12, p. 463-474.

SIMS, Christopher A., Harald UHLIG; 1991, Understanding Unit Rooters: A Helicopter Tour, *Econometrica*, Vol. 59, No. 6, p. 1591-1599.

SMITH, Adam, 1994, *An inquiry into the nature and causes of the wealth of nations*, Modern Library, New York (first edition: 1776).

SUMMERS, Robert, HESTON, Alan, (1991) The PENN World Table (Mark 5): An expanded set of international comparisons, 1950-1988; *The Quarterly Journal of Economics*, May, p.326-368.