Trends and Transitions in The Long Run Growth of Nations

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Abstract

Empirical work on cross-country growth has focussed almost exclusively on the speed of convergence to steady state and the variations in steady state levels. This paper examines the estimated long-run growth rate, i.e. the rate of steady state growth, in a Solow growth model. All estimates of common world steady state growth are shown to be zero or significantly negative under the null model. The null of a common world steady state growth rate is rejected in favor of a modifications of the basic Solow model to allow for heterogeneous long run growth rates across countries. This alternative yields plausible estimates of the capital share and speed of convergence but shows that steady states for different countries are quite diverse in both levels and growth rates. An alternative framework is presented to relate long run growth rates to fundamentals.
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1 Introduction

A small industry has arisen within the economics profession around the question of whether per capita income across countries is converging or not, and if so how fast.[1] As economists have rediscovered yet again the compelling questions of the evolution of the wealth of nations, they inevitably have turned to the available data to help sort through competing theories. In recent years, one empirical focus has been on the speed of convergence to steady state growth. This paper argues that the focus on convergence and its pace, to a substantial extent, has been misplaced. In particular, the empirical literature has concentrated on the convergence questions and virtually ignored the evolution of the steady state growth rate itself. In part, this is a result of the extensive use of cross-sectional estimation techniques and in part this is a result of the false dichotomy between Solow and AK growth models as the relevant theoretical alternatives. This paper tests the 'augmented' Solow growth model against an alternative which allows long run steady state growth rates to vary across countries.[2] Convergence is both possible and rapid in the null and alternative theories and is not the criterion of interest in the estimation.

The empirical growth literature has progressed a long way from the debates of the late 1980's and early 1990's which centered on the speed of convergence to steady state and the share of capital in aggregate output. No longer do researchers equate a negative relationship between initial income (per capita) and subsequent growth rates with countries attaining the same steady state output per capita. Similarly the simple endogenous growth model with production technology of the form

$$Y_{it} = AK_{it} \tag{1}$$

is no longer a serious contender as an alternative to the neoclassical growth model. However, in spite of these developments, the debate over convergence still hangs over the empirical growth literature.[3]

Participating in a 'controversy on convergence', Sala-i-Martin (1996) defends the 'classical' methodology of regressing long run growth rates on

[1] Unfortunately, there is not even agreement on what is meant by convergence. For example, see the divergent views collected in Sala-i-Martin (1996), Quah (1996), Bernard and Jones (1996), and Galor (1996). Bernard and Durlauf (1996) provide a discussion of several alternative definitions.

[2] The augmented Solow model refers to the addition of human capital in the production function and thus the steady state level of output.

[3] 3 of 8 empirical articles in the first volume of the Journal of Economic Growth focused primarily on convergence.

initial income levels and other controls as a useful, if not exclusive, means of determining the speed of conditional convergence to steady state. He argues that the added controls effectively index the variety of steady state outcomes and while poor countries may not be catching up to rich countries, conditional on the levels of the added controls there is global convergence.[4] Taking the argument a step further, if each country could attain the 'best' level of the controls, then indeed there would be global convergence, i.e. all countries would grow along the same path with only transitory deviations.

Quah (1996a,b) presents an alternative (although not necessarily different) view of the world in which there are multiple long run steady state outcomes for output. He argues that a richer framework is needed to understand the dynamics of output over time and that relying on the first and second moments of growth rates is inadequate to capture the complexities of national growth. Quah and Sala-i-Martin's viewpoints can be reconciled if the multiple steady states of Quah are related to the controls added by Sala-i-Martin.

In this paper, we focus on the long-run growth rate in the sense of the neoclassical model. Allowing for level differences in steady states across countries, we start by estimating both the basic Solow model and a version augmented with human capital. From these estimates we are forced to choose between accepting the Solow model with a declining or stagnant world productivity frontier or rejecting the model with a single long run world growth rate. Since a declining or constant level of technology seems excessively unrealistic, we reject the conclusion that the long run steady state growth rates are similar across countries. In addition, we find, as have others, that there is substantial variation in steady state levels. As an alternative we allow individual countries to have different long run trend growth rates and develop a framework to test for factors that shift the long run growth rates of countries.

The methodology we employ has the advantage that it gives estimates of both the relative levels of the steady states across countries as well as estimates of the relative growth rates of the steady state across countries. Typical cross-country regressions confound the transition and steady state behavior by looking only at the rate of growth of output itself, while most studies using panel techniques concentrate on the speed of convergence or the level effects in the steady state. In this paper, we control as much as

[4] This is a tricky distinction as it may not be possible for every country to attain the best level of each control variable which in turn implies that there cannot be global unconditional convergence.

possible for transition processes in output per worker and concentrate on long run growth rates.

Having proposed a simple technique to estimate long run growth rates for individual countries, we present a new conceptual framework for analyzing the variation in steady state growth rates. We argue that there exist both lower and upper bounds on asymptotic growth rates, with the lower bound being zero and the upper bound given by some number 'close to' but greater than zero.[5] The existence of these bounds has implications for both economic theories of long run growth and appropriate empirical techniques.

The paper proceeds along the following lines: first we sketch the basic Solow model and the relevant estimable equations. We also consider and dismiss the AK growth model as the relevant alternative and present a simple modification to the basic Solow framework in its stead. In section 2, we discuss our estimation strategy and its potential drawbacks. Section 3 contains the results for the basic and augmented Solow models with the focus on the estimates of the long run growth rate. We allow for varying growth rates and levels in Section 4. In Section 5, we argue for a new approach to thinking about long run growth rates and suggest appropriate estimation strategies. Section 6 concludes.

2 The Basic Solow Model and A Simple Alternative

It is almost inevitable that any empirical growth paper replicates the equations of the basic Solow growth model. We present a skeleton of the underlying model as well as a more detailed presentation of the usual estimated formulations. Special attention should be paid to the parameters that vary across countries; we will be explicit about simplifying assumptions at a later stage.

Output is produced with a Cobb-Douglas production function with constant returns to capital and labor.[6]

$$Y_{it} = (A_{it}L_{it})^{1-\alpha} (K_{it})^{\alpha} \ , \qquad 0 < \alpha < 1 \tag{2}$$

The growth rates of population and technology are assumed to be exogenous; the former varies across countries but for the moment technology

[5] By 'close' to zero, we are thinking of steady state growth rates less than 5 percent per year.

[6] We restrict our attention in the exposition to a single form of capital without loss of generality. In the empirical work we allow for human capital.

growth is assumed to be constant across countries.

$$\begin{aligned} L_{it} &= L_{i0}e^{n_i t} \qquad (3)\\ A_{it} &= A_{i0}e^{gt} \qquad (4)\end{aligned}$$

Capital depreciates at constant rate δ and a constant proportion of income is saved, so

$$K_{it} = I_{it} + (1-\delta)K_{it-1} \qquad (5)$$

We maintain the assumption of a closed economy so that steady state capital per effective worker,

$$\widehat{k} = \frac{K_{it}}{A_{it}L_{it}},$$

is given by

$$\widehat{k}^{*} = \left(\frac{s_i}{(n_i+g-\delta)}\right)^{\frac{1}{1-\alpha}}. \qquad (6)$$

Numerous authors have derived the out of steady state dynamics of the system given above, see Barro and Sala-i-Martin (1995) for a clear exposition. We omit an unnecessary repetition of the derivation and remind the reader that representing logs of variables in per worker terms by lowercase letters, i.e. $y = \ln\left(\frac{Y}{L}\right)$

$$\Delta y_{it} = (1-\lambda_i)\left(y^{*}_{it-1} - y_{it-1}\right) \qquad (7)$$

where

$$1-\lambda_i = (1-\alpha)(n_i+g+\delta).$$

We then can write the log of output per worker as

$$\begin{aligned} y_{it} &= \underbrace{(1-\lambda_i)\ln(A_{i0}) - (1-\lambda_i)\,g}_{\text{constant}} + \lambda_i y_{it-1} + \qquad (8)\\ &\quad (1-\lambda_i)\,gt + (1-\lambda_i)\left(\frac{\alpha}{1-\alpha}\right)\left[\ln s_i - \ln(n_i+g-\delta)\right] + \epsilon_{it}\end{aligned}$$

or in more compact notation

$$y_{it} = c_i + \lambda_i y_{it-1} + (1-\lambda_i)\,gt + \theta_i Z_{it} + \epsilon_{it} \qquad (9)$$

where

$$\begin{aligned} c_i &= (1-\lambda_i)\ln(A_{i0}) - (1-\lambda_i)\,g\\ \theta_i &= (1-\lambda_i)\left(\frac{\alpha}{1-\alpha}\right) \qquad (10)\\ Z_{it} &= \ln s_i - \ln(n_i+g-\delta).\end{aligned}$$

Typically Equation 9 is estimated in one of two ways, either in levels in a panel[7] or much more frequently the time variation is ignored and it is estimated as a pure cross-section in the form

$$\begin{aligned} y_{iT} - y_{i0} &= g\left(1-\lambda_i\right)\sum_{j=1}^{T-1} j\lambda_i^{T-j-1} + \left(1-\lambda_i^T\right)A_{i0} \qquad (11)\\ &\quad - \left(1-\lambda_i^T\right)y_{i0} + \left(1-\lambda_i^T\right)\left(\frac{\alpha}{1-\alpha}\right)Z_{it} + \sum_{j=0}^{T-1}\lambda_i^j\epsilon_{iT-j}. \end{aligned}$$

This familiar cross-section formulation says that there will be conditional convergence if λ_i is less than one so that the coefficient on initial income is negative. An important potential problem with such a specification is the fact that the constant term contains numerous country-specific components, at least one of which is unobservable. This usually entails making assumptions on the error term. Islam (1995) starts from this problem and estimates the country specific intercept terms maintaining the assumption of a constant growth rate in technology across countries.

As noted by several authors, e.g. Lee, Pesaran, and Smith (1997), even the basic Solow model does not suggest that the speed of convergence, as measured by the parameter λ_i, will be constant across countries. However, assuming constant convergence speeds across countries is particularly convenient for estimation purposes and we will also follow this path in our empirical work.[8]

2.1 The AK Alternative

The debate over exogenous versus endogenous growth models has been muddied by the usual choice of an alternative to the Solow model. The typical alternative usually maintains most of the assumptions of the Solow model except that it employs a production function of the form

$$y_{it} = A_i k_{it} \qquad (12)$$

with constant returns to capital.[9] With such an alternative, the logical place to start an empirical evaluation is through an estimate of the coefficient on

[7] Surprisingly the time trend is often omitted even in the levels specification.

[8] Lee, Pesaran, and Smith (1997) find that while λ_i does vary somewhat across countries, it is not correlated with population growth, as is suggested by the model.

[9] The constant returns feature can be considered a reduced form for a variety of underlying specifications.

k_{it}, or in terms of the derivation given above, on the coefficient on y_{it-1} in Equation 9. If there are constant returns to capital, then $\lambda_i = 1$, while if are decreasing returns to capital then the coefficient on lagged income will be less than unity.

The problem with such an alternative is that it is devoid of interesting transitional dynamics. The response to past output levels is either completely a transitional phenomenon, as in the Solow model, or completely a steady state phenomenon, as in the AK alternative. Excluding all transitional activity would appear to overly restrict the alternatives.[10] A more interesting alternative might allow for some off-steady state activity. Jones and Manuelli (1990) present such an endogenous growth framework with both long run returns to capital bounded away from zero and transitions if the level of capital for a country starts below the steady state. The empirical dilemma, simply stated, is that one usually must decide a priori whether the transition dynamics or long run behavior dominate in a given sample of countries.

To sidestep such problems we present a slight variant of the Solow model below, one which allows for a relatively simple estimation strategy.

2.2 A Slight, but Important Variant

As mentioned above we do not intend to pose the AK endogenous growth model as the alternative to the basic Solow model. Instead we allow for one change, growth rates of 'exogenous' technological progress, g_i, are allowed to vary across countries. We consider two possible specifications for varying growth rates, one with general variations in g_i,

$$g_i \sim N\left(g, \sigma_g^2\right)$$

and the other where long run growth depends on some set of variables (in our case predetermined)

$$g_i = f\left(X_i\right). \tag{13}$$

While in the context of the debates over endogenous and exogenous growth model, a natural element to consider for X_{i0} would the log of initial capital or initial income, $\ln Y_{i0}$, one can employ any of the potential determinants of long run growth.[11]

[10] Even the most ardent proponents of endogenous growth models would be likely to agree that some of post-WWII growth in Europe and Japan was a one-time reaction to the effects of the war.

[11] See Levine and Renelt (1992), Barro (1996), Sachs and Warner (1996) for just a few candidates.

The new specification for log income per worker is

$$y_{it} = \underbrace{(1-\lambda_i)\ln(A_{i0}) - (1-\lambda_i)\,g_i}_{\text{constant}} + \lambda_i y_{it-1} + \tag{14}$$
$$(1-\lambda_i)\,g_i t + (1-\lambda_i)\left(\frac{\alpha}{1-\alpha}\right)[\ln s_i - \ln(n_i + g_i - \delta)] + \epsilon_{it}$$

or again in compact notation,

$$y_{it} = c_i + \lambda_i y_{it-1} + (1-\lambda_i)\,g_i t + \theta_i Z_{it} + \epsilon_{it}. \tag{15}$$

Since the empirical literature has devoted so much attention to the coefficient on initial output in a cross-country regression, it is interesting to note what occurs if the long run growth rate for each country is a linear increasing function of initial income (or variables that are correlated with initial income), $g_i = g + \pi y_{i0}$. The long run average growth rate formulation would be

$$y_{iT} - y_{i0} = (g + \pi y_{i0})(1-\lambda_i)\sum_{j=1}^{T-1} j\lambda_i^{T-j-1} + \left(1-\lambda_i^T\right)A_{i0} \tag{16}$$
$$-\left(1-\lambda_i^T\right)y_{i0} + \left(1-\lambda_i^T\right)\left(\frac{\alpha}{1-\alpha}\right)X_{it} + \sum_{j=0}^{T-1}\lambda_i^j \epsilon_{iT-j} \tag{17}$$

In this case the coefficient on initial log income is given by

$$\underbrace{\pi(1-\lambda_i)\sum_{j=1}^{T-1} j\lambda_i^{T-j-1}}_{\substack{\text{Trend Effect} \\ \text{positive}}} - \underbrace{\left(1-\lambda_i^T\right)}_{\substack{\text{Catch-up Effect} \\ \text{negative}}} \tag{18}$$

whose sign and magnitude now depend on two effects. As in the baseline model, countries that are below their steady states will grow faster and catch-up (negative correlation), but in addition higher initial positions will lead to faster trend growth (positive correlation). This ambiguity in the sign on initial income is also discussed by Bernard and Durlauf (1996) in the context of variables that are correlated with steady state growth rates.

Sala-i-Martin (1996) emphasizes the fact that the speed of convergence $(1-\lambda)$ is often in the range of 2-3 percent per year for a surprisingly wide variety of datasets. In fact, Casselli et al. (1996) go so far as to suggest that speeds of convergence of 2-3% per year are accepted by most economists. With a baseline model where $\pi = 0$ and an alternative with $\pi > 0$, we consider the possibility of misinterpreting consistent estimates of $\widehat{\lambda}$ from a cross-country growth regression. In Figure 1 we plot the estimated $\widehat{\lambda}$ under the null for various combinations of true λ and π in a 30 year sample.[12] It turns out that an estimate $\widehat{\lambda} \in (0.97, 0.98)$ is possible for almost every true value of λ. While this by no means implies that the Sala-i-Martin estimates have been misinterpreted, it leaves open the possibility that the estimates from the long run cross-section regressions are consistent with both the Solow model with its conditional convergence and an alternative with diverging steady states.

We must emphasize that this result is not driven by any econometric issues but rather comes from specific null and alternative theories and the formulation of regressing long run average growth rates on initial levels and controls.[13] For this reason, and those mentioned by Islam (1995), we estimate Equations 9 and 15 in levels.

3 The Estimation Strategy

The appropriate methodology for testing the implications of the Solow growth model has been widely debated in the empirical literature. The most common practice is to run regressions of long run average growth rates on initial income levels plus a set of controls. However, as shown above, such a specification cannot distinguish between those variables that influence the speed of transition to the steady state and those that affect the rate of change of the steady state itself.

Because our focus is on the variation of long run growth rates and its determinants, rather than the speed of convergence, we estimate the model in levels using panel data techniques. One important advantage of such a specification is that we can provide an estimate of the growth rate of long run technological progress. The cross-section methodology is incapable of generating such an estimate. In addition, as argued in Islam (1995), the

[12] In other words, if one incorrectly assumed that the null (Solow) model is true what speed of convergence would one obtain with a consistent estimator that was unbiased in finite samples.

[13] Other work on panel data by Evans (1996), Islam (1995), Lee, Peseran, and Smith (1995), and Caselli, Esquivel, and Lefort (1996) emphasizes econometric issues and all find the speed of convergence to be substantially higher than 2 percent per year. There are numerous econometric arguments against the growth rates-levels regression as well, see Quah(1993), Bernard and Durlauf (1996) and Caselli, Esquivel, and Lefort (1996).

panel approach in levels allows us to also estimate country-specific level effects and has the advantage of being relatively simple to implement.

A literature has developed which focuses on the appropriate estimation methodology for the Solow model in a panel framework. Contributions to this field of research include Islam (1995), Evans (1995), Nerlove (1999), Lee, Pesaran and Smith (1997), and Casselli, Esquivel, and Lefort (1996). This literature has worried primarily about consistent estimation of the speed of convergence to the steady state and has limited consideration of variations in steady states to time-invariant level effects.[14]

Since the focus of this paper is not on the econometrics per se, we initially employ a variety of panel estimators, including a fixed effects specification and a variety GLS weighting matrices. The main results do not depend on the particular panel estimator.[15]

When testing the basic and augmented Solow specifications, we impose homogeneity of parameters across countries within the panel. Strictly speaking this is incorrect since the population growth rate actually should cause the estimated speed of convergence to vary across countries. However, the estimated speed of convergence in practice is not correlated with the population growth rate so we maintain the assumption of a constant convergence speed.[16] In addition, we generally estimate the unrestricted version of the Solow model since we are not as interested in providing estimates of the implied capital share.

When we move to our preferred alternative model, with potentially varying long run growth parameters, we maintain homogeneity in all other parameters and continue to focus on the unrestricted model.

4 Empirics from the Solow Model

As an expository convenience, we will assume throughout this paper that the relatively short time dimension of the data will suffice to give estimates of asymptotic growth rates. To begin, we assume that we can apply the

[14] Lee, Pesaran and Smith (1997) focus on the speed of convergence as well but in doing so estimate parameters for each country individually and then consider the properties of the separate parameter estimates. They reject hypothesis that cross-country growth rates are equal across countries.

[15] We attempted to use a maximum likelihood framework for the estimation as suggested by Nerlove (1999) but we found that estimates were somewhat sensitive to the starting points. In addition, the speed of convergence of the estimator was extremely slow and the results within the range of those we present below.

[16] Lee, Pesaran, and Smith (1997) report that they could find no correlation between the speed of convergence and the population growth rate.

closed economy model of the previous section country by country and that the fundamental parameters do not vary across countries. In particular we assume that α, g, and δ do not vary across countries. Making these assumptions we estimate

$$y_{it} = c_i + \lambda_i y_{it-1} + (1 - \lambda_i)\, gt + \theta_i Z_{it} + \epsilon_{it} \tag{9}$$

using several specifications including fixed effects(within), pooled, and FGLS.

Previous authors have concentrated on the estimates of λ and α. Indeed the choice of estimator matters quite a bit for these parameters. However, our focus is on the estimated long run growth rate, g. Results for various estimators are presented in Table 1 for a panel of 102 countries over 30 years.[17] Here the conclusion from the various estimators is clear and quite gloomy. Estimates of the common world growth rate of exogenous technology are either zero or significantly negative. According to these specifications, potential world output is declining or stagnant and by implication any observed increased in output over the sample period is due to a combination of "excess" capital accumulation and starting positions substantially below potential.

There are several potential objections to the empirical exercise presented above. Several papers have argued that instead of a single steady state for all countries, there exist distinct groups of countries who are converging to separate steady states, i.e. convergence clubs. Alternatively, it may be that the empirical methodology is incapable of uncovering a common, positive trend. Finally, we consider the possibility that the absence of human capital from the specification is influencing the estimates of the exogenous trend. We consider each of these objections in turn.[18]

4.1 Convergence Clubs

One strand of the literature arguing against worldwide convergence is that concerning convergence clubs. Papers in this vein include Durlauf-Johnson (1995), Ben-David (1998), Quah (1996b). To determine if the presence of convergence clubs may be driving our previous result of a non-positive

[17] Results do not change if the oil producing countries are excluded, nor do they change if quinquennial, rather than annual data is employed.

[18] Of course, taking this model literally and using pooled cross-country data to estimate trend growth can be argued to be excessive. Pooling countries as different as Chad and the United States may be asking too much of the data. However, this is exactly the standard method in the recent empirical growth literature and is appropriate if one wants to posit a single model to explain cross-country variations in output growth.

asymptotic growth rate, we divide the countries into three equally sized samples based on their initial output per worker. Results are presented in Table 3.

Again we find for all three subsamples of countries, no evidence for positive long run growth rates. As before the fixed effect specification comes closest to giving significant positive estimates, however, even there the largest point estimate for trend growth among the samples is 0.5% per year for the rich countries and is still not significantly different from zero.

4.2 Growth among the Rich

Up to this point, the Solow model with a common growth rate for technology has fared poorly. However, there remains the possibility that the methodology, rather than the model, is driving the results. To check this possibility, we consider the estimates of the model for the 22 countries in the OECD. Typically these economies are thought to be converging to one another and share similar technologies and thus potential output paths.[19] DeLong (1988) argued that using the OECD to look for convergence was inappropriate since they are all ex-post winners from a growth perspective. This provides us with a nice check on the reliability of the methodology as we have strong priors that we should find a positive common technological trend.

The results for the unrestricted basic Solow model for a panel of 22 OECD countries are presented in Table 4. Reassuringly, we obtain positive and significant growth rates, on the order of 1.3-1.5% per year. Convergence is faster for this group of leading countries, between 7.7% and 9.2% per year.

These results suggest that for appropriately grouped countries the basic Solow model with positive exogenous technical change can be reconciled with the data. However, considering the sample of countries as a whole, or even grouped by initial income the model yields implausible estimates of the trend growth rate. As suggested by numerous proponents of the Solow model, we next consider human capital as an additional accumulable factor in the next section and re-estimate the trend growth rate.

4.3 Augmented with Human Capital

Most proponents of the neoclassical framework, notably Mankiw, Romer, Weil (1992), and Barro and Sala-i-Martin (1996), concede that the basic

[19] For views on convergence among the OECD countries see Bernard and Jones (1995, 1996).

Solow model needs to be augmented by a measure of human capital to account for cross-country growth patterns. Islam (1995) and most authors who use a panel framework find that human capital does not enter with the expected sign. Instead Islam (1995) finds that measures of human capital are correlated with the individual country effects and act as level shifters in his specification.

We augment the basic Solow model and employ the Barro-Lee (1993) measure of human capital stocks in a panel framework.[20] Due to data availability, we must now estimate a quinquennial panel for 89 countries. Note, however, that none of the results of the preceding sections change for either the somewhat smaller set of countries or for the five year as opposed to the annual data. Again since we are not interested in the point estimates of the various capital shares, we consider only the unrestricted version.

The results for the augmented Solow model are given in Table 5 for the new panel of 89 countries. As before, the estimated trends are either small and insignificant or negative and significant.[21] These results are very similar to those found by other authors, human capital seems not to be related to growth during transitions. In a subsequent section we examine whether human capital is correlated with estimates of individual long run growth rates and levels.

5 Variations Across Countries

In assessing the performance of the basic or augmented Solow model in yielding plausible estimates of long run growth rates, we find that it comes up short. The prevalent negative, or zero, point estimates of the long run growth rate are sufficiently implausible to encourage us to consider alternative models. At the same time the model seems to do a reasonable job in approximating the transition paths to the steady state, i.e. the coefficients on savings, population, and initial income. To maintain the parsimonious nature of the Solow model, we choose to consider a simple alternative where long run growth rates and levels are allowed to vary across countries.

Since technological progress is assumed to be exogenous in our baseline model, we push this assumption a bit more and allow countries to face differing paths of technology within the sample period. We retain the assumptions

[20] For bevity, we omit the deriviation of the equations with human capital.

[21] We considered several alternative human capital measures, primary and secondary school variables, all of which entered with a negative sign and none of which changed the estimates of the trend.

of the model that the basic production function is identical across countries and (incorrectly) that the speed of convergence to the long run path is common across countries, but allow the trend growth rates to vary.

$$y_{it} = c_i + \lambda_i y_{it-1} + (1 - \lambda_i)\, g_i t + \theta_i Z_{it} + \epsilon_{it}. \tag{15}$$

Results for the homogeneous parameters are presented in Table 6. Estimates of the country-specific growth rates and intercept shifters are in Table 7.[22]

5.1 Variations in Levels

The methodology outlined above allows us to estimate both levels and growth rates of steady state output for each country. In effect we have a noisy measure of both the variation in steady state levels and growth rates. Column 1 of Table 7 reports the estimates of variations in long run levels from the random effects specification with hetergeneous growth rates. The range of levels is substantial even after allowing growth rates to vary across countries. As expected, many sub-Saharan countries show low levels, -5% or more below the mean, while countries at the top of the range are seemingly more diverse, including Egypt, USA and Hong Kong.

If we have adequately controlled for transitory phenomena in the estimation procedure, in theory at this point we can correlate our estimates of the levels with the usual set of explanatory variables such as initial income, human capital, openness to trade etc. We caution however, that at best the procedure outlined above yields a noisy estimate of the steady state and such cross-country regressions must be undertaken with appropriate caution remembering the econometric pitfalls of such an estimation. In fact, in the next section we outline a new methodology for thinking about steady states and the associated appropriate empirics.

We report regression results in Table 8 and Figures 2-4 of the estimated random effects on initial income and measures of initial human capital . Our estimates of steady state levels are correlated with both initial output per work and measures of human capital.[23] Variation in initial output explains

[22] At this point the choice of FGLS estimator becomes even more important. Choosing the Balestra-Nerlove method yields a speed of convergence of 2.2% per year and 'asymptotic' growth rates ranging from -20% to 15% per year with the average long-run growth rate across countries -4.0% per year. This seems highly implausible so we only report results from the fixed effect and Nerlove-GLS estimators.

[23] Islam (1995) reports estimates of the variation in steady state levels from a fixed effects specification assuming a common steady state growth rate. He also finds large differences across countries that are correlated with human capital.

over 40% of the variation in levels, a 10% percent increase in initial income raises the steady state level by 2.0%. Interestingly, both initial primary and secondary school enrollment ratios are also strongly positively correlated with the level differences, unlike the results from the panel regressions where changes human capital variables did little to explain growth.

5.2 Variations in Long Run Growth Rates

Column 2 of Table 7 reports the estimated long run growth rates for the 102 countries in our sample. As with the estimated level effects, the variability in growth rates is quite large and in fact the estimated growth rates and levels are positively correlated as shown in Figure 5. This argues against some form of convergence in the steady states. As with the levels, we cautiously report cross-country regressions of the estimated long run growth rates on initial GDP per worker and measures of initial human capital in Table 9. Figures 6-8 show the bivariate plots. Unlike the levels results, the growth rate estimates show no correlation with initial GDP, however they are positively related to human capital measures. Interestingly, when both human capital and initial productivity are included in the specification, long run growth rates are negatively related to the productivity measure but strongly positively correlated to both human capital measures.

These results, both for levels and growth rates, suggest that human capital may indeed be playing a role in long run growth. The mechanism, however, is not through the typical accumulation mechanism associated with factors of production but instead through the evolution of the steady state for each country. Both estimated steady state levels and growth rates are higher for countries with higher initial measures of human capital. We reiterate our warning that the cross-section regression results reported here are suggestive rather than conclusive.

6 A New View of Asymptotic Growth Rate

In this section we propose an alternative view on the variability of growth rates of output per worker over very long periods of time across countries. A fundamental assumption in the usual neoclassical exogenous growth model is that there is a common asymptotic growth rate for all countries. In that model, deviations in either direction from that asymptotic rate are due to transition phenomena driven by variations in accumulation rates. The previous sections argued that at least for one 30 year period the evidence is strongly against such an assumption.

Endogenous growth models start from a different strong assumption. They typically predict that changes in investment rates or in policy measures, such as tax rates, will have permanent effects on growth rates. So far the empirical work by Jones (1995) and others, typically on data from OECD economies, has shown this prediction of the endogenous growth models fails to hold. This failure is generally viewed as strong evidence against endogenous growth models.

In this section we argue that both these assumptions are too strong and that there are natural restrictions on the long run growth rates of countries that have implications for both theory and empirics. We argue that it is reasonable to think of the existence of both upper and lower bounds for asymptotic growth rates as well as a range of possible values between the two extremes. In such a world, even after controlling for transitory factors we might expect to find countries growing at a variety of speeds ranging from the upper bound to the lower. The distribution of countries would depend on a vector of factors that influence the steady state.[24]

6.1 A Lower Bound

The argument for a lower bound on the steady state growth rate is quite simple. We posit that a growth rate of zero is the asymptotic lower bound and any observed episodes, even very long run, of negative average growth rates are merely periods of transition. Any lower bound below zero would imply that eventually the country would fall below subsistence levels of income and perish.

Conjecture 1 *There exists a lower bound for the steady state growth rate of log per worker real gross domestic product for any country. The value of the lower bound is zero.*

An argument against the existence of a distinct lower bound for long run growth rates is given in the strict version of the neoclassical growth model. In that case, all countries will eventually attain the same asymptotic growth rate, g, and any deviations above or below are due to purely transitory effects. Outside of a formal model, the most compelling argument against a lower bound of zero for long run steady state growth is that eventually the productivity disparities between rich and poor countries would become infinite, or at least sufficiently large to induce capital flows across countries. However, it would appear to be relatively easy to find examples of countries

[24] These factors may or may not also influence transition speeds.

whose observed growth rates have been effectively zero for many decades, or even centuries, and for whom the growth in income disparities relative to the OECD has been substantial.[25] Extreme examples of this kind include Chad and Afghanistan among others.

6.2 An Upper Bound

The existence of an upper bound for steady state growth is again relatively uncontroversial. Even the most optimistic advocates of pro-growth policies rarely argue for sustainable growth rates above 5% per year over very long horizons.[26] More typically, it is assumed that growth rates in the 1-3% range are the upper bound in the long run.

Conjecture 2 *There exists an upper bound for the steady state growth rate of log per worker real gross domestic product for any country. The value of the upper bound, g^*, is greater than zero.*

Of course, a major difficulty arises because the exact value of the upper bound is unknown and must be imposed or estimated from finite data. However, the result of the two conjectures is that asymptotic growth rates are bounded above and below as shown in Figure 9.

6.3 The Middle Ground

In Figure 9, we have implicitly assumed that the SS growth rate for each country depends on some set of fundamentals. While it is beyond the scope of this paper to exhaust the potential candidates for these fundamentals, other authors have proposed that market institutions, democracy, property rights, educational attainments, patent protection and other be included in the set. For the moment, we think of the fundamentals as being represented by an index, X, which is a function of the underlying elements.

We suggest that the SS growth rate is a (probably non-linear) function of the index X and in particular there are three distinct ranges for both X and g, the steady-state growth rate. In Figure 10, the first range is given by

[25] For example, countries with ill-defined property rights and an absence of the rule of law may not attract capital inflows no matter how large the productivity differentials. However, the conceptual framework proposed below still allows for the possibility that the very poorest countries can raise their steady state growth rates. Rather, it just does not assume that this will inevitably happen if accumulation occurs.

[26] Remember we are excluding all transition effects and discussing the movements of the efficiency frontier itself.

X less than A where the corresponding SS growth rate is zero for all values of X below A. By this we mean to suggest that for some range of particularly bad fundamentals the SS growth rate is close to or exactly zero.

The second relevant range is shown by X>B. For these “good” values of the fundamentals, the growth rate attains the theoretical maximum given by g^*. One implication of this assumption is that further improvements in the fundamentals do not result in faster steady state growth.

The third area is where X lies between A and B. If A<<B, then in this range there is some variation in the SS growth rate which depends on the fundamentals. Figures 9-11 offer alternative possibilities for the response of the growth rate to the fundamentals in this range, including a linear response (Figure 9), a discrete jump if A=B (Figure 10), and various continuous non-linear responses (Figures 11).

The discrete jump corresponds to models discussed by Azariades and Drazen (1990), Quah (1996a) and Galor (1996) where economies make discontinuous jumps to higher steady states depending on their acquisition of some factor such as human capital. However, it seems more plausible to think of the growth rate increasing in a continuous fashion on X over some range. An open empirical question is whether most countries fall into the middle range between A and B or whether in fact countries have segregated themselves into two types, those with good, and those with bad sets of fundamentals.

6.4 Implications for Growth Empirics

The conceptual framework developed above has several important implications for growth empirics. First, it argues that instead of using per capita or even per worker growth rates of output, researchers interested in the variation of long run outcomes should employ estimates of long run steady state growth rates, purged of all transitory elements.[27] One such approach to disentangle transitory from long run movements was offered in Section 2.

A second important empirical caveat harks back to the debate over sample selection bias in the convergence literature. Testing growth theories (especially endogenous growth models) using a subset of countries such as

[27] This raises the specter of a lengthy debate over the appropriate method of distinguishing long run and transition components in growth rates analogous to the unit root debates in the time series literature. However, choosing a particular method of decomposition is certainly preferable to assuming that all effects are transitory or all are permanent as has been the practice to date. The methodology employed in Section 2 offers a tractable starting point in this regard.

the OECD is likely to be inappropriate. If the framework presented here is correct, then we should not expect to see growth rates respond to change in fundamentals for certain types of countries. These correspond to regions where X>B, very good fundamentals, and X<A, very poor fundamentals. The same sample selection issues may apply for countries at the low end of the range.

Finally, depending on the response of steady state growth rates to the vector of fundamentals, linear regression of growth rates on fundamentals may not be able to capture the underlying relationship. This is true if there are only two type countries, as in Figure 10, or if the relationship is non-linear, as in Figure 11. The appropriateness of the linearity assumption should be tested in the data.[28]

7 Conclusion

In this paper, we have tried to return the focus of the empirical growth literature back to the variation of long-run growth rates. We argue that a series of events in the growth debate have shifted focus to the speed of convergence and that the prevalent empirical methodologies are not adequate for researchers who want to understand the sources of the variation in long run productivity and output movements across countries.

Rather than focus our attention on the merits and properties of individual estimators, we choose to use a simple panel estimation strategy which allows us to separate transition and long run movements in output. This methodology has the virtue of being easily implementable while not falling prey to the problems inherent with the typical cross-country growth regression. In particular, we are able to estimate "steady-state" growth rates and "steady-state" levels for individual countries.

Our empirical findings are quite clear. The basic Solow model, even augmented by human capital, produces a negative point estimate of the long run growth of technological change. This is strongly at odds with our priors and leads us to inquire after the source of the negative estimate. We conclude that the estimation strategy is sound, OECD countries show a positive and significant trend growth rate.[29] The problem lies in the assumption of a

[28] The hypothesis of a linear relationship between elements of X and long run growth rates can be nested in a more general non-linear framework and will be explored in future research.

[29] Similar work on US states also shows a significant and positive steady state growth rate of 1.3 percent per year. This would appear to confirm that the panel methodology yields sensible estimates when the units of observation (states or OECD countries) are

common trend growth rate across countries.

The observed heterogeneity of estimated long run growth rates across countries is substantial, although smaller than the variation in output growth rates themselves. In addition, the heterogeneity of steady state output levels is substantial as well. Both levels and growth rates are positively correlated with measures of initial human capital, suggesting an alternative mechanism for human capital to influence long run growth rates.

Finally, we present a series of conjectures about the distribution of steady state growth rates to help guide future theoretical and empirical work. We posit that long run growth rates are bounded above and below. The upper bound is unknown but is unlikely to be above 5 percent per year and more likely to be between 1-3 percent per year. The lower bound is reasonably assumed to be zero with negative growth rates over any interval due to transitory or medium run phenomena. Within the range defined by the upper and lower bound, the long run growth rate for a given country is assumed to be related, in a potential non-linear fashion, to a set of economic characteristics of the economy. Future empirical work on the sources of long-run growth should directly include the restrictions implied by the existence of the upper and lower bounds.

likely to share a common long run growth rate.

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Figure 1

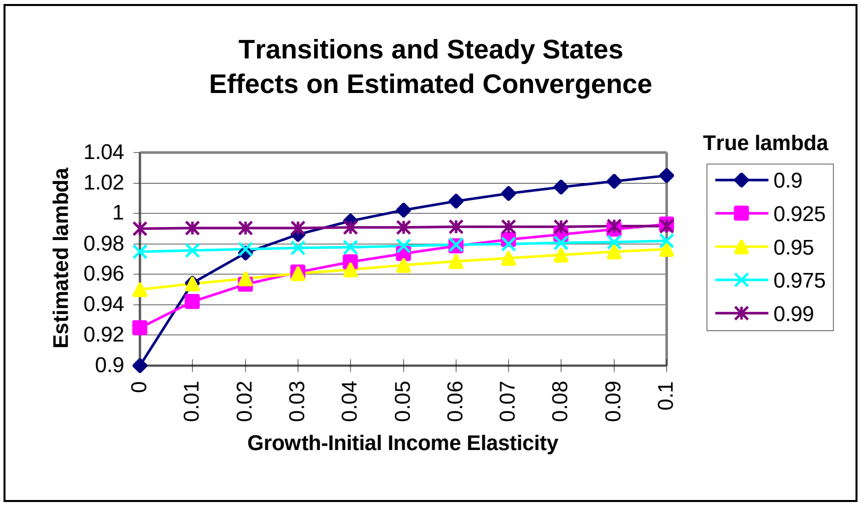

Transitions and Steady States
Effects on Estimated Convergence
Estimated lambda
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Growth-Initial Income Elasticity
True lambda
0.9
0.925
0.95
0.975
0.99

Figure 2

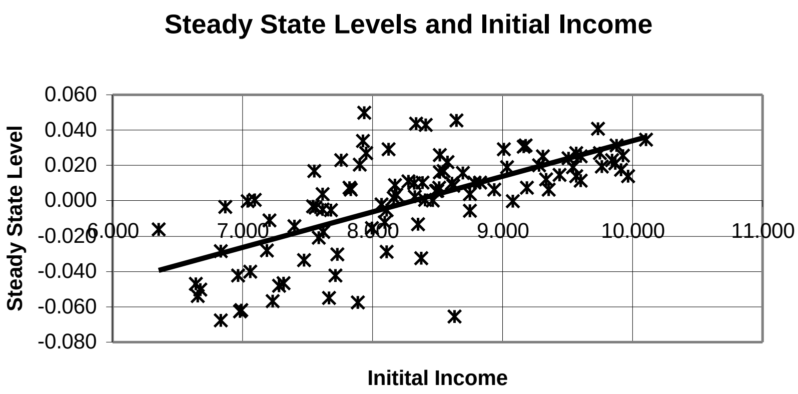

Steady State Levels and Initial Income
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
6.000
7.000
8.000
9.000
10.000
11.000
Steady State Level
Initital Income

Figure 3

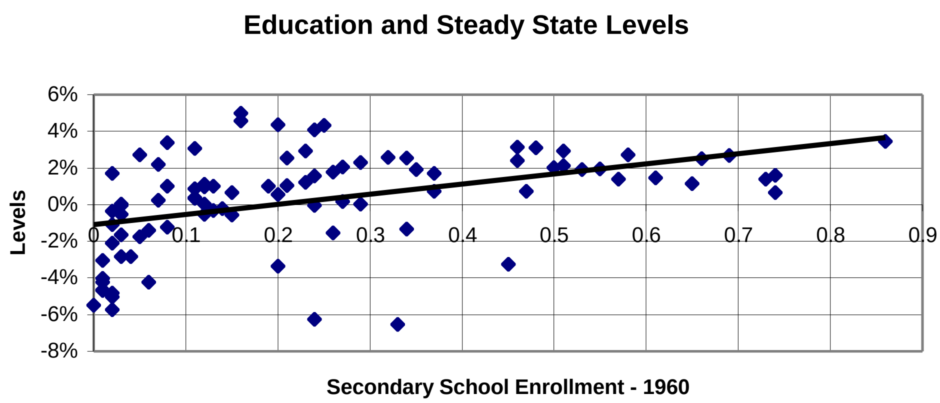

Education and Steady State Levels
6%
4%
2%
0%
-2%
-4%
-6%
-8%
Levels
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Secondary School Enrollment - 1960

Figure 4

Education and Steady State Levels

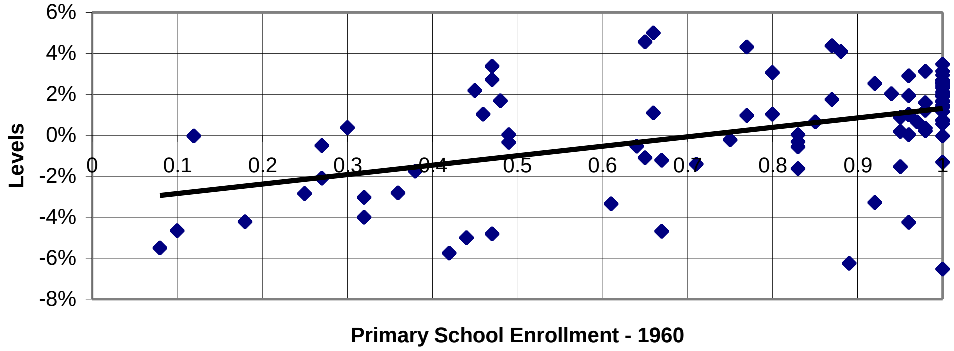
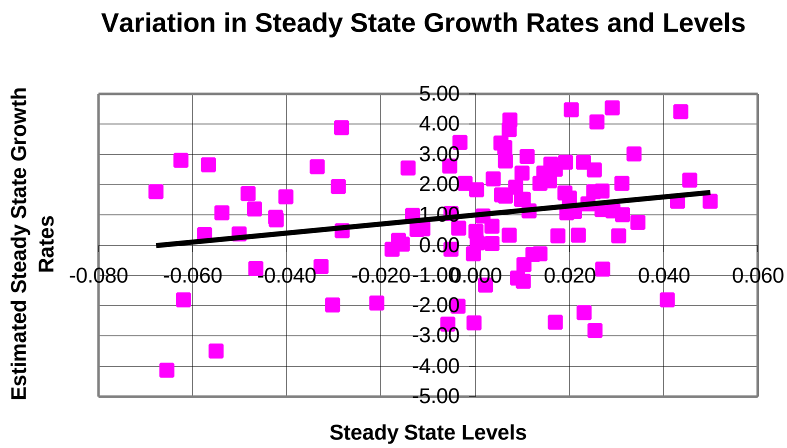


Figure 5



Variation in Steady State Growth Rates and Levels
Estimated Steady State Growth Rates
Steady State Levels
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-0.080
-0.060
-0.040
-0.020
0.000
0.020
0.040
0.060

Figure 6

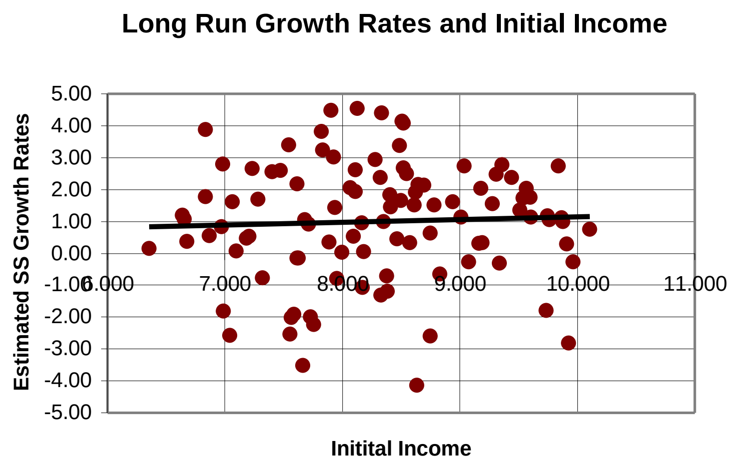

Long Run Growth Rates and Initial Income
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.000
7.000
8.000
9.000
10.000
11.000
Estimated SS Growth Rates
Initital Income

Figure 7

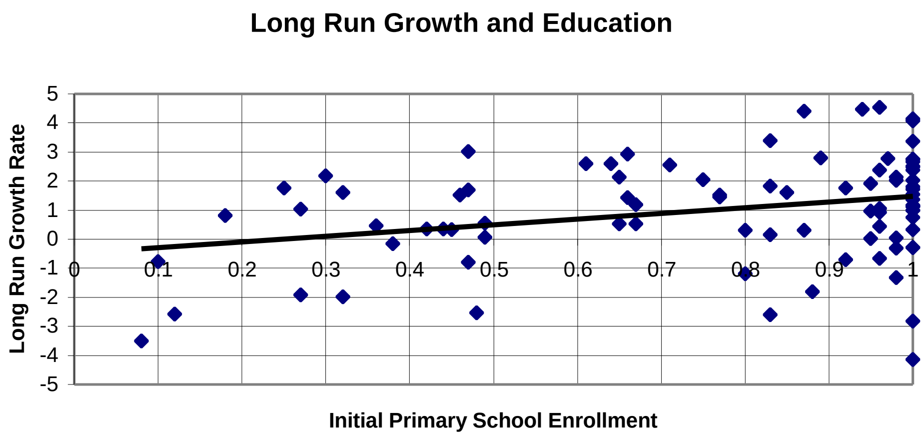

Long Run Growth and Education
Long Run Growth Rate
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Initial Primary School Enrollment

Figure 8

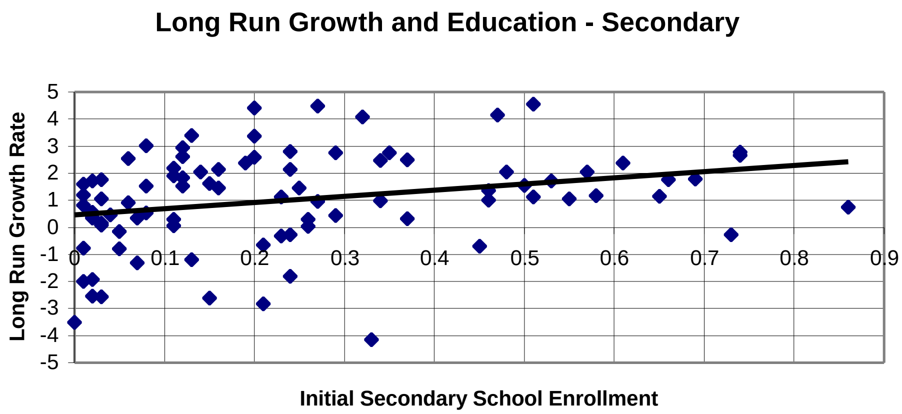

Long Run Growth and Education - Secondary
Long Run Growth Rate
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Initial Secondary School Enrollment

Figure 9

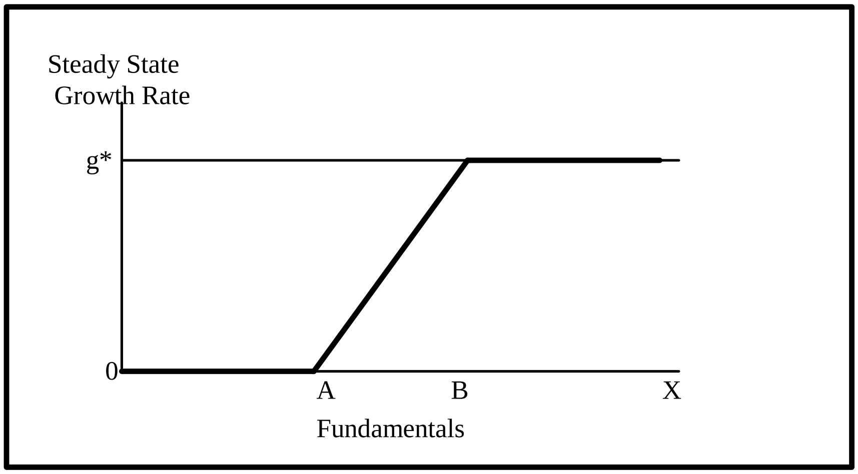


Figure 10

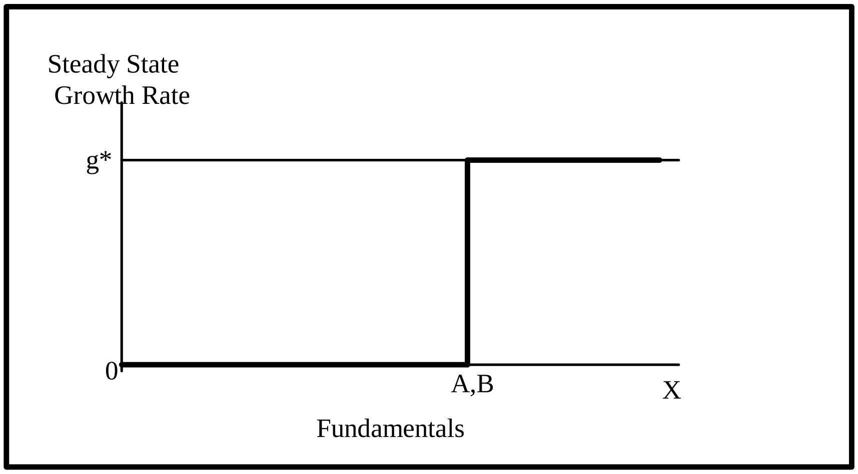
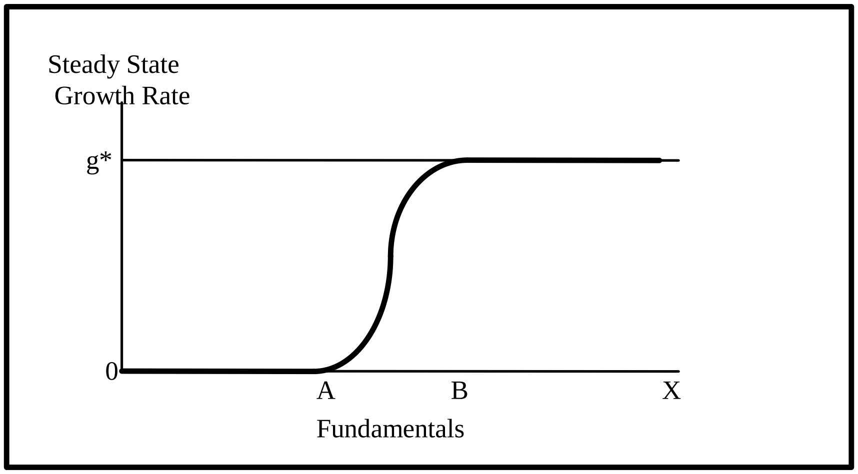


Figure 11


Steady State
Growth Rate
g*
0
A
B
X
Fundamentals

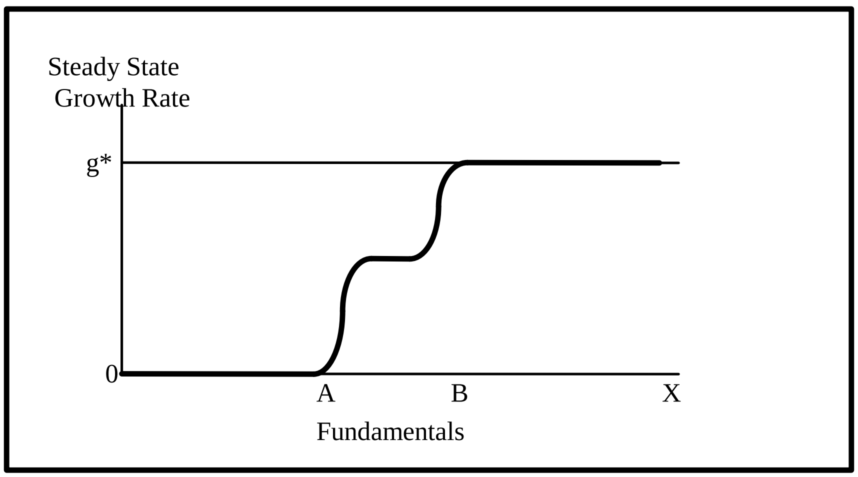

Steady State
Growth Rate
g*
0
A
B
X
Fundamentals

Table 1: Basic Solow Model - All Countries
Annual Data, 1960-1990, Panel Estimates

Restricted	g	λ	α
Fixed Effects	0.0009	0.069	0.396
	(0.0026)	(0.007)	(0.024)
Pooled	-0.156	0.007	0.731
	(0.039)	(0.001)	(0.030)
Balestra-Nerlove (GLS)	-0.072	0.014	0.0661
	(0.017)	(0.002)	(0.027)
Nerlove (GLS)	-0.014	0.039	0.0511
	(0.004)	(0.004)	(0.026)
Unrestricted			
Fixed Effects	0.0009	0.069	
	(0.003)	(0.007)	
Nerlove (GLS)	-0.014	0.039	
	(0.003)	(0.005)	

Note: 102 countries are included.

Table 2: Basic Solow Model - All Countries
5 Year Intervals, 1960-1990, - Panel Estimates

Restricted	g	λ	α
Fixed Effects	0.002	0.074	0.365
	(0.003)	(0.009)	(0.031)
Pooled	-0.147	0.008	0.723
	(0.040)	(0.002)	(0.033)
Balestra-Nerlove (GLS)	-0.080	0.013	0.0667
	(0.020)	(0.002)	(0.031)
Nerlove (GLS)	-0.016	0.036	0.0512
	(0.006)	(0.005)	(0.031)
Unrestricted			
Fixed Effects	0.003	0.078	
	(0.003)	(0.010)	
Nerlove (GLS)	-0.013	0.032	
	(0.005)	(0.005)	

Note: 102 Countries included in the sample.

Table 3: Basic Solow Model - Income Groups
Annual Data, 1960-1990, Panel Estimates

	Poor	
Unrestricted	g	λ
Fixed Effects	0.001	0.076
	(0.004)	(0.013)
Nerlove (GLS)	-0.008	0.045
	(0.008)	(0.010)
	Middle	
Fixed Effects	0.004	0.070
	(0.005)	(0.011)
Nerlove (GLS)	-0.004	0.053
	(0.007)	(0.009)
	Rich	
Fixed Effects	0.005	0.083
	(0.003)	(0.013)
Nerlove (GLS)	-0.003	0.053
	(0.005)	(0.009)

Note: 34 countries are in each category, grouped by GDP per worker in 1960.

Table 4: Basic Solow Model - OECD
Annual Data, 1960-1990, Panel Estimates

Unrestricted	g	λ
Fixed Effects	0.015	0.092
	(0.002)	(0.009)
Nerlove (GLS)	0.013	0.077
	(0.002)	(0.008)

Note: 22 countries are included.

Table 5: Augmented Solow Model
5 year intervals, 1960-1990, Panel Estimates

Human	g	λ
Fixed Effects	0.003	0.076
	(0.003)	(0.010)
Nerlove (GLS)	-0.015	0.038
	(0.006)	(0.005)
Primary		
Fixed Effects	0.003	0.076
	(0.003)	(0.010)
Nerlove (GLS)	-0.015	0.038
	(0.006)	(0.005)
Secondary		
Fixed Effects	0.003	0.079
	(0.003)	(0.010)
Nerlove (GLS)	-0.015	0.038
	(0.006)	(0.005)

Note: 89 countries are included.

Table 6: Solow Model - Heterogenous Growth - All Countries
Annual Data, 1960-1990, Panel Estimates

Restricted	average g	λ	α
Fixed Effects	0.013	0.187	0.268
		(0.012)	(0.015)
Nerlove (GLS)	0.010	0.135	0.322
		(0.009)	(0.018)
Unrestricted			
Fixed Effects	0.013	0.196	
		(0.012)	
Nerlove (GLS)	0.011	0.143	
		(0.010)	

Note: 102 countries are included.

Table 7: Estimates of SS Growth Rates and Levels - All Countries
Annual Data, 1960-1990, Panel Estimates

Country	RandomEffect	g (%)	ΔGDP(%)
ALGERIA	0.010	1.52	2.08
ARGENTINA	0.012	-0.31	0.56
AUSTRALIA	0.021	1.12	1.51
AUSTRIA	0.020	1.55	3.04
BANGLADESH	0.034	3.01	1.83
BELGIUM	0.027	1.80	2.65
BENIN	-0.021	-1.92	-0.11
BOLIVIA	-0.005	2.61	1.57
BRAZIL	0.009	1.91	2.29
BURKINA FASO	-0.054	1.07	1.03
BURUNDI	-0.042	0.82	0.00
CAMEROON	-0.011	0.53	2.04
CANADA	0.031	0.99	1.89
CAPE VERDE IS.	-0.057	2.65	2.29
CENTRAL AFR.R.	-0.040	1.60	0.14
CHAD	-0.004	-2.01	-1.73
CHILE	0.000	-0.28	1.01
CHINA	-0.062	2.80	2.37
COLOMBIA	0.010	1.52	2.04
COMOROS	-0.062	-1.80	0.51
CONGO	0.007	3.82	1.97
COSTA RICA	0.010	-0.65	1.28
CYPRUS	0.007	4.14	4.30
CZECHOSLOVAKIA	-0.029	1.94	2.81
DENMARK	0.011	1.14	1.74
DOMINICAN REP.	0.002	-1.31	1.71
ECUADOR	0.000	1.83	2.35
EGYPT	0.050	1.44	3.01
EL SALVADOR	0.010	-1.20	0.76
FIJI	0.006	1.61	1.47
FINLAND	0.006	2.77	2.87
FRANCE	0.024	1.36	2.71
GABON	0.009	-1.08	2.75
GAMBIA	0.000	-2.57	1.39
GERMANY, WEST	0.019	1.72	2.50
GHANA	-0.018	-0.15	-0.29
GREECE	0.017	2.50	4.12
GUATEMALA	0.022	0.34	1.13
GUINEA-BISS	-0.068	1.77	1.57
GUINEA	-0.028	3.88	1.80
GUYANA	-0.065	-4.14	-2.12
HONDURAS	-0.012	0.52	1.04
HONG KONG	0.044	4.40	5.67
ICELAND	0.015	2.37	2.28
INDIA	-0.034	2.60	2.03
INDONESIA	-0.014	2.55	3.74
IRELAND	0.019	2.74	3.51
ISRAEL	0.031	2.03	2.99
ITALY	0.025	2.48	3.41
IVORY COAST	-0.005	-0.14	1.39
JAMAICA	-0.033	-0.70	0.57
JAPAN	0.016	2.67	5.03
JORDAN	0.043	1.45	3.45
KENYA	-0.048	1.70	0.83
KOREA, REP.	0.020	4.48	5.93
LESOTHO	-0.016	0.16	4.28
LUXEMBOURG	0.023	2.75	2.34
MADAGASCAR	0.023	-2.24	-1.35
MALAWI	-0.047	1.19	1.55
MALAYSIA	0.010	2.38	3.71
MALI	-0.047	-0.77	-1.03
MAURITANIA	-0.055	-3.51	-0.85
MAURITIUS	0.016	2.13	1.78

MEXICO	0.031	0.31	1.94
MOROCCO	0.027	-0.80	2.90

Table 7 (cont) Estimates of SS Growth Rates and Levels - All Countries
Annual Data, 1960-1990, Panel Estimates

Country	RandomEffect	g (%)	ΔGDP(%)
MOZAMBIQUE	0.017	-2.54	-0.67
NAMIBIA	0.006	1.65	2.22
NETHERLANDS	0.027	1.18	2.01
NEW ZEALAND	0.014	-0.28	0.59
NIGERIA	-0.028	0.47	1.52
NORWAY	0.014	2.03	2.39
PAKISTAN	0.004	2.18	2.76
PANAMA	0.000	0.45	1.74
PAPUA N.GUINEA	-0.030	-1.99	0.95
PARAGUAY	0.004	0.05	1.93
PERU	-0.006	-2.60	0.27
PHILIPPINES	-0.015	0.03	1.59
PORTUGAL	0.006	3.37	4.11
RWANDA	-0.003	0.55	1.57
SENEGAL	-0.005	1.05	0.34
SEYCHELLES	0.006	3.23	4.29
SINGAPORE	0.026	4.08	5.27
SOUTH AFRICA	0.004	0.63	1.40
SPAIN	0.029	1.13	3.90
SRI LANKA	0.002	0.96	1.64
SWEDEN	0.019	1.06	1.64
SWITZERLAND	0.018	0.30	1.63
SYRIA	0.046	2.15	3.42
TAIWAN	0.029	4.54	5.66
THAILAND	-0.003	3.40	4.26
TOGO	-0.050	0.36	2.31
TRINIDAD&TOBAGO	0.041	-1.80	0.54
TUNISIA	0.011	2.94	2.71
TURKEY	-0.002	2.05	3.31
U.K.	0.025	1.76	1.98
U.S.A.	0.035	0.74	1.36
UGANDA	0.000	0.07	-0.18
URUGUAY	0.007	0.32	0.63
VENEZUELA	0.025	-2.82	-0.53
YUGOSLAVIA	-0.013	0.99	2.87
ZAMBIA	-0.057	0.35	-0.85
ZIMBABWE	-0.042	0.92	0.28

Note: Growth rate estimates from GLS specification.

Table 8: Regressions of "Steady State" Levels

Intercept	-0.1671	-0.0110	-0.0330
	(-8.84)	(-2.84)	(-4.34)
GDP	0.0201		
	(8.89)		
Secondary		0.0555	
		(4.66)	
Primary			0.0463
			(4.95)
Adjusted R^2	0.436	0.191	0.211
Observations	102	89	89

Note: t-statistics are in parentheses.

Table 9: Regressions of "Steady State" Growth Rates

Intercept	0.288	-0.476	0.462	6.165
	(0.18)	(-0.87)	(1.68)	(2.88)
GDP	0.086			-0.922
	(0.44)			(-3.12)
Primary		1.943		3.163
		(2.91)		(2.47)
Secondary			2.281	2.383
			(2.70)	(2.53)
Adjusted R^2	-0.008	0.078	0.067	0.163
Observations	102	89	89	89