Are Poor Countries above their Steady-State Income Levels? – A Time-Series Analysis

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Abstract

This paper criticizes Cho and Graham's argument that poor countries converge from above their steady-state income levels, based on their misspecification of formulating the steady-state income by omitting the variation in the base period technology across countries when estimating steady-state income. This paper also questions the cross-country regression methodology, which generally ignores the changes in variables over time. A time-series approach is employed to analyse the long-run behaviour of actual and steady-state income levels for a group of seven developing countries, which are observed to be above their steady-states in Cho and Graham (1996). An error-correction-based-test is used to examine the existence of cointegration. The results suggest that these countries' actual and steady-state income per capita tend to move together over time, which is consistent with the Solow model's prediction.

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1. Introduction

A good model for economic growth is expected to be helpful in explaining the wide variation in economic experiences observed throughout the world. In 1956, Robert M. Solow developed the neoclassical model of growth, which is now called the "Solow Growth Model". This model suggests that the steady-state income per capita of a country is positively correlated with its saving rate and negatively correlated with its population growth rate, with both factors being exogenously determined. This model also predicts conditional convergence; that is, each economy converges to its own steady-state value of capital and output per worker (usually in efficiency units), with a speed of convergence inversely related to the (absolute) distance from the steady state (e.g., Barro and Sala-i-Martin, 1995, Ch.1).

Mankiw Romer and Weil (hereafter MRW, 1992) provide an empirical cross-sectional study of the augmented Solow growth model using data from most of the countries in the world during the period 1960 to 1985.[1] They show that the neoclassical growth model fits the data on growth in these countries very well.[2]

However, using the same data set as MRW, Cho and Graham (hereafter CG, 1995) estimate the steady-state levels of income per capita for the 98 non-oil countries in 1960 and plot them against those countries' actual income per capita in 1960. They observe that, on average, relatively poor countries converge to their steady-state positions from above, while relatively richer countries converge from below. This surprising finding suggests a contradiction to the neoclassical growth model, which is usually interpreted as implying that the opposite should hold. Now, we need to ask

[1] MRW examine three samples of countries. The first sample consists of 98 'non-oil' countries; the second sample consists of 75 countries, omitting small countries and those countries that receive a better than "D" grade in terms of the quality of primary data in Penn World Table; and the third sample has 22 OECD countries.

[2] The augmented Solow growth model refers to the textbook Solow model extended to incorporate human capital accumulation as a determinant of steady-state income per capita.

ourselves whether this observation by CG is a real challenge to the validity of the neo-classical Solow model and whether their argument is in fact credible.

Owen (2004) argues that this surprising result is unreliable because it ignores the variability in the base-period 'level of technology' when formulating the steady-state level of income per capita and is, therefore, not necessarily an argument against the plausibility of the neoclassical growth model. However, the result from CG provides us with the motivation to find out whether their argument that poor countries converge from above their steady-states is a real phenomenon regardless of their misspecification in formulating the steady-state value of income per capita.

Islam (1995) uses a panel data approach to analyse growth regressions, which is an alternative methodology to the cross-country approach, to allow variations in the aggregate production function across countries and sets up a very useful dynamic framework. However, as well as the advantages that a panel-data approach brings, there are also potential problems associated with this methodology. In this paper, we therefore adapt a time-series approach.

Our goal in this paper is to find out whether CG's observation is supported when we use a time-series approach to correct and complete CG's argument, as well as to see whether poor countries actually converge from above their steady-state levels of income per capita. Since we realize that the regression of one non-stationary series on another is likely to yield spurious results, we will perform unit root tests for each time series of interest in this analysis. Then we will determine whether there is a cointegration relation by examining, if so, the error correction representation of the models. The latter will give us an estimate of the gap between the actual and estimated steady-state level of income per capita and hence the solution to the problem that we are targeting. Due to the availability and accessibility of data, we will make use of the data from **seven** developing countries during the period 1960-1995 to form a time-series regression for each particular country.

This paper is organised as follows. Section 2 provides a review of relevant earlier empirical work on the neoclassical growth model. Section 3 contains a critical review of Cho and Graham (1995). Section 4 describes and explains the sources of data and the choice of countries we use to perform the analysis. Section 5 explains the methodology used in this paper and interprets the results. In Section 6, we extend the augmented Solow model to contain health capital accumulation and interpret the results that we obtain. And, finally, in Section 7 we conclude and make suggestions for further work.

2. Literature Review of Earlier Relevant Work

The Solow growth model assumes that the rate of saving, population growth, and technological progress are exogenous. The production process generates returns from two inputs, capital and labour, which are paid their marginal products and both exhibit diminishing returns. One production function that satisfies these requirements is the Cobb-Douglas production function,[3] which is expressed at time t as:

$$(1) \qquad Y_{i,t} = K_{i,t}{}^{\alpha}(A_{i,t}L_{i,t})^{1-\alpha} \qquad 0 < \alpha < 1,$$

where Y is output, A is the level of technology, K is capital and L is labour. Subscript i and t denote country i and time t respectively. L and A are assumed to grow exogenously at rates n and g:

$$(2) \qquad L_{i,t} = L_{i,0}e^{nt},$$

$$(3) \qquad A_{i,t} = A_{i,0}e^{gt}.$$

The model also states that a constant proportion, s, of output is invested. The stock of capital per effective unit of labour is $\hat{k} = K / AL$, and $\hat{y}$ is the level of output per effective unit of labour, $\hat{y} = Y / AL$. The change in k is determined by:

$$(4) \qquad \frac{d\hat{k}_{i,t}}{dt} = s\hat{y}_{i,t} - (n + g + \delta)\hat{k}_{i,t},$$

[3] To use the neoclassical model to explain international variation in growth requires the assumption that different countries use roughly the same production function at a given point in time. This assumption rests on the argument that the production function should not be viewed literally as a description of a specific production process, but as a mapping from quantities of inputs into a quantity of output; i.e., assuming different countries have the same production function is merely to say that if they had the same inputs, they would produce the same output. (Mankiw, 1995)

where $\hat{y}_{i,t} = s\hat{k}_{i,t}^{\alpha}$, and δ is the depreciation rate. Since at steady state $\frac{d\hat{k}_{i,t}}{dt} = 0$, rearranging equation (4) we get:

$$(5) \qquad \hat{k}_i * = [s_i / (n_i + g + \delta)]^{1/(1-\alpha)}.$$

This equation shows that the steady-state capital per effective worker is determined positively by the saving rate and negatively by the population growth rate. Substituting (5) back into the production function and taking logs of both sides of the equation, we end up with an equation to estimate the steady-state income per capita:

$$(6) \qquad \ln\left[\frac{Y_{i,t}}{L_{i,t}}\right] = \ln A_{i,0} + gt + \frac{\alpha}{1-\alpha}\ln(s_i) - \frac{\alpha}{1-\alpha}\ln(n_i + g + \delta).$$

This equation implies that countries with higher saving rates and lower population growth rates would have higher steady-state income per capita, whereas countries with lower saving rates and higher population growth rates would have lower steady-state income per capita.

MRW in 1992 wrote a paper "A Contribution to the Empirics of Economic Growth", in which they argued that the predictions of a modified Solow model are consistent with the evidence from examining recently available data for a large set of countries. They began the discussion by using equation (6), which is what we normally call the 'Textbook Solow model'. MRW assume that g and δ in the model are constant across countries.[4] g reflects primarily the advancement of knowledge and is assumed not to

[4] "We chose this value of $g + \delta$ to match the available data. In U.S. data the capital consumption allowance is about 10 percent of GNP, and the capital-output ratio is about three, which implies that δ is about 0.03; Romer [1989a, p.60] presents a calculation for a broader sample of countries and concludes that δ is about 0.03 or 0.04. In addition, growth in income per capita has averaged 1.7

be country-specific and it is also expected that depreciation rates do not vary greatly across countries. The A_0 term, however, reflects not just technology but resource endowments, climate institutions, and so on, which are expected to differ across countries. As a result of this, equation (6) can be expressed alternatively as:

$$(7) \qquad \ln\left[\frac{Y_{i,t}}{L_{i,t}}\right] = a + \frac{\alpha}{1-\alpha}\ln(s_i) - \frac{\alpha}{1-\alpha}\ln(n_i + g + \delta) + \varepsilon_i,$$

where MRW specify $\ln A_{i,0} = a + \varepsilon_i$, in which a is a constant and ε_i is a country-specific error term. They then estimate equation (7) by OLS for a cross section of countries and find that the coefficient on In(s) is positive and the coefficient on In(n+g+δ) is negative, consistent with the model's prediction. However, capital's share of output α implied by the coefficient in the restricted regression[5] for the non-oil sample is 0.59 (with a standard error of 0.02) and the data strongly contradict the prediction that α = 1/3.[6] MRW show that both the saving rate and population growth rate affect income per capita in the way that the model predicts; however, they do not have the right magnitudes. They argue that this is due to the fact that the original Solow model omits the accumulation of human capital[7] and that by including

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percent per year in the United States and 2.2 percent per year in our intermediate sample; this suggests that g is about 0.02." (MRW, 1992, p.413-414, fn. 6)

[5] This imposes that the restriction on the coefficient of In(s) is equal to the coefficient of ln(n+g+δ).

[6] The 'stylized' value of α is usually taken to be approximately 1/3.

[7] MRW emphasize that previous authors have provided evidence of the importance of human capital for growth in income. For example, Azariadis and Drazen [1990] find evidence that there is a threshold externality associated with human capital accumulation. Similarly, Rauch [1988] finds that among countries that had achieved 95 percent adult literacy in 1960, there was a strong tendency for income per capita to converge over the period 1950-1985. Romer [1989b] finds that literacy in 1960 helps explain subsequent investment and that, if one corrects for investment. There is also older work stressing the role of human capital in development; for example, see Drueger [1968] and Easterlin[1981]." (MRW, 1992, p.416, f.n.7)

this as well as physical capital they end up with the so-called augmented Solow model:[8]

$$(8) \qquad \ln\left[\frac{Y_{i,t}}{L_{i,t}}\right] = \ln A_{i,0} + gt + \frac{\alpha}{1-\alpha-\beta}\ln(s_{k,i}) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n_i + g + \delta)$$

$$+\frac{\beta}{1-\alpha-\beta} In(s_{h,i}).$$

Using the Secondary School Enrolment Rate[9] as a proxy for human capital investment, s_h, the estimates for both α and β for the non-oil sample have the expected sign and the magnitudes of α ≈ β ≈ 1/3. MRW then argue that the augmented Solow model provides an almost complete explanation of why some countries are rich and other countries are poor, and of the wide variation in cross-country growth.

MRW derive equation (8) which shows how steady-state income per capita depends on population growth and accumulation of physical and human capital at time t, where A_0 is the initial level of technology, g is the exogenous progress rate of technology, δ is the common rate of depreciation of physical and human capital, n is the rate of labour growth, and s_k and s_h are the fractions of income invested in physical and human capital respectively. Slightly changing the form of equation (8), let $y^*(t)$ denote steady-state income per capita:

$$(9) \qquad \ln(y^*_{i,t}) = (\ln A_{i,0} + gt) - \alpha_1 \ln(n_i + g + \delta) + \alpha_2 \ln(s_{k,i}) + \alpha_3 \ln(s_{h,i}).$$

$$= \ln A_{i,t} + \ln \hat{y}_i *,$$

[8] This is equation (11) in MRW (1992).

[9] This is the percentage of the working-age population that is in secondary school.

where $\alpha_1 = (\alpha + \beta)/(1-\alpha-\beta), \alpha_2 = \alpha/(1-\alpha-\beta), \alpha_3 = \beta/(1-\alpha-\beta)$.

Approximating about the steady state y* yields:[10]

(10) $$\frac{d\ln(\hat{y}_{i,t})}{dt} = \lambda[\ln(\hat{y}^*) - \ln(\hat{y}_{i,t})],$$

where λ is the speed of convergence.[11] Equation (10) suggests a natural regression for the rate of convergence, which implies that:

(11) $$\ln(\hat{y}_{i,t}) = (1-e^{-\lambda t})\ln(\hat{y}_i{*}) + e^{-\lambda t}\ln(\hat{y}_{i,0}),$$

where $\hat{y}_{i,0}$ is the initial state of income per effective worker. Subtracting $\ln(\hat{y}_{i,0})$ from both sides yields:

(12) $$\ln(\hat{y}_{i,t}) - \ln(\hat{y}_{i,0}) = (1-e^{-\lambda t})[\ln(\hat{y}_i{*}) - \ln(\hat{y}_{i,0})].$$

Substituting for $\hat{y}*$ steady-state income per effective worker in equation (12) would imply (CG 1996, p.286, equation (3a)):

(13a) $$\ln(y_{i,t}) - \ln(y_{i,0}) = gt - (1-e^{-\lambda t})[[\ln(y*_{i,0} - \ln(y_{i,0})]$$

(13b) $$= \gamma_0 + \gamma_1\ln(y_{i,0}) + \gamma_2\ln(n_i + g + \delta) + \gamma_3\ln(s_{k,i}) + \gamma_4\ln(s_{h,i}),$$

where

$$\gamma_o = gt - \gamma_1\ln(A_0), \quad \gamma_1 = -(1-e^{-\lambda t}) < 0, \quad \gamma_2 = \alpha\gamma_1 < 0,$$
$$\gamma_3 = -\alpha_2\gamma_1 > 0, \quad and \quad \gamma_4 = -\alpha_3\gamma_1 > 0.$$

[10] MRW (1992, p.422-3) examine the dynamics of adjustment to steady states by taking a Taylor series expansion in physical capital per effective worker around the steady state.

[11] From the specification, λ = (n + g + δ) (1 – α – β).

Cho and Graham (1995) examine the results using the data for the 98 'non-oil' countries in MRW's sample. Apart from the residual terms, the results are:

'Unconditional convergence' regression:

$$\ln(y_{i,t}) - \ln(y_{i,0}) = -0.27 + 0.094\ln(y_{i,0})$$

'Conditional convergence' regression:

$$\ln(y_{i,t}) - \ln(y_{i,0}) = 3.04 - 0.289\ln(y_{i,0}) - 0.505\ln(n_i + g + \delta) + 0.524\ln(s_{k,i})$$
$$+0.233\ln(s_{h,i}),$$

where time 0 and t denote the years 1960 and 1985 respectively. The results suggest that unconditionally, (13a), the coefficient on $\ln y_{i,0}$ is positive and conditionally, (13b), the coefficient on $y_{i,0}$ is negative. CG (1995, p.287) find that the implication of these results is that "Economies with higher income per capita are, in general, further below their steady-state position, provided all the economies are below their steady states". Equation (13a) implies that countries with an annual growth rate less than g will be above their steady-state income levels. This follows because if $(1-e^{-\lambda t}) > 0$, $\{\ln(y(_{i,t}) - \ln(y(_{i,0})\}/t \gtrless g \leftrightarrow \ln(y^*_{i,0}) \gtrless \ln(y_{i,0})$ (CG 1995, p.289, fn.6). Besides, CG also provide an expression for estimating the steady state for each country by assuming g = 2% per year (for example, Barro et al. 1993) in order to identify $A_{i,0}$ and by using equation (13b) with a sample period of 25 years. The expression is therefore:

$$\text{(13b')} \quad In(y^*_{i,0}) = \{\gamma_0 - (0.02)(25) + \gamma_2 In(n_i + g + \delta) + \gamma_3 In(s_{k,i}) + \gamma_4 In(s_{h,i})\}/(-\gamma_1).$$

By calculating out the steady-state income per capita for each country in 1960 and plotting this against their current position in 1960, CG (1995, p.288) find that "On average, relatively poor countries converge to their steady-state positions from above, while rich countries converge from below".[12]

On this basis, CG cast doubt on the common conjecture rooted in the neoclassical growth model, which implies that lower income countries converge to their steady state from farther *below*. In fact, Cho and Graham find that, in contrast to the common conjecture, the results from conditional convergence regression estimates imply that most poor countries are converging from farther *above* their steady-state income levels. They argue that this surprising result challenges the validity of the neo-classical Solow growth model and call for an alternative, e.g., the recent endogenous growth literature.[13]

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[12] By plotting $ln(y^*_0)$ against $ln(y_0)$, CG find that a fitted regression line is $ln(y^*_0)) = -2.65 + 1.32\ ln(y_0)$ where the standard error of the slope is 0.12. Thus, the slope is significantly greater than 1. This is also obvious by looking at Fig. 1 in CG (shown in Appendix A, Figure A.1). "CG's result therefore appear to imply that, even when the determinants of y^*_0 are included, for the model to fit the data, one corollary is that many countries (especially poor ones) have been converging to their steady states from *above* (Aghion and Howitt 1998)" (Owen 2004, p.5)

[13] The recent endogenous literature initiated by Romer (1986) and Lucas (1988) has gained popularity since the postwar cross-country growth experiences suggested that rich countries tended to grow faster or at least no slower than the poor countries, which has been interpreted as being in conflict with the neoclassical model, which predicts income per capita convergence to a steady-state level.

3. Criticisms of Cho and Graham

These criticisms of CG are based on the discussion from Owen (2004). In order to form equation (13b'), CG take the value of g to be 2% per year to identify A_0 from g in equation (13b). However, in this case, CG make a stronger assumption than MRW in defining A_0. MRW assume that $\ln A_{i,0} = a + \varepsilon$, where a is a constant and ε_0 is a country-specific shock, which is controversially independent of the explanatory variables. Instead of assuming a is constant, CG assume A_0 is constant across countries. This implies that CG's identification of A_0 make the estimation of $\ln y^*_{i,0}$ incorrect in that the country-specific ε term is omitted.

There are two assumptions that are used in testing the 'over-developed' less-developed country: (i) is A_0 constant across different countries (or, at least, that any deviations are random) and (ii) g is constant across all countries at all times. Although it is commonly assumed in many empirical studies of the neoclassical model that g does not vary across countries, it is not realistic to assume that A_0 is invariant among countries in a cross section spanning a wide range of levels of development (Caselli, Esquivel and Lefort 1996, p. 380)

It is argued by Durlauf and Quah (1999) that the steady-state balanced-growth predictions and predictions local to steady state, i.e., the size of the convergence gap between the steady state and the current level, depend on $\ln(A_0)$. By using $\ln(y_{i,t}) \equiv \ln(y^*_{i,t}) + \ln(A_t)$:

(14) $$\ln(y_{i,t}) = \ln(A_{i,0}) + gt + (1 - e^{-\lambda t})[\ln(\hat{y}_i^*) - \ln(\hat{y}_{i,0})] + \ln(\hat{y}_{i,0})$$

$$= \ln(\hat{y}_i^*) + \ln(A(0)) + gt - e^{-\lambda t}\left[\ln(\hat{y}_i^*) - \ln(\hat{y}_{i,0})\right]$$

Equation (14) can be interpreted as implying that income per capita for the country in time t is determined by a convergence component (the last term on the RHS) and a steady-state growth path component (the difference between the income per capita at its steady state and in the initial period). For example, if two economies, i and j, have identical values of the determinants of $\hat{y}^*$ and the same rate of growth of technology, g, but economy i has a higher level of $A(0)$ than economy j, then i will be on a higher steady-state growth path and, for any given level of y(0), will have a numerically larger convergence gap. The latter can be seen by subtracting $\ln(y_{i,0})$ from both sides of equation (9), with $t = 0$:

$$(15) \qquad \ln(y^*_{i,0}) - \ln(y_{i,0}) = \ln(A_0) + \ln(y_i^*) - \ln(y_{i,0})$$

As Owen (2004, p.7) argues "any meaningful attempt to estimate the size or sign of the convergence gaps for different countries must therefore allow for cross-country variation in A_0; Otherwise it is likely that base-period income per capita will be compared with an inappropriate steady-state growth path". For example, if economies i and j have the same value of y_0 but j has a sufficiently lower value of A_0 compared to economy i then it is feasible, at time 0, for j to be above and i to be below their respective steady-state growth paths in the base period, i.e., if

$$[\ln(\hat{y}^*) + \ln(A_0) + gt]_i > \ln(y_0)_{i,j} > [\ln(\hat{y}^*) + \ln A_0 + gt]_j \,,$$

It is perfectly possible in neoclassical growth model for lower-income countries to be above and higher-income countries to be below their steady states. However, we need information on cross-country variation in A_0.

Therefore, CG's argument is unreliable because when they attempt to estimate the size of the convergence gaps for different countries, they do not take into consideration of the cross-country variation in A_0 and with an inappropriate steady-state growth path their result of the comparison of the base-period income per capita with the steady state is incorrect.

Moreover, CG as with other the cross-country studies of growth, merely look at the variation of the steady-state conditioning variables across countries and fail to consider the fact that population growth rates and investment rates in physical and human capital are varying over time. Taking the average of the variables over the period from 0 to t would imply that the steady-state income per capita should be constant over time for every country during that period, but this contradicts the notion that the steady-state income levels should also be varying over time when we do a single-country analysis.

Therefore, because the steady state for each particular country is stochastic, we can question CG's argument further. Even if we observe that some poor countries are currently above their steady state in 1960, this is not surprising, because we expect that, for each country, the actual income per capita would move above or below its steady state. Observing a country above its steady state is not at all an argument against the neoclassical growth model; rather it is consistent with it in the sense that when a country is currently above its steady state, you expect it to come back towards its steady state and vice versa.

4. Data Sources and Selected Countries

4.1 Variable Description and Data Sources

The data I use for real income per capita, population, and net investment rate from 1960 to 1995 for each country in our analysis are obtained from the Penn World Table Version 6.1. (Heston, Summers and Aten 2002) I use the labour quality index constructed by Bosworth and Collins (1996) as a proxy for human capital accumulation.

y – Real GDP per capita Chain (RGDPCH) in PWT 6.1 is used.

n – Year-on-year population growth rates for 1961 to 1995 are calculated from the annual population data. The annual population growth rate for 1960 is obtained from the website at http://globalis.gvu.unu.edu/, which is based on UN population estimates and projections in the UN Common Data Base.

(n+g+d) - To make the model comparable with that of MRW, in the term $\ln(n+g+\delta)_{i,t}$, the technology progress g in our analysis is fixed at 0.02 and the depreciation rate δ is assumed constant at 0.03. This term is therefore measured as $\ln(n_{i,t}+0.05)$.

Sk - We use investment share of real GDP for the net investment rate from 1960 to 1995 to get the measure of $\ln(s_k)_{i,t}$.

Sh - Our human capital measure is different from that of MRW because it is impossible to obtain annual school enrolment rates for these developing countries prior to the 1990s. Therefore we use the series from Bosworth and Collins (1996), which is based on the educational attainment data constructed by Barro and Lee (1994a).[14] Following their extrapolation procedures, Bosworth and Collins extend the data to 1995, and seven countries in their sample are not in Barro-Lee data set.[15] It is also argued by Bosworth and Collins that many studies have found it difficult to detect a significant relationship between the change in years of schooling and economic growth and there are serious measurement errors in cross-country data on education attainment. They conclude that "years of schooling alone is a poor index of labour quality because it assigns workers with zero education a weight of zero and it implies disproportionate changes in labour quality for countries with low initial levels of schooling"(Bosworth and Collins 1996, p.151). They try to follow Denison and others in using estimates of relative wage structure for workers with different years of schooling to construct weights for aggregating workers across education levels to obtain their labour quality index. The following equation from Bosworth and Collins (1996, p. 151) shows how this labour quality index is constructed:

$$(21) \qquad H = \sum W_j P_j \, .$$

This index weights the percentage of a country's population that has attained level j of schooling (P_j, where j ranges from 1:no schooling to 7:beyond secondary completed) by their estimate of the return to level j of schooling (W_j). The weights are based on the observed relative earnings of different educational groups and reflect the assumption that percentage returns to schooling are constant across levels of schooling and countries. Therefore, we use this index to get a measure of $\ln(s_h)$ for each country. However, strictly, this is more of a proxy for the stock of human capital

[14] "Barro and Lee use a combination of data sources to infer the percentage of each country's adult population (aged twenty-five and older) that had obtained a particular level of education for each year from 1960 to 1990). Census data provide direct measures of a country's stock of education in a particular year. However, such data only available for selected years, particularly in developing countries. Therefore enrolment data are used to interpolate between census years and, along with data on literacy rates, to fill in missing cells." (Bosworth and Collins 1996, p.148)

[15] They are China, Cote d'Ivoire, Egypt, Ethiopia, Madagascar, Morocco, and Nigeria.

than a flow of measure such as school enrolments, but his is not critical given that we do not decompose the coefficient α_3 in equation (9), the composition of which in terms of the underlying α and β coefficients, would be affected by this difference.

4.2 Selected Countries

Among the group of the 24 lowest income countries in MRW, 16 of them are estimated by CG to be above their steady-state income levels in 1960 in both unrestricted and restricted models (See Table A.2 in the Appendix). These are the countries that we are interested in.

However, Bosworth and Collins (1996) only have data for seven of the 16 countries: Bangladesh, Ethiopia, Malawi, Mali, Tanzania, Uganda and Zaire.[16] Therefore, we use them to represent the group of developing countries that are observed to be above their steady state according to CG and examine whether this is true.

The following table contains the geography of these countries and their data reliability grading in PWT 6.1.[17]

Table 1. Country Region and Data Grading

Country	Region	Grade
Bangladesh	Asia, Southwest	C
Ethiopia	Africa, East	C
Mali	Africa, Central	C
Malawi	Africa, West	C
Tanzania	Africa, West	C
Uganda	Africa, West	D
Zaire*	Africa, Central	D

[16] The data sets for these countries are provided in Appendix B.

[17] In the Grading of PWT Country Estimates, 'A' denotes a high score and 'D' a low score on the scale (PWT 6.1, Data Appendix).

* Zaire was originally known as the Democratic Republic of the Congo.

4.3 Limitations on the Data and Samples

The quality of the data, as reflected in the grades in Table 1, is an important drawback in analysis for developing countries particularly when we try to apply a time-series approach. As Durlauf, Johnson and Temple emphasize.

> *"For many developing countries, some of the most important data are only available on an annual basis, with limited coverage before the 1960s. Moreover, the listing of annual data in widely used sources and online databases can be misleading, because some key variables are measured less frequently. For example, population figures are often based primarily on census data, while measures of average educational attainment are often constructed by interpolating between census observation using school enrolments. When examining published data, it is not always clear where this kind of interpolation has been used."*
>
> (Durlauf, Johnson and Temple 2004, p.99)

Some of the variables for certain countries in our discussion display relatively little time variation and, as we will see later, might not show significance in explaining growth. Some of them do appear to show significant variation, but this variation may not correspond to the concept we have in mind. It is therefore important to emphasize that the results obtained are only as reliable as the data available.

5. Methodology and Results

From the discussion above, we have show that CG's contradictory observation against the common conjecture of the neoclassical growt h model is not a real challenge to the model. Although CG's argument is essentially not credible, it provide us with a motivation to find out whether their point of saying that poor countries converge from above their steady-state is a real phenomenon regardless of their misspecification in formulating the steady-state value of income per capita. We therefore consider an econometric approach other than cross-country regression in performing the analysis.

4.1 A Panel Data Approach

A common feature of the empirical studies using cross-country study on the issue of growth convergence is the assumption of identical aggregate production functions for all the countries. Mankiw considers this common feature as appropriate by arguing that any change in the capital stock for an economy could be viewed as a movement along the same production function, rather than as a shift to a completely new production function. Although this argument is plausible, it is not tested, and it would more convincing if we can incorporate differences in the production function across countries.

Islam (1995), Durlauf and Johnson (1995) and Caselli et al. (1996) began to challenge the view that the productivity shift parameter of the underlying production function is homogenous across countries. From an econometric point of view, this led to researchers resorting to panel data methods that exploit the time dimension of data sets (e.g., Andrés, Boscá and Doménech, 2004). Islam (1995) provides a panel data analysis to correct for omitted variable bias in a single cross-section regression in which the country-specific component of the aggregate production function is assumed to be correlated with the included explanatory variables.

The use of a panel data approach has both advantages and disadvantages. The main advantage is that it permits unobservable country-specific heterogeneity in growth regressions, which can lead to omitted variables bias in cross-sectional analysis. The panel data approach also helps to solve the degrees-of-freedom problem associated with the cross-section methodology and by including more frequent observations on each country increases the number of degrees of freedom (Islam 1995, Barro and Sala-i-Martin 1995, chap.12). However, the main disadvantage of using panel data is that it may lead to correlation between lagged dependent variables and the unobserved error. The resulting regression bias depends on the number of observations in time and only disappears when that number becomes infinite. (Barossi-Filho, Silva and Diniz, 2005). Moreover, the bias does not disappear with time averaging. Thus, if the dynamic panel were the underlying structure, standard cross-section regressions will not consistently uncover the true structural parameters. The other potential disadvantage in using panel-data methods is that a decomposition of the constant term in the growth regression into economy-specific and time-specific effects can be argued to be a proliferation of free parameters not directly motivated by economic theory (Durlauf and Quah 1999). Furthermore, the use of a panel-data approach such as using fixed effect estimators or differencing data may result in losing long run information on cross-country variation in growth as its determinants.

5.2 A Time-Series Approach

Bernard and Durlauf (1995, 1996), Durlauf (1989) and Quah (1992) set up an alternative approach to long-run output dynamics and convergence based on time-series ideas. The target for a time-series method to analyse is convergence which is not identified as a property of the relation between initial income and growth over a fixed sample period, but instead as a characteristic of the relationship between long-run forecasts of per capita output, taking as given initial conditions.

Examination of time-series data for each country in isolation serves as the most natural way to understand growth, which potentially varies substantially over time, and countries experience distinct events that contribute to this variation (Durlauf, Johnson and Temple, 2004). Our purpose in using time-series analysis for each selected poor country is to compare the initial-period income per capita with that of its steady state to see whether it converges from below its steady state or above.

The model underpinning our analysis should not be too different from the one used in MRW and CG for fear of losing comparability. The model we intend to use here is:

(16) $$\ln(y^*_t) = (\ln A_t) + \alpha_1 \ln(n + g + \delta)_t + \alpha_2 \ln(s_k)_t + \alpha_3 (s_h)_t$$

Notice that we drop the country subscript *i* because we use time-series approach here The model above, at first glance, already appears suitable for estimation. However, since most of the macroeconomic time-series variables contain unit roots, a concern about spurious regression arises when we regress one non-stationary series on another. Not surprisingly, as we will see later on, most of the series that we use for countries in our analysis have unit roots. To avoid this spurious regression problem, we could use first differenced variables to transform the time series to stationarity. However, we might lose some valuable long-run relationship between the variables, which is exactly what we need for our analysis, a relationship that defines a country's steady-state income per capita in terms of its determinants.

5.21 Unit Root Testing

The unit root testing strategy we employ in our analysis is the Augmented Dickey-Fuller [ADF] test, which is most commonly used in the time-series literature despite the limitations this approach has.

The Dickey-Fuller test assumes the time-series under examination be an AR(1) process. "However, this may not adequately describe the more complex patterns exhibited in actual economic time series" (Patterson, 2000). A generalization is to relax the assumption to allow a wider class of variations of error autocorrelation, i.e. AR(p), when we using the conventional DF test. We can select the value of p that is likely to ensure white noise residuals in the fitted equation using a number of different methods. In this section, we use Akaike's Information Criteria [AIC], which is reported in the software we use to obtain the results in this paper, i.e., SHAZAM 9.0 Professional. The AIC is calculated for $p = 1, \ldots, p^*$ and p is chosen where the criterion is at a minimum.

In addition, we employ the unit root testing strategy from Perron (1998). The detailed testing procedure can be found in Appendix C.

The following summary table shows the unit root test results for each variable of interest in this paper.

Table 2. Unit Root Testing Results

Variables	Bangladesh	Ethiopia	Malawi	Mali	Tanzania	Uganda	Zaire
lny	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
ln(n+g+d)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(0)
lnSk	I(0)	I(1)	I(1)	I(0)	I(0)	I(1)	I(1)
lnSh	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)

From the table above we can see that all of the lny series appear to have unit roots. ln(n+g+d) for Ethiopia, Uganda and Zaire display stationarity. lnSk for Bangladesh, Mali and Tazania is stationary, and lnSh in all countries apart from Uganda has a unit root. Since these series for each country are I(1) and I(0), it is very likely that some of them are cointegrated to determine the long-run behaviour of income per capita.

5.22 An Error-Correction Representation

The error-correction model is used to ensure variable stationarity and preserve long-run relationships in the sense that it combines long-run information with the short-run adjustment mechanism. This approach has been used frequently and successfully throughout the literature, examples of which are Nehru and Dareshwar (1994), Cellini (1997), Morales (1998), and Loening (2005).

In time-series data, the population growth rate and the capital accumulation rates are not constant over time, but they are stochastic variables. Consequently, the steady-state path for income per capita for each country displays stochastic behaviour as well over time, which is quite distinctive from the cross-country prediction that the steady state is fixed at some constant level. Our interpretation should therefore be focusing on the pattern of steady-state income per capital in every country examined.

"The error-correction model can be estimated in different ways. Banerjee et al. (1993) show that the generalized one-step error-correction model is a transformation of an autoregressive distributed lag model. As such, it can be used to estimate relationships among non-stationary processes." (Loening 2005, p.30) The error-correction model of the human capital augmented Solow model that we employ in our analysis can be specified as follows:[18]

[18] The specification of the short-run dynamics is not based on any specific theory, and the simplistic choice is to consider only the first difference of the regressors affecting the equilibrium level of income per capita as in (Cellini,1997) And we did not include additional lags of the differenced variables because of loss of degrees of freedom and we only have 36 data points in our analysis. We did try to include a lagged difference in $\ln y_t$, but it does not make much difference to the result, so we do not include it in our specification. However, it is considered ideal that each country could have its own specification of the error-correction model based on Hendry's (1995) concept of general-to-specific modelling.

$$(17)\quad \Delta \ln y_t = \beta_1 \Delta \ln(n+g+\delta)_t + \beta_2 \Delta \ln(s_k)_t + \beta_3 \Delta \ln(s_h)_t$$

$$+ \gamma[\ln y_{t-1} - C - \alpha_0 T - \alpha_1 \ln(n+g+\delta)_{t-1} - \alpha_2 \ln(s_k)_{t-1} - \alpha_3 \ln(s_k)_{t-1}] + u_t$$

,

where C is a constant term and T is a time trend. This equation can be estimated by ordinary least square (OLS) technique, but the coefficients cannot be formed without knowledge of α_1, α_2 and α_3.[19] However, we can estimate the re-parameterized form:

$$(18)\qquad \Delta \ln y_t = \beta_1 \Delta \ln(n+g+\delta)_t + \beta_2 \Delta \ln(s_k)_t + \beta_3 \Delta \ln(s_h)_t$$

$$+ \gamma \ln y*_{t-1} - \gamma C - \gamma\alpha_0 T - \gamma\alpha_1 \ln(n+g+\delta)_{t-1}$$

$$- \gamma\alpha_2 \ln(s_k)_{t-1} - \gamma\alpha_3 \ln(s_k)_{t-1} + u_t .$$

Estimates of the parameter γ can now be used to calculate the required elasticities α_1, α_2 and α_3. The loading coefficient γ contains additional information because it can be interpreted as a measure of the speed of adjustment at which the system moves towards its equilibrium on the average. In addition, Banerjee et al. (1998) argue that, in a single equation framework, a significant coefficient serves as a test for cointegration. The technology parameter, in its simplest formulation the base-period technology level is proxied by the constant term, C.

Therefore, the long run steady-state income per capita for each country in our analysis has the expression:[20]

$$(19)\qquad \ln y*_{t-1} = C + \alpha_0 T + \alpha_1 \ln(n+g+\delta)_{t-1} + \alpha_2 \ln(s_k)_{t-1} + \alpha_3 \ln(s_k)_{t-1}.$$

[19] The use of OLS assumes that the differenced conditioning variables on the RHS of equation (17) are exogenous and this may not be true. Ideally, we could in principle use Instrumental Variables (IV).

[20] As Cellini (1997, p148 fn.10) argues, one can compute the steady-state by resorting to the linear specification in the error-correction equation (18), which assumes no technological effects in the short run.

Then we can compare this with the actual income per capita for that country at a certain time, e.g. in 1960. We can also track the movement of a country's actual income per capita against that of its steady state.

5.23 Testing for Cointegration and the results

> *"Over the last several years, testing for cointegration has become an important facet of the empirical analysis of economic time series, and various tests have been proposed and widely applied."*
>
> (Kremers, Ericsson and Dolado, 1992, p. 341)

The method of testing for cointegration used in this paper is the error-correction-based test, i.e., to test existence of cointegration in the error-correction form. This test is a single-step dynamic-model procedure initialized by Banerjee, Dolado, Hendry and Smith (1986). It is argued in Kermers, Ericsson and Dolado (1992) that this test uses available information more efficiently than the residual-based Dickey-Fuller test, which is considered of having low power.

The two-step Engle-Granger procedure is based on a DF statistic used to test whether the residuals from a static cointegration regression is stationary, i.e., appears to be I(0). However, this test approach ignores potential information contained in the short-run elasticity, i.e. the first differenced conditioning variables, by imposing a common factor restriction. The error-correction-based test is characterized by the t-statistic of the coefficient on the error-correction term in a dynamic model reparameterised as an error-correction mechanism, i.e., the coefficient γ in equation (18). We test the null hypothesis of $\gamma = 0$ against the alternative of $\gamma < 0$, and if the null is rejected at certain significance level, we conclude that the cointegration relationship exists. The critical value for the test statistic we use is from Ericsson and MacKinnon (2002, p.306, Table 4).

Table 3 on the next page reports estimated coefficients on the parameters in equation (19) and the results of some diagnostic tests.[21] We find that for all countries, the coefficient γ is negative and between -1 and 0, which allows convergence to equilibrium to occur. Note that this coefficient is not interpreted in the same way as it is in cross-country regressions. In cross-country studies we interpret the negative sign as evidence of catching up among countries. In a time-series study, this coefficient is rather interpreted as reflecting the tendency of a country's current level of income to move towards its own steady-state income level.

The error-correction-based test using Ericsson and MacKinnon (2002, p.306, Table.4) critical values with sample size equal to 36 and 4 variables in the error correction term shows no cointegration apart from Malawi. The goodness of fit (R^2) in for Malawi is 0.5805, which is quite reasonable, and F test statistic shows that the explanatory variables are jointly significant in explaining the variations in the dependent variable. Besides, no diagnostic test shows severe problem with neither the normality assumption of the specification of the model. The coefficient on both lagged and differenced Sh is quite significant and has the expected sign of positive, which means that increase in human capital has positive effects on both short run and long run. However, our coefficient on ln(n+g+d) has a statistically positive sign, which contradicts our prediction. However, this could due to the fact that during our sample period, Malawi's population growth had been helping to increase the total productivity of the country. We work out the steady-state income per capita for Malawi using equation (19) over time and plot them against the actual levels of income, which gives us the figure 1 on page 28.

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[21] We use PcGive10 in testing the cointegration. The AR(1-2) test is for testing serial correlation , which is an F test. PcGive10 reports the normality test based on Shenton and Bowman (1997), which follows an $\chi^2(2)$ distribution. For heteroscedasticity, a While test is used, which follows an F distribution. The RESET test due to Ramsey (1969) tests the specification of a functional form.

Table 3. Estimates and Tests on Linear ECM (Dependent Variable is Δy)

	Bangladesh	Ethiopia	Malawi	Mali	Tanzania	Uganda	Zaire
Constant	0.1225	-19.9771	-12.7703*	32.4187**	28.5326***	-25.7651*	5.8283
	(2.9990)	(19.0700)	(8.2680)	(18.4700)	(10.9700)	(15.1600)*	(10.7000)
Trend	0.0000	-0.0054	0.0025	0.0093*	0.0028	-0.0093	-0.0052
	(0.0037)	(0.0061)	(0.0026)	(0.0059)	(0.0035)	(0.0062)	(0.0098)
lny_1	-0.4515	-0.2569	-0.9047**	-0.3217	-0.7027	-0.5230	-0.1873
	(0.1329)	(0.1671)	(0.2083)	(0.1325)	(0.1997)	(0.1707)	(0.1373)
ln(n+g+d)_1	-0.6080**	-0.1394	0.1184***	0.2052	3.5591	-0.2798	0.4997
	(0.2251)	(0.0794)	(0.0528)	(0.5063)	(2.0900)	(0.2477)	(1.1640)
ln(Sk)_1	0.0110	0.1447	0.0323	-0.2154***	0.1975***	0.0465	0.0690
	(0.3959)	(0.0767)	(0.4184)	(0.0661)	(0.0685)	(0.0664)	(0.0526)
ln(Sh)_1	0.3215	4.6837	3.9534***	-6.5571*	-3.1227**	6.0809**	-0.6377
	(0.5770)	(4.2550)	(1.8130)	(4.0090)	(1.5470)	(3.2560)	(1.8070)
dln(n+g+d)	-0.4901*	-0.1039	-0.0049	0.5199	-0.5728	-0.3041	-0.3979
	(0.3622)	(0.0550)	(0.0454)	(0.5883)	(3.5440)	(0.4392)	(1.6290)
dln(Sk)	-0.0122	0.0906	-0.1540	-0.2485***	0.3006***	0.0730	-0.0186
	(0.0372)	(0.0565)	(0.4441)	(0.0598)	(0.0422)	(0.0706)	(0.0440)
dln(Sh)	-7.6365***	16.2288	5.1307*	23.1422*	-21.0292**	12.2396	-1.9059
	(2.9110)	(14.2500)	(3.5960)	(15.2300)	(10.8300)	(13.9600)	(6.8030)
R-SQUARED	0.4614	0.3611	0.5805	0.6063	0.8040	0.3158	0.3075
RSS	0.0385	0.0743	0.0873	0.0535	0.0700	0.1440	0.1516
F (8,26)	2.7840**	1.8370	4.4970***	5.0060***	13.3300***	1.5000	1.4430
D-W test	1.9500	1.8900	2.0500	2.1600	1.7300	1.6300	2.2400
AR 1-2 test: F(2,24)=	0.7510	6.5645**	2.0076	0.1885	0.8844	1.8346	4.7347**
Normality test: Chi^2(2)=	3.9559	7.6457*	0.5983	3.4824	4.7055*	26.6580***	3.8370
Heteroskedasticity test: F(16,9)=	2.1942	0.9535	1.3700	0.2438	0.3082	3.9181**	1.6562
RESET test: F(1,25)=	0.6081	2.3416	0.3929	4.1781*	0.3741	21.2460***	2.5295

t critical value at 10% in Ericsson and MacKinnon (2002) where $k = 4$ calculated to be $t = -3.8741028$, at 5% is -4.2814833.
***means significant at 1%, **means significant at 5% level, *means significant at 10% level.
Values in brackets are standard errors.

Figure 1. Malawi Steady-state vs. Actual Income per Capita.

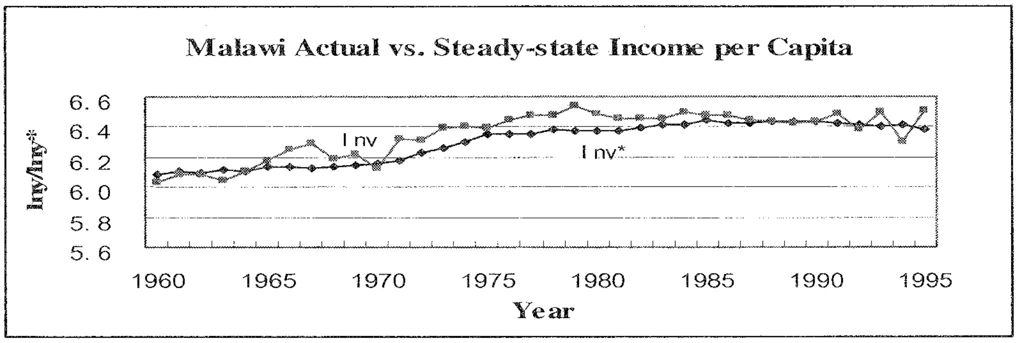


Figure 1 shows that unlike CG's observation, Malawi's actual steady-state income per capita is below its steady state in 1960 and it is evident in that these two series of income per capita appear to be cointegrated and there is tendency for them to move together over time. When the actual income per capita is above that of its steady state and it could stay for some time, but it decreases towards the steady state eventually and moves above and below it over time. This observation is consistent with the Solow model's implication of conditional convergence, i.e. given the steady-state conditioning variables, which in this case are stochastic over time, a country will converge to its own stochastic steady-state income per capita over time.

Although there is no strong evidence based on the ECM-based cointegration test, that there is cointegration for the other countries, most of their conditioning variables have expected signs in the regression, but some diagnostic tests show they have many problems in many aspects. For example, there is serious normality problem in Uganda according to the normality test and the model is clearly misspecified based on the Ramsey's RESET test. However, I still work out the steady state for those countries according to equation (19) and the graphs of relative movements of actual and steady-state income per capita for all of the seven countries are contained in Appendix D. However, to the extent that evidence for a cointegrating steady-state relationship is lacking, these graphs do not really represent convergence gaps as we have interpreted them.

6. Augmented Solow Model with Health Capital

Labour quality in the form of human capital has a significant influence on economic growth and MRW's augmented Solow model includes human capital as one of the determinants of the steady-state income per capita for each economy. However, they merely use education as a proxy for human capital and in fact most cross-county empirical studies identify labour quality narrowly with education (Bloom, Canning & Sevilla 2001). It has been considered that healthier workers who are physically and mentally more energetic and robust are more likely to be more productive in production, thus yield higher level of production. Therefore, it is reasonable for us to translate these effects into an aggregate effect of population health on economic growth; that is to incorporate health capital as a conditioning variable in our augmented Solow model.

In fact it has long been recognized that human capital should also be accumulated through improvements in health (eg: Schultz, 1961; Mushkin, 1962). Denison (1962) points out that funds used for education - both public and private – largely reduce consumption and thus make a positive net contribution to economic growth. However, relatively little empirical attention has been given to the 'health capital' component of human capital until Knowles and Owen (1995), in which an extended MRW model is presented and the results of including a proxy for health capital in an extended MRW empirical growth model are reported.

6.1 The model

MRW's augmented Solow growth model is represented by equation (8) in Section II, which includes education as one component of human capital. We can extend MRW's model to incorporate health as another component of human capital. The underlying

Cobb-Douglas production function is of the form equation (1) in Knowles and Owen (1995):

$$(20) \qquad Y_{i,t} = K_{i,t}^{\ \alpha} E_{i,t}^{\ \beta} X_{i,t}^{\ \psi} (AL)_{i,t}^{\ 1-\alpha-\beta-\psi},$$

where Y is real output, K the stock of physical capital, E the stock of educational human capital, X the stock of health capital, L the labour input, and A the labour-augmenting level of technology. α denotes the elasticity of output with respect to physical capital; β denotes the elasticity of output with respect to education capital and ψ is the elasticity of output with respect to health capital. It is assumed that $\alpha + \beta + \psi < 1$.

We extend equation (8) to include the accumulation of health capital to reach the extended version of MRW's Equation (11):[22]

$$(21) \qquad \ln\left[\frac{Y_{i,t}}{L_{i,t}}\right] = \ln A_{i,0} + gt - \frac{\alpha+\beta+\psi}{1-\alpha-\beta-\psi}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha-\beta-\psi}\ln(s_k)$$
$$+ \frac{\beta}{1-\alpha-\beta-\psi}\ln(s_h) + \frac{\psi}{1-\alpha-\beta-\psi}\ln(s_e),^{23}$$

For the purpose of estimation, we also need to account for health capital in our error-correction representation, which results in the following expression:

$$(22) \qquad \Delta \ln y_t = \beta_1 \Delta \ln(n+g+\delta)_t + \beta_2 \Delta \ln(s_k)_t + \beta_3 \Delta \ln(s_h)_t + \beta_4 \Delta \ln(s_{he})_t$$
$$+ \gamma[\ln y*_{t-1} - C - \alpha_0 T - \alpha_1 \ln(n+g+\delta)_{t-1} - \alpha_2 \ln(s_k)_{t-1}$$
$$- \alpha_3 \ln(s_k)_{t-1} - \alpha_4 \ln(S_e)_{t-1}] + u_t.$$

[22] This equation is based on equation (11) of Knowles and Owen (1995, p. 101).

[23] Again, life expectancy is more of a proxy for the stock of health capital, but we do not decompose the coefficient, so the form of the coefficient does not matter too much.

Therefore, the steady-state income per capita can be formulated as:

$$\text{(23)} \qquad \ln y^*_{t-1} = C + \alpha_0 T + \alpha_1 \ln(n+g+\delta)_{t-1} + \alpha_2 \ln(s_k)_{t-1} \cdot$$
$$+ \alpha_3 \ln(s_h)_{t-1} + \alpha_4 \ln(s_{he}) + A_{t-1}$$

6.2 A Proxy for Health Capital

There are essentially two measures of health capital for each country and they are health inputs and health outcomes or indicators. The measures for health inputs are for example the fraction of the population with access to clean drinking water, the number of physicians per capita, and the nutrient composition of the diet. The measures of health indicators tell much the same story in that they suggest that health outcomes, including human capital in the form of health, are also better in rich than poor countries, which forms the basis for inferring that health differences play a proximate role in explaining income differences among countries (Weil 2005). [24]

Since it is difficult to access the data for health inputs for each poor country in our analysis, the series that we will use as a proxy for health capital is life expectancy, a form of health indicator. This measure has been successfully employed in many cross country growth studies (for example, Barro and Lee (1994), Knowles and Owen (1995), Bloom and Sachs (1998) and Gallup et al. (2000), and most of them have found that life expectancy has a positive effect on economic growth; that is a country with a longer life expectancy would have a higher income per capita.

The life expectancy data (She) in our analysis is from the World Development Indicators 2003. This series of data starts from the year 1960, and finishes at 2001, but we will only use the part from 1960 to 1995. However, there are only two data points

[24] Weil (2005) also discusses various channels through which health affects the level of output in a country.

in a five-year interval, for example, the series starts its first measure in 1960, and the next measure is in 1962, followed by another measure in 1965. Therefore, we have to somehow modify the data in order for it to be continuous on the time period that we are interested in. We use simple linear interpolation method. The interpolation process is for example, to work out the data point for 1961, we simply average the data points for 1960 and 1962.

6.3 Results

The unit root test shows that the health variables for all of the countries apart from Bangladesh are I(1). So we would hope that they variables are cointegrated.

Originally, we thought that adding a health component of human capital would be helpful in determining the variation in income per capita for these developing countries, in the sense that health problems in poor countries should be crucial. However, this attempt is not indeed fruitful in the sense that it does not help finding cointegration for any of these countries. The results on the next page show that coefficients on health capital is statistically significant in explaining income in Malawi and Zaire, but the others are non-significant and some do not even have the correct sign.

More surprisingly, when we add the health capital variable in our previous 'cointegration' success, Malawi has a coefficient of -1.0807 on the error correction term, which violates our converge-to-equilibrium hypothesis of having $-1 < \gamma < 0$. However, the diagnostic tests do not show any particular problems and the R^2 is still reasonable. Besides, figure 2 of Malawi on page 34 with health capital does not appear to be very different from Figure 1. Nevertheless, there is a bigger gap between the two curves in the period from 1964 to 1985.

Table 4. Estimates and Tests on Linear ECM with Health (Dependent Variable is Δy)

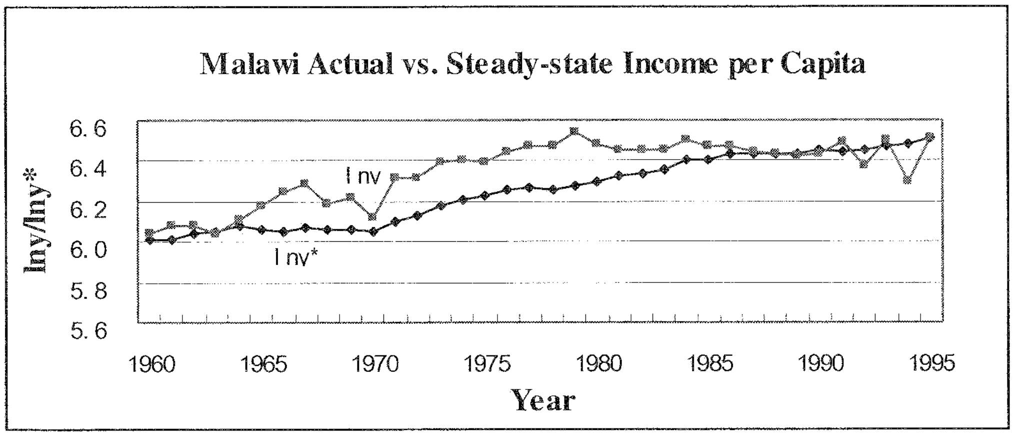
	Bangladesh	Ethiopia	Malawi	Mali	Tanzania	Uganda	Zaire
Constant	12.4756	-21.8722	-9.8716	45.1877	16.9575	-25.0966	10.3633
	(19.7500)	(19.7200)	(8.6500)	(42.5100)	(17.5800)	(18.8000)	(9.8400)
Trend	0.0271	-0.0075	0.0100*	0.0105	0.0023	-0.0105	-0.0083
	(0.0486)	(0.0102)	(0.0059)	(0.0091)	(0.0090)	(0.0079)	(0.0171)
lny_1	-0.4255	-0.2903	-1.0807	-0.2628	-0.6688	-0.5314	-0.7420
	(0.2110)	(0.1755)	(0.2453)	(0.1466)	(0.2162)	(0.1854)	(0.2217)
ln(n+g+d)_1	-0.5465***	-0.1020	0.1067**	0.3722	3.3031	-0.3099	-0.7676
	(0.2425)	(0.0926)	(0.0537)	(0.5337)	(2.8910)	(0.2968)	(0.9936)
ln(Sk)_1	0.0167	0.1483	-0.0448	-0.2082***	0.1372	0.0612	0.0405
	(0.0426)	(0.0872)	(0.4668)	(0.0697)	(0.1136)	(0.0880)	(0.0427)
ln(Sh)_1	-0.7326	5.0706	3.6857**	-9.5143	-1.5366	5.9559*	-3.6397**
	(1.4100)	(4.4250)	(2.0580)	(9.7330)	(2.9040)	(3.8200)	(1.7070)
ln(She)_1	-2.0445	0.1254	-0.2368	0.2712	0.7804	-0.0047	2.6529
	(4.1020)	(1.1840)	(0.7531)	(0.7295)	(1.0220)	(0.6203)	(2.1970)
dln(n+g+d)	-0.4522	-0.0819	0.0030	0.5925	-2.8823	-0.3525	-0.8499
	(0.3736)	(0.0641)	(0.0457)	(0.6100)	(4.5920)	(0.6395)	(1.3100)
dln(Sk)	-0.0054	0.0944	-0.1616	-0.2610***	0.2680***	0.0781	-0.0159
	(0.0433)	(0.0595)	(0.4536)	(0.0619)	(0.0769)	(0.0780)	(0.0361)
dln(Sh)	-10.3219**	15.9813	3.3407	32.1965*	-21.9032**	12.8138	-10.9225*
	(5.4720)	(22.7400)	(3.8200)	(22.2900)	(11.1600)	(14.7800)	(6.5540)
dln(She)	4.3482	-1.9190	6.0712*	-1.3132	6.2840	-1.0782	10.9803***
	(5.4790)	(2.2820)	(4.2280)	(1.2920)	(13.0700)	(4.3320)	(3.7170)
R-SQUARED	0.4796	0.3806	0.6138	0.6280	0.8099	0.3178	0.5909
RSS	0.0372	0.0720	0.0803	0.0506	0.0679	0.1436	0.0896
F (10,24)	2.2120*	1.4750	3.8150***	4.0510***	10.2200**	1.1180	3.4670***
D-W test	2.0800	2.0300	1.9800	2.3600	1.7700	1.6500	1.7900
AR 1-2 test: F(2,22)=	0.8701	9.4009***	0.9643	1.5874	0.8574	1.6444	0.8467
Normality test: Chi^2(2)=	4.0962	10.5700***	0.7361	2.9107	3.0563	26.4180***	2.3817
Heteroskedasticity test: F(20,3)=	0.6727	0.9091	0.3354	0.0859	0.1884	1.6491	1.1006
RESET test: F(1,23)=	0.7968	4.7379*	0.3889	2.0357	0.5691	20.1740***	2.4059

t critical value at 10% in Ericsson and MacKinnon (2002) where $k = 5$ is t = -4.037776, at 5% is -4.469348.

***means significant at 1% level, **means significant at 5% level and * means significant at 10% level.

Values in brackets are Heteroscedasticity consistent standard errors

Figure 2. Malawi Actual vs. Steady-state Income per Capita



Uganda still has normality problem and the model is still misspecified. Ethiopia's normality problem becomes more crucial. However, we still graph the steady-state against actual income per capita for these countries in Appendix E. The problem is probably that our linear interpolation method has removed some variations in the series and this also suggests that we might need to look for an alternative proxy for health capital which varies more over time and is of a better proxy for health status for that particular country.

7. Conclusions and Suggestions for Further Work

We argue that CG's observation is not a real challenge to the neoclassical growth model since their argument is based on a misspecification of the steady-state income level, i.e. they ignore the base period technology differences among countries, which is admitted by MRW. Moreover, we also question the cross-country methodology in examining growth of not taking into consideration the variation of the conditioning variables over time.

Despite the fact that CG's argument is not reliable, it provides the motivation for writing this paper because they bring about the "dynamic issue" when they regress the actual and steady-state income levels against each other in 1960. Were poor countries below their steady-state income levels in 1960 or not and what about 1961, 1962…?

Obviously, we need a methodology which accounts for "time" and also suitable for single-country analysis – single-country time-series analysis. However, when we use data over a period of time to perform a time-series regression we bear in mind that some series are non-stationary and that the spurious regression problem could occur if we perform a regression using non-stationary variables. Indeed, most time-series data have a unit root in our analysis and therefore an error-correction approach is employed in order to test for cointegration. This method combines both short-run adjustment and a long-run relationship, and the latter is what we really want in answering our question of the relative position of a country's actual and steady-state income levels.

It is recognized in the literature that the Solow model satisfies a cointegration relation (Cellini, 1997). In this paper we follow Cellini's assumption that "total factor productivity is exogenous and deterministic, as in Solow's model, while the determinants of the steady-state (i.e., the growth rates of employment and physical and human capital accumulation) are considered as time series integrated of order one. Thus, for the model to be consistent with the stochastic nature of actual data, current and steady-state productivity levels must be cointegrated, so that the stationarity of their difference is consistent with the observed stationarity of productivity growth rates" (Cellini 1997, p137).

We rarely find cointegration in our analysis although some *t*-ratios are close to reject the null of no cointegration. This might be due to the data that we use are somehow misleading. However, our cointegration result for Malawi provides a good example to overturn CG's argument of saying that poor countries converge from below their steady states.

We then specify our model to include health capital as a determinant since we assume that health is of particular importance to these developing countries. However, the result does not change much and this might be because our data does not have much variation over time and we have to rely on interpolation.

There is some further work we could possibly do. First of all, our error correction model does not follow any particular theory and we could use a general-to-specific modelling technique for each country although data limitations restrict the sample size and hence the generality of any model. Secondly, our assumption of making the right-hand-side variables exogenous can be relaxed; for example, we know that health capital might be endogenous and we can find an instrumental variable (IV) which is strongly correlated with it yet ~~has~~ does not relate to income and perform a two stage least square (2SLS) estimation. However, doing this is very difficult because it is hard to find lagged values could be used as instruments in a time-series context. Moreover, we could do a single-country analysis, in which we could add some conditioning variables which are of particular importance to this country; e.g. wars, farmers and other specific institutional or policy changes.

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Appendix A

Figure A.1

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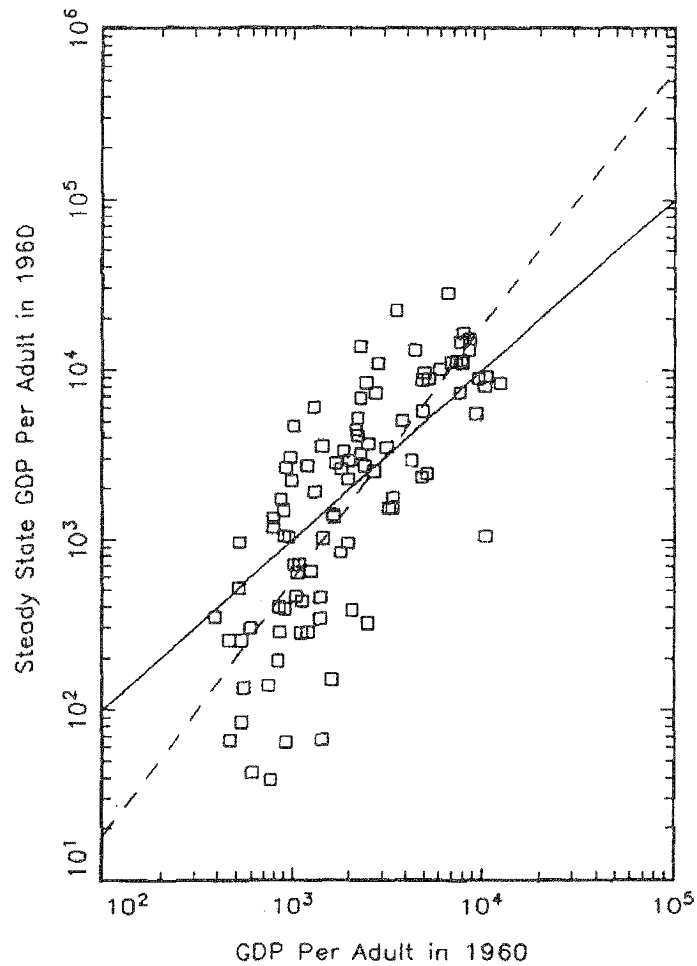


Fig. 1. Current vs. steady-state positions, 98 countries. Data from Mankiw et al. (1992).

Figure source: Cho and Graham (1996,p.288, Fig.1)

Table A.1

	Low income	**Lower middle income**	**Upper middle income**	**High income**
Number of countries	24	25	25	24
GDP per adult in 1960	\$683	\$1,282	\$2,553	\$7,126
Steady-state GDP per adult	\$333	\$938	\$3,247	\$8,389

Table source: Cho and Graham (1996, p. 288, Table 1)

Table A. 2

Country No. in MRW	Country Name	Unrestricted [a]	Restricted [b]
5	Burkina Faso	*	*
6	Burundi	*	*
7	Cameroon		
8	Central Afr. Rep.	*	*
9	Chad	*	*
11	Egypt		
12	Ethiopia	*	*
18	Kenya		*
20	Liberia		
22	Malawi	*	*
23	Mali	*	*
24	Mauritania		
28	Niger	*	*
30	Rwanda	*	*
32	Sierra Leone	*	
33	Somalia	*	*
37	Tanzania	*	*
38	Togo		
40	Uganda	*	*
41	Zaire	*	*
46	Bangladesh	*	*
47	Burma		
58	Nepal	*	*
119	Indonesia		

a denotes the unrestricted model
b denotes the restricted model

*denotes the country whose actual income per capita in 1960 is above its steady-state income per capita.

Appendix B

Table B.1. Data for Bangladesh

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	51419.00	1057.28	7.11	106.85	39.83
1961	52685.82	1020.68	8.46	107.32	40.23
1962	54006.47	1088.56	12.27	107.79	40.63
1963	55383.01	1114.95	8.97	108.26	41.17
1964	56817.50	1105.34	11.17	108.73	41.70
1965	58312.00	1089.11	12.30	109.21	42.24
1966	59865.14	1085.57	12.31	109.32	42.78
1967	61475.55	1021.08	14.24	109.43	43.32
1968	63145.29	1054.61	17.99	109.54	43.63
1969	64876.42	1056.02	16.22	109.66	43.94
1970	66671.00	1104.56	13.88	109.77	44.25
1971	68527.66	1040.20	10.84	110.80	44.56
1972	70445.03	914.36	5.34	111.83	44.87
1973	72425.17	875.49	11.14	112.86	45.25
1974	74470.14	988.88	8.88	113.89	45.62
1975	76582.00	963.43	7.95	114.92	46.00
1976	78572.99	978.41	8.44	116.32	46.38
1977	80556.22	956.15	9.75	117.72	46.76
1978	82555.74	982.67	11.74	119.11	47.37
1979	84595.65	1022.65	11.53	120.51	47.98
1980	86700.00	973.30	16.21	121.91	48.59
1981	88631.71	1059.29	15.20	122.29	49.20
1982	90825.22	1077.08	14.71	122.67	49.81
1983	93185.66	1132.75	10.75	123.05	50.43
1984	95618.21	1157.25	10.31	123.43	51.05
1985	98028.00	1164.58	11.05	123.81	51.67
1986	100956.86	1187.21	10.32	124.12	52.29
1987	103570.67	1197.62	10.85	124.44	52.90
1988	105954.05	1206.38	10.80	124.75	53.52
1989	108191.62	1209.51	10.77	125.07	54.14
1990	110368.00	1278.13	9.77	125.38	54.76
1991	112426.78	1293.35	9.73	125.70	55.38
1992	114311.55	1341.40	9.25	126.01	56.00
1993	116106.93	1390.21	9.19	126.33	56.77
1994	117897.54	1418.28	9.56	126.64	57.54
1995	119768.00	1467.07	9.79	126.96	58.30

Table B.2. Data set for Ethiopia

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	22771.00	526.75	5.51	102.18	36.11
1961	23186.04	535.72	5.60	102.27	36.51
1962	23666.36	538.89	5.70	102.36	36.91
1963	24202.44	545.56	5.79	102.47	37.31
1964	24785.79	556.12	5.28	102.59	37.71
1965	25409.00	573.12	5.36	102.71	38.11
1966	26065.71	578.51	5.70	102.81	38.51
1967	26750.60	583.69	6.71	102.92	38.91
1968	27459.40	601.30	6.51	103.03	39.32
1969	28188.92	614.51	5.75	103.15	39.73
1970	28937.00	607.57	4.76	103.27	40.14
1971	29701.27	615.27	4.76	103.57	40.55
1972	30479.14	628.22	4.97	103.88	40.96
1973	31275.42	643.03	4.66	104.20	41.16
1974	32098.49	640.10	4.30	104.51	41.36
1975	32954.00	625.40	4.29	104.85	41.56
1976	33841.04	623.59	5.29	104.99	41.76
1977	34759.76	619.29	5.15	105.14	41.96
1978	35711.36	623.62	2.96	105.31	41.96
1979	36696.85	635.44	3.35	105.53	41.96
1980	37717.00	641.45	3.63	105.74	41.96
1981	38772.37	634.35	3.91	105.79	41.96
1982	39863.32	622.42	3.99	105.86	41.96
1983	40990.00	673.08	3.40	105.94	42.49
1984	42152.32	604.37	4.74	106.06	43.02
1985	43350.00	507.32	2.93	106.17	43.55
1986	44658.93	537.32	4.59	106.26	44.08
1987	46087.06	584.46	4.11	106.39	44.61
1988	47643.23	553.28	5.56	106.49	44.74
1989	49337.26	565.44	3.58	106.59	44.87
1990	51180.00	573.82	3.10	106.68	45.00
1991	52954.00	510.42	2.66	106.78	45.13
1992	54790.00	446.68	2.39	106.88	45.27
1993	53297.00	505.18	3.96	106.76	44.88
1994	54890.00	520.63	4.35	106.64	44.49
1995	56530.00	528.16	4.70	106.53	44.10

Table B.3. Data for Malawi

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	3529.00	418.56	9.28	112.34	37.92
1961	3611.05	437.24	12.31	112.47	38.18
1962	3697.02	438.17	7.65	112.60	38.43
1963	3786.63	419.27	8.97	112.73	38.65
1964	3879.35	448.18	6.28	112.87	38.87
1965	3975.00	480.46	11.55	113.00	39.09
1966	4055.57	515.48	14.22	112.82	39.31
1967	4154.71	537.65	11.09	112.64	39.53
1968	4268.71	488.18	14.61	112.46	39.82
1969	4391.16	500.73	16.72	112.28	40.11
1970	4518.00	455.17	25.22	112.10	40.40
1971	4650.50	554.28	18.01	113.05	40.69
1972	4789.28	551.38	22.64	114.00	40.98
1973	4934.24	600.51	15.48	114.95	41.38
1974	5085.62	604.21	19.55	115.90	41.78
1975	5244.00	595.42	24.79	116.85	42.18
1976	5417.83	627.43	18.91	116.96	42.58
1977	5602.88	646.66	17.53	117.06	42.98
1978	5795.52	647.97	28.70	117.16	43.39
1979	5989.99	690.08	21.52	117.26	43.80
1980	6183.00	653.77	18.18	117.37	44.21
1981	6361.70	637.07	12.47	117.73	44.62
1982	6549.06	633.91	15.32	118.09	45.03
1983	6748.07	635.82	16.51	118.45	45.19
1984	6960.73	664.48	8.42	118.81	45.35
1985	7188.00	649.94	12.49	119.17	45.51
1986	7426.57	648.14	6.73	119.06	45.67
1987	7677.06	628.52	8.64	118.94	45.83
1988	7940.15	621.22	10.95	118.82	45.42
1989	8216.54	615.06	11.60	118.70	45.02
1990	8507.00	620.61	10.48	118.59	44.61
1991	8743.48	656.98	11.92	118.47	44.20
1992	8986.54	589.33	10.46	118.35	43.79
1993	9236.35	664.49	7.65	118.23	43.17
1994	9493.11	544.24	8.97	118.12	42.55
1995	9757.00	672.69	5.03	118.00	41.94

Table B.4. Data for Mali

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	4350.00	982.62	4.63	102.28	36.60
1961	4434.79	938.43	4.83	102.29	36.69
1962	4519.03	887.85	5.61	102.30	36.78
1963	4604.54	919.94	6.21	102.31	36.67
1964	4694.27	746.67	10.28	102.32	36.56
1965	4790.00	778.84	7.97	102.33	36.45
1966	4874.02	759.25	10.00	102.43	36.34
1967	4978.43	748.13	9.97	102.54	36.23
1968	5096.63	761.22	9.34	102.65	36.78
1969	5217.78	743.24	9.52	102.76	37.32
1970	5335.00	783.92	8.34	102.86	37.86
1971	5450.23	791.83	7.77	103.02	38.41
1972	5564.47	814.12	8.59	103.18	38.95
1973	5677.75	784.77	9.01	103.34	39.16
1974	5790.79	779.34	7.33	103.50	39.38
1975	5905.00	846.16	8.01	103.66	39.59
1976	6031.92	947.66	6.90	103.86	39.80
1977	6165.22	972.98	8.10	104.07	40.01
1978	6303.83	940.24	8.39	104.27	40.71
1979	6445.74	1009.00	8.81	104.48	41.41
1980	6590.00	944.42	8.63	104.68	42.10
1981	6731.94	881.62	8.96	104.92	42.80
1982	6881.34	821.98	9.17	105.16	43.50
1983	7039.87	868.69	6.51	105.40	44.10
1984	7208.81	884.06	6.35	105.64	44.70
1985	7389.00	859.02	8.39	105.88	45.30
1986	7579.71	774.07	10.20	105.93	45.91
1987	7781.53	752.13	9.33	105.99	46.51
1988	7995.06	745.38	8.91	106.05	46.00
1989	8220.98	816.17	8.30	106.11	45.49
1990	8460.00	754.70	10.09	106.16	44.99
1991	8702.48	754.52	9.78	106.22	44.48
1992	8948.33	796.36	9.52	106.28	43.98
1993	9197.45	761.82	9.22	106.34	43.98
1994	9449.71	770.99	7.57	106.39	43.98
1995	9705.00	811.70	7.24	106.45	43.98

TableB.5. Data for Tanzania

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	10205.00	381.53	19.56	126.52	40.72
1961	10495.87	363.36	23.20	125.74	41.19
1962	10797.84	375.16	19.70	124.97	41.66
1963	11111.86	383.90	18.11	124.19	42.14
1964	11439.30	475.90	22.92	123.42	42.62
1965	11781.00	485.68	26.15	122.64	43.10
1966	12136.68	505.74	26.82	122.25	43.58
1967	12506.10	538.58	29.31	121.85	44.06
1968	12889.05	553.87	29.36	121.46	44.54
1969	13285.18	546.98	26.52	121.06	45.02
1970	13694.00	565.07	35.04	120.67	45.50
1971	14108.60	583.26	38.15	120.32	45.98
1972	14533.15	571.68	32.41	119.97	46.46
1973	14970.53	603.02	31.36	119.62	46.96
1974	15425.14	585.05	32.42	119.28	47.46
1975	15900.00	578.04	29.93	118.93	47.96
1976	16396.26	633.47	31.27	118.84	48.46
1977	16912.15	628.08	34.21	118.74	48.96
1978	17448.05	626.85	30.93	118.65	49.30
1979	18004.26	655.23	33.28	118.56	49.64
1980	18581.00	605.70	31.16	118.47	49.98
1981	19178.49	602.85	32.80	118.76	50.32
1982	19796.93	601.47	33.19	119.06	50.66
1983	20436.09	540.35	25.07	119.35	50.73
1984	21095.55	596.76	29.34	119.65	50.80
1985	21775.00	632.35	34.40	119.94	50.87
1986	22474.44	645.33	29.63	119.88	50.94
1987	23193.82	758.58	41.70	119.82	51.01
1988	23932.98	483.70	10.86	119.77	50.69
1989	24691.76	492.16	9.21	119.71	50.37
1990	25470.00	493.70	10.50	119.65	50.05
1991	26277.69	494.62	12.67	119.59	49.74
1992	27103.52	436.28	12.57	119.54	49.42
1993	27943.58	477.51	12.10	119.48	49.12
1994	28793.00	469.24	11.15	119.42	48.82
1995	29646.00	467.15	9.92	119.36	48.52

Table A.6. Data for Uganda

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	6562.00	560.48	1.18	110.80	44.06
1961	6768.00	539.32	1.41	110.85	44.76
1962	7034.59	568.16	1.33	110.90	45.46
1963	7345.77	566.63	1.58	110.95	46.03
1964	7687.35	569.09	2.01	111.01	46.59
1965	8047.00	581.49	1.87	111.06	47.16
1966	8414.19	608.74	1.68	111.45	47.72
1967	8780.24	596.67	1.90	111.85	48.29
1968	9138.27	599.26	1.87	112.24	48.77
1969	9483.26	615.98	2.10	112.64	49.26
1970	9812.00	607.55	1.69	113.03	49.75
1971	10119.79	656.21	1.69	112.98	50.24
1972	10400.45	634.99	1.04	112.93	50.73
1973	10666.21	612.97	1.06	112.88	50.32
1974	10937.74	610.47	1.19	112.83	49.78
1975	11227.60	617.25	0.89	112.78	49.51
1976	11534.24	609.17	0.81	112.82	49.10
1977	11861.88	604.11	1.03	112.85	48.69
1978	12196.85	565.90	1.55	112.89	48.61
1979	12516.09	451.43	1.15	112.92	48.53
1980	12806.90	443.05	1.24	112.96	48.45
1981	13078.75	630.20	1.30	113.17	48.37
1982	13339.65	661.10	2.79	113.38	48.29
1983	13596.10	691.55	2.39	113.58	48.30
1984	13857.08	682.45	2.28	113.79	48.31
1985	14134.00	648.22	2.26	114.00	48.32
1986	14460.24	630.88	2.33	114.45	48.33
1987	14838.94	639.99	3.17	114.89	48.34
1988	15273.80	643.85	3.76	115.34	47.81
1989	15769.14	652.37	3.45	115.79	47.28
1990	16330.00	686.25	3.23	116.23	46.75
1991	16894.46	695.56	3.34	116.68	46.22
1992	17461.53	704.70	3.01	117.12	45.70
1993	18030.20	737.52	2.93	117.57	45.05
1994	18599.39	761.66	2.92	118.02	44.41
1995	19168.00	806.54	3.53	118.47	43.76

Table B.7. Data for Zaire

Year	Population (000)	Real GDP per capita	Net investment rate (%)	Labour quality index	Life expectancy
1960	15333.00	979.89	3.64	106.92	41.36
1961	15735.76	845.93	3.28	107.24	41.66
1962	16159.49	1035.30	1.64	107.56	41.96
1963	16604.48	1012.98	4.64	107.88	42.36
1964	17070.76	947.03	5.37	108.20	42.76
1965	17558.00	948.26	5.01	108.52	43.16
1966	18116.13	982.57	4.29	108.91	43.56
1967	18658.96	958.04	3.72	109.30	43.96
1968	19194.24	1008.64	3.64	109.69	44.36
1969	19729.08	1050.79	4.71	110.08	44.76
1970	20270.00	1055.61	4.67	110.48	45.16
1971	20822.91	1045.87	6.12	111.17	45.56
1972	21393.09	963.59	6.07	111.87	45.96
1973	21985.23	1027.31	5.86	112.56	46.37
1974	22603.38	1054.78	6.16	113.26	46.78
1975	23251.00	961.03	6.28	113.95	47.19
1976	23936.54	885.16	5.34	114.97	47.60
1977	24654.12	829.13	9.97	115.99	48.01
1978	25404.72	788.78	4.65	117.01	48.33
1979	26189.34	739.99	7.88	118.03	48.65
1980	27009.00	723.41	10.29	119.05	48.97
1981	27842.73	729.12	8.27	120.36	49.29
1982	28731.42	714.36	6.45	121.66	49.60
1983	29669.26	675.31	7.59	122.96	49.94
1984	30650.39	668.68	7.85	124.27	50.28
1985	31669.00	643.09	8.51	125.57	50.62
1986	32728.97	651.17	7.65	126.02	50.96
1987	33834.18	641.14	7.02	126.46	51.30
1988	34978.82	637.51	6.39	126.91	51.39
1989	36157.03	580.41	7.04	127.36	51.47
1990	37363.00	572.39	2.09	127.80	51.55
1991	38598.90	476.75	2.31	128.25	51.63
1992	39865.05	504.93	2.57	128.69	51.71
1993	41161.76	413.29	1.91	129.14	50.71
1994	42489.32	330.37	2.96	129.59	49.72
1995	43848.00	321.80	2.63	130.04	48.72

Appendix C

Data Generating Process for ADF

RE3 $y_t = \tilde{\mu} + \tilde{\beta} t + \tilde{\alpha} y_{t-1} + \tilde{u}_t$

RE2 $y_t = \mu^* + \alpha^* y_{t-1} + u^*_t$

RE1 $y_t = \hat{\alpha} y_{t-1} + \hat{u}_t$

The test null and alternative hypotheses are:

For $t_{\hat{\alpha}}, t_{\alpha^*} t_{\tilde{\alpha}}$, $H_0 : \alpha = 1 \; vs. \; H_1 : \alpha < 1$

For ϕ_1 $H_0 : \mu = 0, \alpha = 1 \; vs. \; H_1 : at\ least\ one\ of\ \mu \neq 0, \alpha \neq 1$

For ϕ_2 $H_0 : \mu = 0, \beta = 0, \alpha = 1 \; vs. \; H_1 : at\ least\ one\ of\ \mu \neq 0, \beta \neq 0, \alpha \neq 1$

For ϕ_3 $H_0 : \mu = 0, \alpha = 1 \; vs. \; H_1 : at\ least\ one\ of\ \beta \neq 0, \alpha \neq 1$

The Perron (1998) Testing Procedure

Step 1

Estimate RE3

Is $\alpha = 1$ ($t_{\tilde{\alpha}}$) and $\alpha = 1 \cap \beta = 0$ (Φ_3)?

Reject: conclude no unit root
Not reject: move to step 2

Step 2

Is $\alpha = 1 \cap \beta = 0 \cap \mu = 0$ (Φ_2)?
Reject: conclude $\{y_t\}$ has a unit root
Not reject: move to step 3

Step 3

Estimate RE2

Is $\alpha = 1$ (t_{α^*})

Reject: conclude no unit root
Not reject: move to step 4

Step 4

Estimate RE3

Is $\alpha = 1 \cap \mu = 0$ (Φ_1)?
Reject: conclude $\{y_t\}$ has a unit root
Not reject: move to step 5

Step 5

Does y have (approximate) a zero mean?
Reject: conclude $\{y_t\}$ has a unit root
Not reject: move to step 6

Step 6

Is $\alpha = 1$ ($t_{\hat{\alpha}}$) ?

Rejection: conclude no unit root
Not reject: conclude $\{y_t\}$ has a unit root

Appendix D

Figure D.1

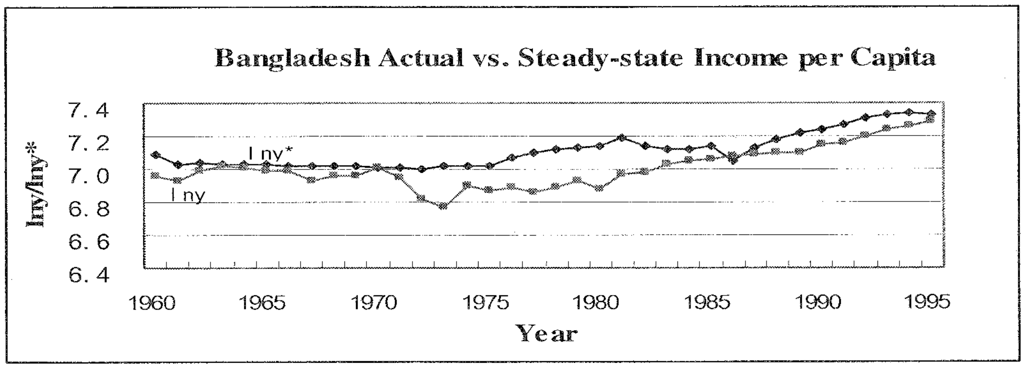


Figure D.2

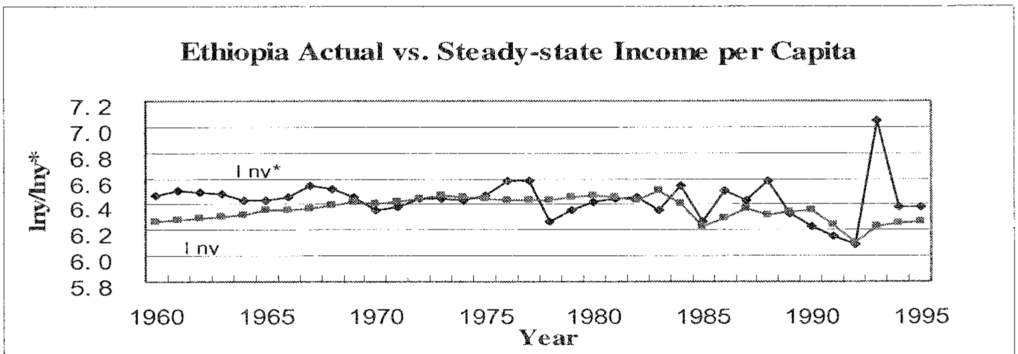


Figure D.3

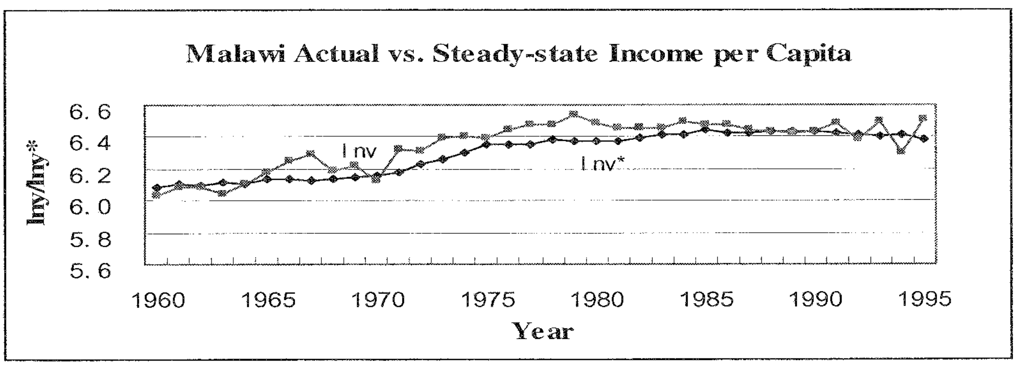


Figure D.4

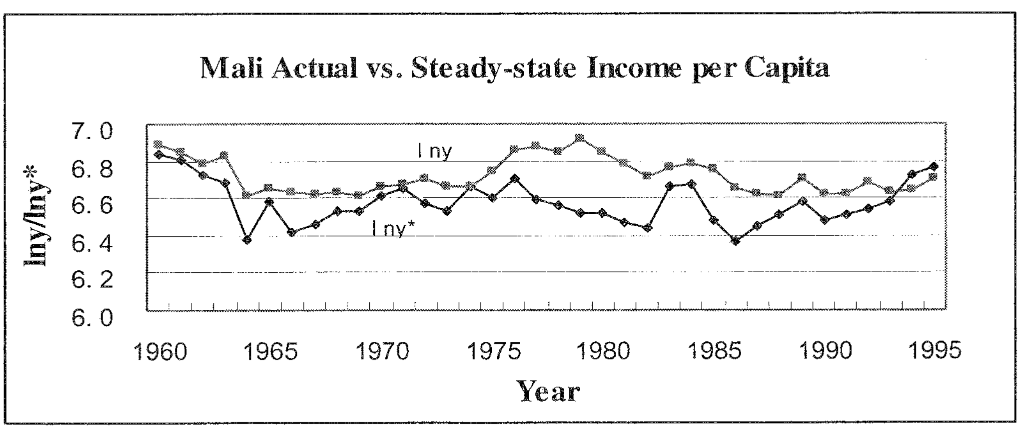


Figure D.5

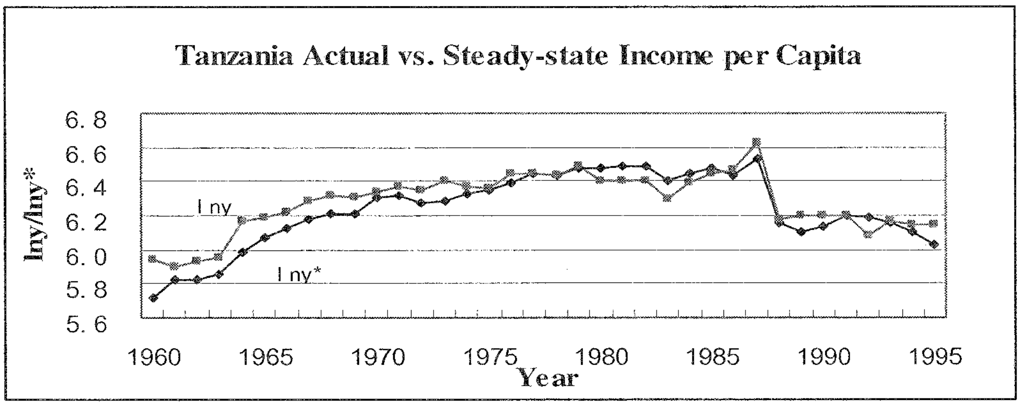


Figure D.6

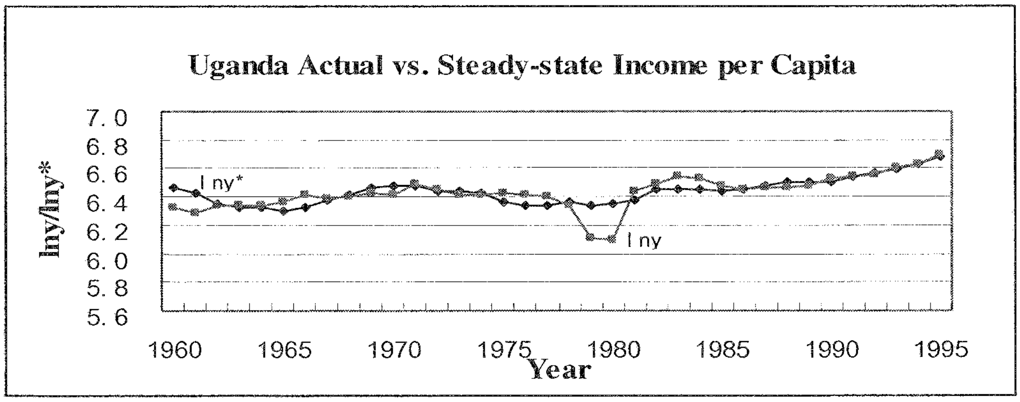
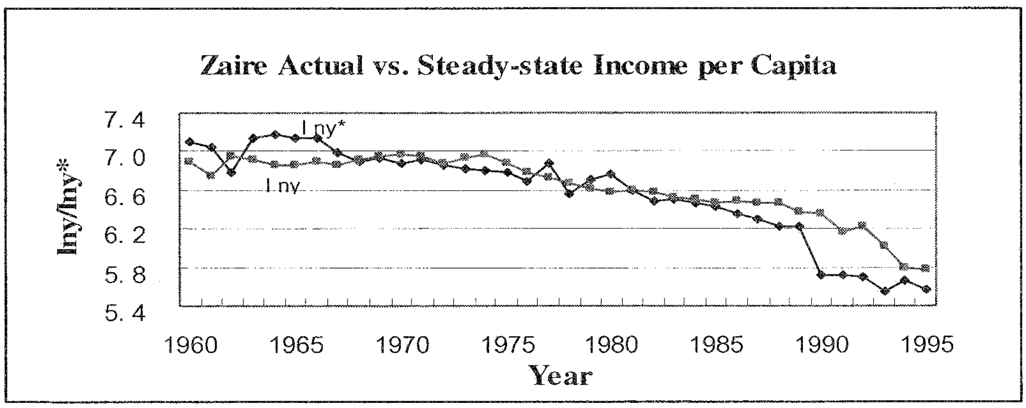


Figure D.7



Appendix E

Figure E.1

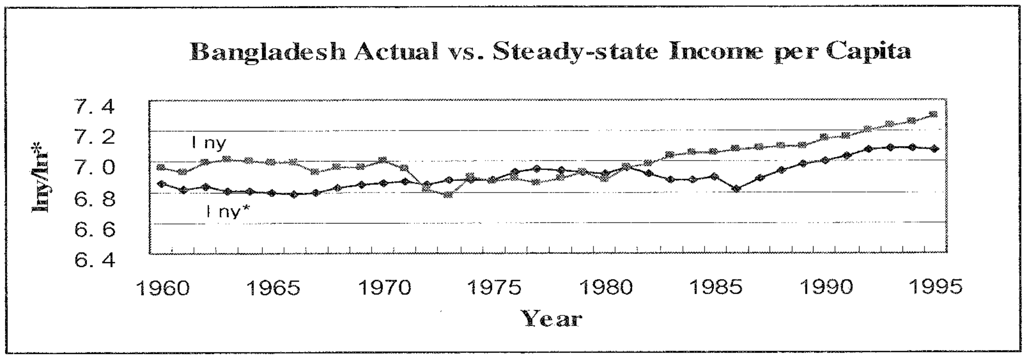


Figure E.2

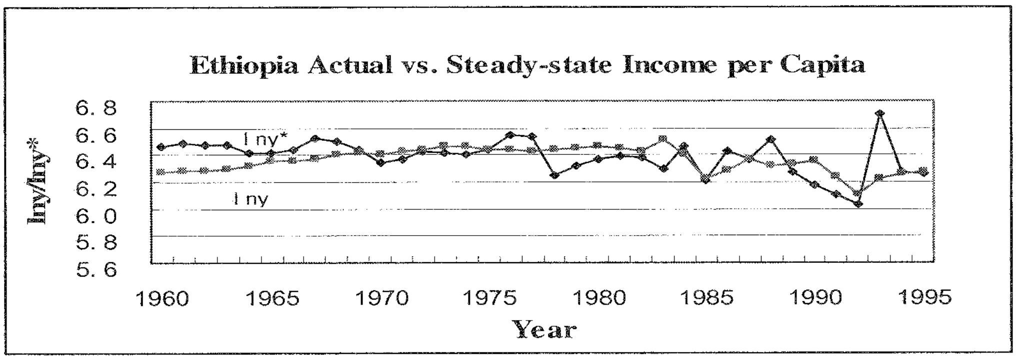


Figure E.3

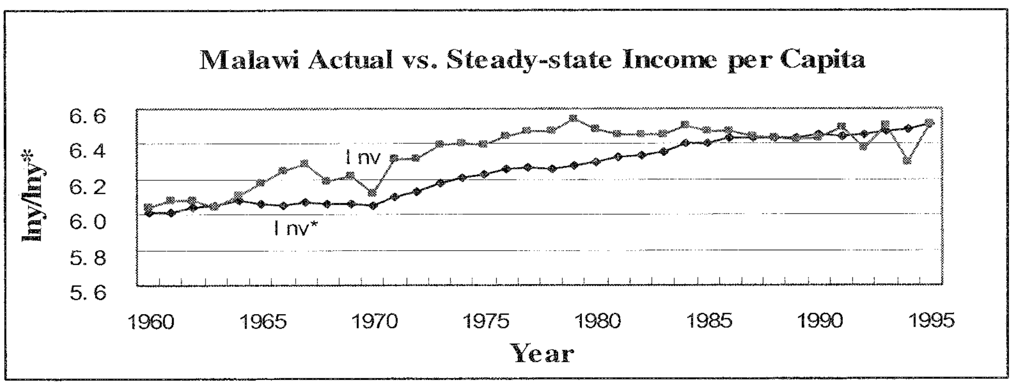


Figure E.4

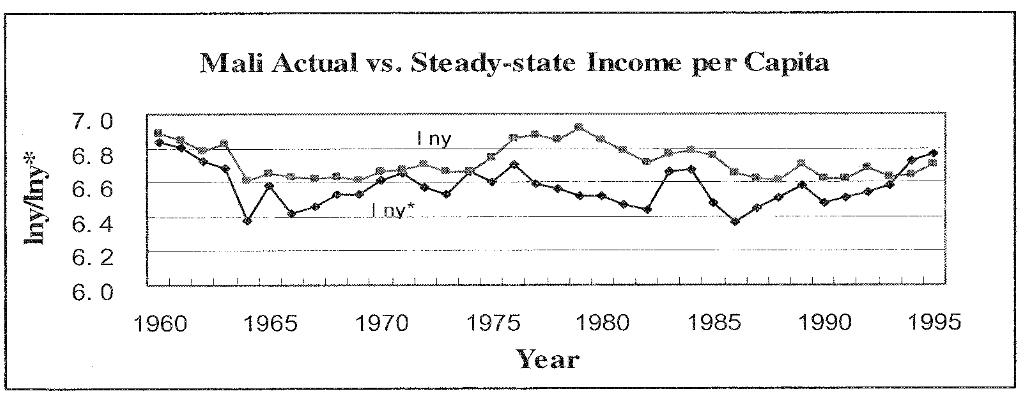


Figure E.5

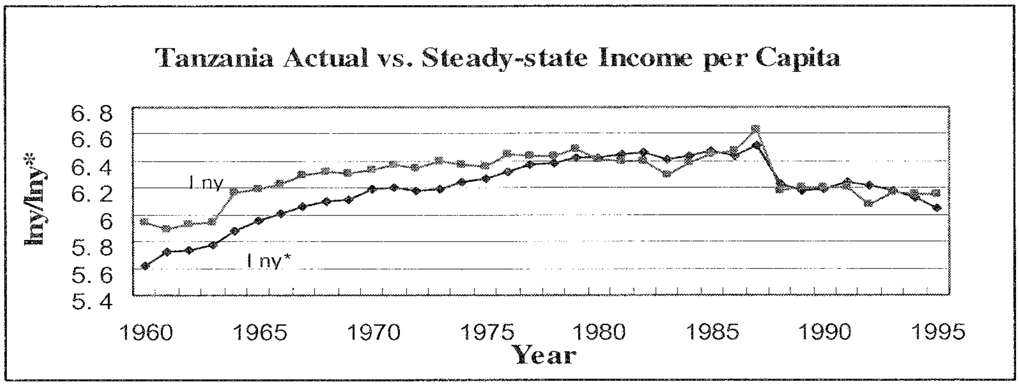


Figure E.6

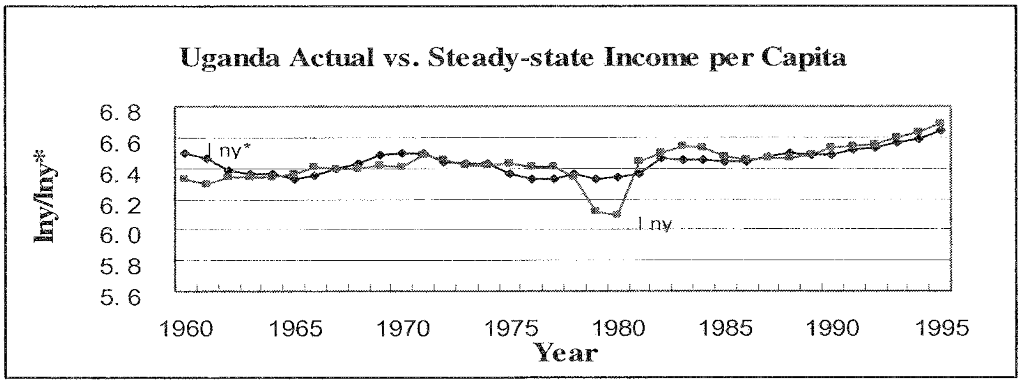


Figure E.7